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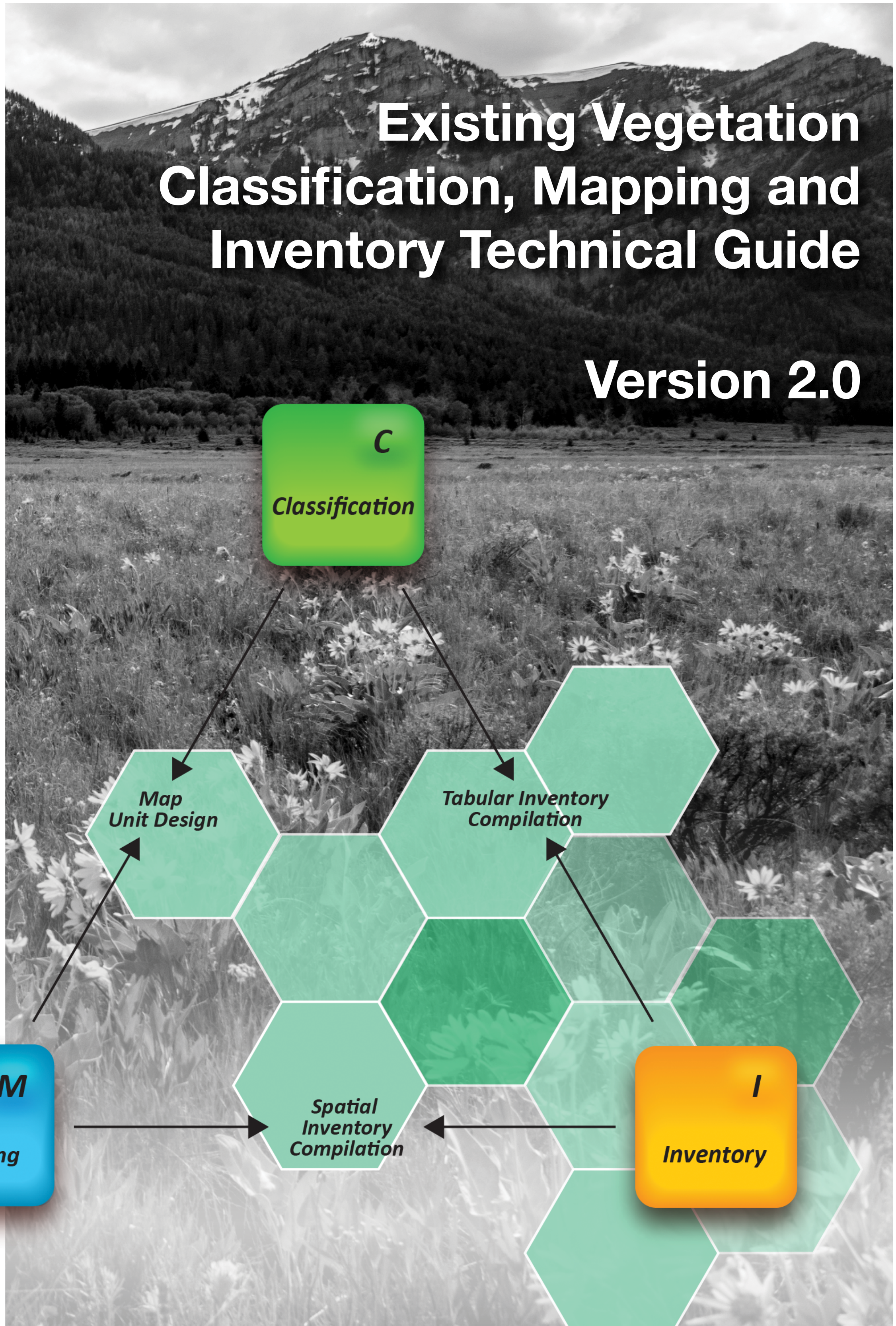
Existing Vegetation Classification, Mapping and Inventory Technical Guide

Version 2.0



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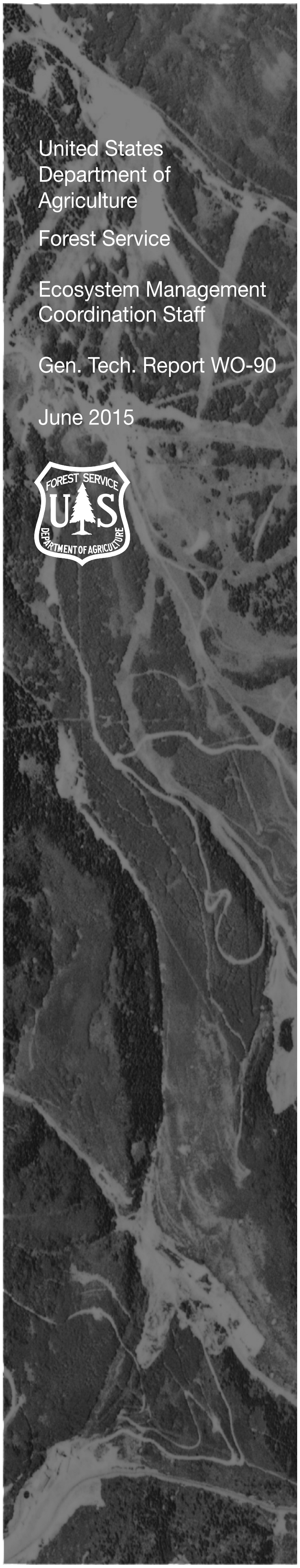

United States Department of Agriculture

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Existing Vegetation Classification, Mapping, and Inventory Technical Guide Version 2.0

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Appendix J. Imputation of Inventories

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Executive Summary

The Forest Service, an agency of the U.S. Department of Agriculture, manages 193 million acres (78 million hectares) that comprise the National Forest System (NFS) and represent a variety of landscapes and ecosystems across the Nation. In addition to managing the NFS, the Forest Service provides fire and forest health protection and technical and management assistance to other landowners through State and Private Forestry programs. The agency also provides research and international assistance to a wide variety of stakeholders through Research and Development and International Programs.

The purpose of the *Existing Vegetation Classification, Mapping, and Inventory Technical Guide—Version 2.0* (hereafter this technical guide) is to provide guidance for developing existing vegetation classification, map, and inventory data and information products that (1) comply with Federal and agency standards, (2) are consistent and continuous across the landscape, and (3) are responsive to the evolving business needs of the Forest Service and its partners. This technical guide also includes Geographic Information System (GIS) Data Dictionary and national application standards and guidelines that apply to existing vegetation data and information products.

This technical guide employs a conceptual framework based on the relationships among vegetation classification, mapping, and inventory processes to provide vegetation information products needed to support Forest Service and partner decisionmaking. It provides guidance for:

- Existing vegetation classification, which is the grouping of similar entities into named types or classes based on shared characteristics. Classification answers the question, "What is it?"
- Existing vegetation mapping, which is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and structural characteristics. Mapping answers the question, "Where is it?"
- Existing vegetation inventory quantifies the amount, composition, and condition of vegetation types with known statistical precision. Inventory answers the question, "How much is there?"

In summary, section 1, the introduction, provides program managers and agency leaders an understanding of agency business requirements; Federal Geographic Data Committee standards, roles, and responsibilities; and the conceptual framework employed in this technical guide. Section 2 focuses on existing vegetation classification procedures and is targeted to vegetation specialists involved in the process of classifying vegetation types. Section 3 addresses existing vegetation mapping methods and is targeted to remote sensing and geospatial specialists involved in vegetation mapping projects. Section 4 provides guidance on design and integration of existing vegetation inventories into classification and mapping processes and is targeted to designers, implementers, and users of base-, mid-, and broad-level existing vegetation inventories. More detailed descriptions of target audiences is provided at the beginning of each section.

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1.0 Existing Vegetation Classification, Mapping, and Inventory Framework

The Forest Service, an agency of the U.S. Department of Agriculture (USDA), manages 155 national forests, 20 national grasslands, and 1 national prairie. These 193 million acres (78 million hectares) of Federal land in the National Forest System (NFS) represent a variety of landscapes and **ecosystems**[1] across the Nation. In addition to managing the NFS, the Forest Service provides fire and forest health protection and technical and management assistance to other landowners through State and Private Forestry (S&PF) programs. The agency also provides natural resource research and international assistance to a wide variety of stakeholders through Research and Development (R&D) programs and International Programs. **Classification**, mapping, and **inventory** of existing vegetation are fundamental to the stewardship, conservation, and appropriate use of forests and grasslands within the United States and those countries supported by Forest Service programs.

1.1 Overview

Existing vegetation is the plant cover, or **floristic composition** and vegetation structure, occurring at a given location at the current time. Existing vegetation is the primary natural resource at the heart of nearly everything the Forest Service does, and is the highest priority investment for inventories and assessments. Classification, mapping, and inventory of existing vegetation, however, historically have lacked consistent standards. As a result, many vegetation descriptions, **maps**, and inventories have not been sharable across Forest Service administrative unit boundaries or with land and resource management partners. This technical guide establishes Forest Service guidelines and procedures for existing vegetation classification, mapping, and inventory activities to improve the consistency and utility of existing vegetation products.

Target audiences are identified in detail in each of the four sections of this technical guide. In summary, the target audience for section 2, Existing Vegetation Classification, is vegetation specialists who are involved in the process of classifying **vegetation types**; for section 3, Existing Vegetation Mapping, the target audience is **remote sensing** and **geographic information system** (GIS) specialists and associated professional employees involved in **vegetation mapping** projects; and for section 4, Existing Vegetation Inventory, the target audience is designers and implementers of base-, mid-, and broad-level inventories. Each target audience benefits from the contextual information presented in this section, Existing Vegetation Classification, Mapping, and Inventory Framework. The target audience for this section also includes program managers and agency leadership with responsibilities related to vegetation classification, mapping, or inventory.

1.2 Purpose

The purpose of this technical guide is to provide guidance for developing existing vegetation classification, map, and inventory products that (1) comply with Federal and agency standards, (2) are consistent and continuous across the landscape, and (3) are responsive to the **business needs** of the Forest Service. This technical guide also includes GIS Data Dictionary and national application

[1]The glossary at the end of this guide defines the terms in bold text throughout the guide.

standards and guidelines that apply to existing vegetation data and information products. This guide is a revision of the Existing Vegetation Classification and Mapping Technical Guide, Version 1.0 (Brohman and Bryant 2005). Neither Version 1.0 nor this revision addresses classification or mapping of **potential natural vegetation** (PNV); however, general relationships of existing vegetation and potential vegetation are discussed in section 1.5.2.

Section 1 of this technical guide describes the agency's business needs requiring existing vegetation information and provides the overall context and strategy for sections 2, 3, and 4. Section 2 addresses floristic and **physiognomic classification** of existing vegetation. Section 3 describes hierarchical mapping of existing vegetation at multiple levels. Section 4 addresses **quantitative inventory** and integration of inventory with classification and mapping.

1.3 Existing Vegetation Business Requirements

A complete **business requirements** analysis for existing vegetation information was completed before beginning revision of Version 1.0 of the Existing Vegetation Classification and Mapping Technical Guide (Spencer and Solem 2011). Business requirements for existing vegetation originate primarily from laws, regulation, and policy related to vegetation inventory, mapping, and management. Classification, mapping, and inventory are designed to meet Forest Service business requirements at the national, broad, mid, and base levels (see section 1.4.2), often using existing tools such as remotely sensed imagery, **protocols** such as Common Stand Examination, and databases such as Field Sampled Vegetation (FSVeg) and Field Sampled Vegetation Spatial (FSVeg Spatial). At the mid and base levels, for example, the departure between existing and desired vegetation **composition**, **structure**, and distribution is a fundamental consideration in developing vegetation management programs and designing treatment options. At all levels, the use of existing vegetation information developed using scientifically sound procedures and being in compliance with **Federal Geographic Data Committee** (FGDC) standards enhances Forest Service classification, mapping, and inventory procedures.

1.3.1 Laws, Regulations, and Policy

The Organic Act of 1897 authorizes the Forest Service to manage vegetation resources within the NFS. The Multiple Use and Sustained Yield Act of 1960, the National Forest Management Act of 1976, and a host of other laws establish further requirements for management. This collection of laws provides the Forest Service the authority to manage vegetation resources within the NFS and provides a legislative mandate to provide technical assistance to States, tribes, other countries, and private landowners managing forests and grasslands. Research and development activities associated with vegetation management are also authorized and include technology transfer to national and international forest and grassland interests. In addition, the Forest and Rangeland Resources Planning Act (RPA) of 1974 directs the Forest Service to inventory all forested land of the United States, and the National Forest Management Act of 1976 requires an inventory of national forests and grasslands.

Policy and procedures for land management planning and environmental compliance activities are outlined in Forest Service Manual (FSM) Chapters 1920 and 1950, respectively, and in the Code of Federal Regulations. Land management plans generally describe the desired condition for resources within the planning area, and project decisions determine the actions that will move the area toward or maintain the area in the desired state. Project decisions should comply with environmental regulations (e.g., National Environmental Policy Act, Endangered Species Act, Clean Water Act) and with the specific forest or grassland land management plan.

1.3.2 Vegetation Classification, Mapping, Inventory, and Management

Vegetation management relies on the ability to quantify, categorize, and describe distinct vegetation communities and locate them across the landscape. Utilization, conservation, restoration, or protection of vegetation communities is a component of most management decisions on NFS. Current and emerging issues, such as climate change, watershed and terrestrial condition assessments and **monitoring**, and implementation of the Cohesive Wildland Fire Management Strategy, demand information at broad levels across all vegetation types and management jurisdictions.

Much of the information needed to meet the diversity of business needs is provided by existing vegetation classification, mapping, and inventory activities, including—

- Describing vegetation communities and **habitats** and their distribution in an area.
- Characterizing effects of natural disturbances or management activities on plant and animal **species**, including threatened and endangered species and **community** distributions.
- Identifying management objectives and related management opportunities.
- Assessing resource conditions, determining capability and suitability, and evaluating forest and rangeland health.
- Assessing risks for invasive species, fire, insects, and disease.
- Developing fire and fuels analysis products (e.g., fire regime condition **class**).
- Conducting project planning and watershed analyses and predicting activity outcomes at the project and land management planning levels.

1.4 Conceptual Framework

Vegetation classification, mapping, and inventory are three distinct but related processes that provide basic vegetation information needed for Forest Service management decisionmaking.

- Vegetation classification is the grouping of similar entities into named types or classes based on shared characteristics. Classification answers the question, “What is it?”
- Vegetation mapping is the process of delineating the geographic distribution, extent, and landscape **patterns** of vegetation types and structural characteristics. Mapping answers the question, “Where is it?”
- Vegetation inventory quantifies the amount, composition, and condition of vegetation types with known statistical precision. Inventory answers the question, “How much is there?”

The classification, mapping, and inventory guidelines described in this technical guide will enable users to classify existing vegetation, use new or existing classifications to derive defensible estimates of current conditions, and monitor spatial and temporal changes in vegetation **attributes**. No single set of inventory data or single map is appropriate to address all types of questions at all levels of analysis, but an explicit relationship between **datasets** can provide for consistency and integration.

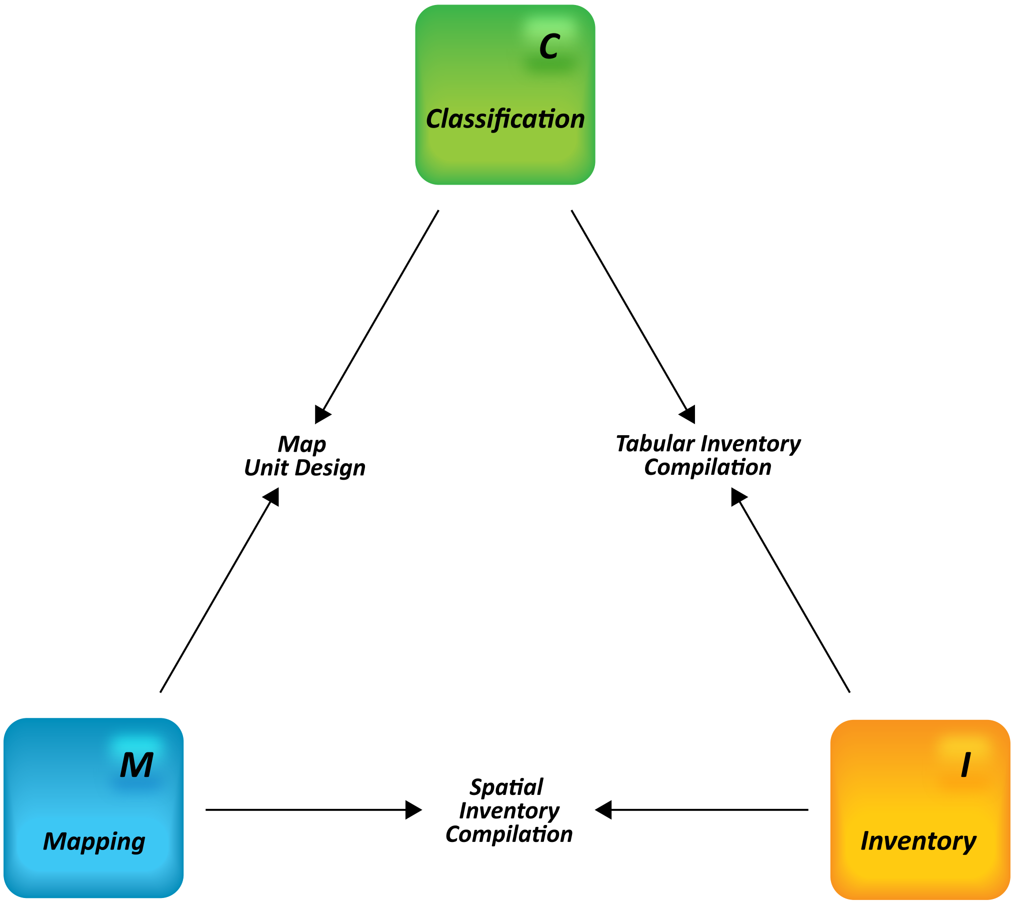
This technical guide presents a section on each of the three processes. The order in which they are presented does not suggest an order of operations or workflow. These activities are often implemented concurrently or in different orders at multiple levels to meet information needs and program of work requirements.

1.4.1 Conceptual Model

Some combination of classification, mapping, and inventory is often necessary to meet the complex information needs of the Forest Service. Some questions require a **population** estimate with a specified level of statistical precision that can be obtained only from an inventory. Other questions are inherently spatial, such as vegetation pattern or connectivity, and can be addressed only by a vegetation map. Questions increasingly have both inventory and mapping dimensions requiring both processes, however, and some level of classification is required to define what will be mapped or inventoried.

Figure 1-1 presents the conceptual model depicting general relationships among classification, mapping, and inventory. The corners of the triangle represent classification, mapping, and inventory processes, and the sides of the triangle represent the major process relationships that provide feedback and integration (Brewer et al. 2006). For instance, classification provides the basic logic for defining vegetation types, and the **map unit design** process (section 3.4.4) works within mapping technology and other constraints to provide the optimum set of **map units** to delineate the geographic distribution of vegetation types. Inventory data similarly contribute to the map unit design process through **tabular inventory compilation**, which provides estimates of **abundance** and distribution of various vegetation types from the classification. Figure 1-1 is repeated in sections 2, 3, and 4 of this technical guide with detailed descriptions of the process relationships depicted in the figure from the perspective of that section.

Figure 1-1.—*Relationship of vegetation classification, mapping, and inventory.* The corners of the triangle represent classification, mapping, and inventory activities, while the sides of the triangle represent the major process relationships that provide feedback and integration.



1.4.2 Classification, Mapping, and Inventory Levels

To avoid confusion regarding the use of the term *scale* for classification, mapping, and inventory activities and analyses, this technical guide uses the term *level* to describe the relationships among Forest Service management units; business requirements; classification, map, and inventory activities; and analysis scales. The levels described in the following bullet points and included in table 1-1 are national, broad, mid, and base.

- National-level products are intended to support nationwide or global information needs. Products at this level may be developed programmatically (e.g., National Land Cover Database [NLCD] tree **canopy cover** layer) or aggregated from existing lower level products, when feasible.
- Broad-level products are intended to support State, multistate, or regional information needs. Products at this level may be developed programmatically or aggregated from existing mid-level products, when feasible.
- Mid-level products are intended to support forest or multiforest information needs. Products at this level are typically developed programmatically from remotely sensed data, but they should integrate standard base-level products where they exist.
- Base-level products support forest and district local information needs and represent the highest thematic detail, **spatial resolution**, and **accuracy**. Base-level information is the least likely to be spatially extensive due to the cost of development; however, it offers the most flexibility for upward integration within the map hierarchy. Products at this level are typically developed from large-scale, remotely sensed data and field data.

Table 1-1.—*Relationships among classification, mapping, and inventory levels and Forest Service business requirements.*

Forest Service business requirements	Ecological unit hierarchy	Ecological unit mapping scale	Potential natural vegetation classification	Existing vegetation classification	Existing vegetation map unit design	Existing vegetation map product examples	Map extent	Inventory data sources/sampling protocols
National level: FIA, Resource Planning Act (RPA), International programs, fire and aviation, Forest Health Monitoring (FHM)								
National strategic inventory (FIA Phase I), forest cover, forest and rangeland health/ sustainability	Division, province	ECOMAP 1997 1:30,000,000 to 1:5,000,000 General polygon size: 10,000–100,000 mi^2	Groups of Series	NVC Formation Class, Formation Subclass, Formation, NFS Physiognomic unit, Major Land Resource Areas (MLRA)	National Land Cover Database (NLCD), one or more NVC upper level classes or groups of Formation Class, Subclass, Formation	National Land Cover Datasets, LANDFIRE	National (millions of square miles)	Forest Health Monitoring (FHM), FIA, National Resources Inventory (NRI)
Broad level: RPA, FIA, Fire, FHM, forest planning and monitoring								
Bioregional assessments, conservation strategies (region/subregion)	Section, subsection	1:7,500,000 to 1:250,000 General polygon size: 10–1,000 mi^2	Series	NVC Divisions, Macrogroups, Groups, Dominance types or alliances (e.g., Society for Range Management (SRM), Society of American Foresters (SAF) cover types)	One or more NVC mid level classes or groups of Divisions, Macrogroups, Groups, Cover types or Cover type groups, Dominance type groups	SAF forest type map, Gap Analysis Program (GAP), NLCD, LANDFIRE	State, multi-state, or region (20+ million acres)	FHM, FIA, NRI
Mid level: Forest planning and monitoring, fire, FIA								
Forest/multi-forest planning/monitoring, 4th/5th hydrological unit code (HUC) watershed assessments, National Fire Plan implementation (forest level) forest and rangeland health assessments, terrestrial and aquatic habitat assessments	Landtype association	1:250,000 to 1:60,000 General polygon size: 1,000–10,000 acres	Series, climax plant association (sensu Daubenmire 1968)	Dominance types, alliances, (associations optional where needed)	Dominance types, alliances, alliance groups and/or complexes, canopy cover groups, size/height groups (e.g., vegetation stand structure [VSS])	R5 Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG) California Wildlife Habitat Relationships (CWHR), R1 VMAP, R3 Midscale EV Maps, GAP, National Wetlands Inventory (NWI)	Forest or multi-Forest or Grassland (50,000+ acres)	FIA intensified plots, compartment exams, field training data plots, PACFISH-INFISH Biological Opinion Effectiveness Monitoring (PIBO-EM)
Base level: Project planning, forest plan implementation, land treatments								
Forest Plan Implementation project planning and land treatments, e.g., fuel treatments, grazing management, timber management, habitat management, range analysis, stand exams, effectiveness monitoring	Landtype, Landtype phase	1:60,000 to 1:24,000 General polygon size: < 1,000 acres	Climax plant associations and phases (sensu Daubenmire 1968)	Alliances, associations	Alliances, association, association complexes, canopy cover classes, size/height classes, vertical and horizontal structure	Resource photo interpretation maps, stand maps (e.g., R8 Continuous Inventory of Stand Conditions [CISC], R2 Common Vegetation Unit [CVU],range allotment analysis maps	5th/6th HUC Watershed or Project Area (< 50,000 acres)	Stand exams, rangeland protocols, Terrestrial Ecological Unit Inventory (TEUI) integrated plots

*The NVC Forest and Woodlands Formation Class, when finalized, may not fully correspond to the Forest Service Forest and Woodland Physiognomic Unit. The NVC Forest and Woodlands Formation Class may include krummholz and other stunted tree communities, while the Forest Service physiognomic classification places stunted tree communities in shrublands.

1.5 Classification, Mapping, Inventory, and Monitoring Relationships

Several processes and programs that complement this technical guide are already in place or are in development. Some relationships that span the topics of classification, mapping, and inventory are described here. Others are addressed in later sections of this guide.

1.5.1 Relationship to the FGDC National Vegetation Classification Standard

The procedures described in this technical guide are designed to be compatible with the FGDC National Vegetation Classification (NVC) Standard published in 2008, which was an update to the FGDC (1997) NVC Standard. The objective of the 2008 NVC **Standard** follows:

> The overall purpose of this National Vegetation Classification Standard …is to support the development and use of a consistent national vegetation classification (…referred to as the "NVC") in order to produce uniform statistics about vegetation resources across the nation, based on vegetation data gathered at the local, regional, and national levels…. It is therefore important that, as agencies map or inventory vegetation, they collect enough data to translate it for national reporting, aggregation, and comparisons. The ability to crosswalk other vegetation classifications and map legends to the NVC will facilitate the compilation of regional and national summaries (FGDC 2008: 2).

In addition, Executive Order 12906 designates the FGDC as the lead organization to coordinate the development of the National Spatial Data Infrastructure (NSDI), which is defined as "…the technology, policies, standards, and human resources necessary to acquire, process, store, distribute, and improve utilization of geospatial data" (Executive Order 12906, 1994:1). This Executive order authorizes the FGDC to develop the standards required to implement the NSDI and requires Federal agencies to meet those standards. The gravity of this responsibility is best demonstrated with excerpts from Executive Order 12906:

> Federal agencies collecting or producing geospatial data … shall ensure, prior to obligating funds for such activities, that data will be collected in a manner that meets all relevant standards adopted through the FGDC process (Executive Order 12906 1994: 2).

All Federal agencies and programs that collect or produce vegetation data should be consistent with policies of the FGDC as outlined in the Office of Management and Budget Revised Circular A-16, which established the FGDC in 1990. FGDC's mission is to "…promote the coordinated development, use, sharing, and dissemination of surveying, mapping, and related spatial data" (OMB 1990: 5). The FGDC is authorized to "…establish, in consultation with other Federal agencies and appropriate organizations, such standards…as are necessary to carry out its government wide coordinating responsibilities" (OMB 1990: 6).

Types of FGDC Standards

The FGDC establishes two kinds of standards: data and process (FGDC 1996).

> **Data standards.** "…describe objects, features or items that are collected, automated, or affected by activities or functions of agencies…. Data standards are semantic definitions that are structured in a model" (FGDC 1996: 7).

> **Process standards.** "…describe how to do something, procedures to follow, methodologies to apply, procedures to present information, or business rules to follow to implement standards" (FGDC 1996: 8).

Five types of data standards and 10 types of process standards exist (FGDC 1996). Those relevant to existing vegetation classification are as follows:

> **Data classification standards.** "…provide groups or categories of data that serve an application…. Examples are wetland and soil classifications" (FGDC 1996: 7). In other words, a data classification standard specifies and defines a set of categories that should be used, or crosswalked to, by Federal agencies.

> **Classification methodology standards.** "…are the procedures to follow to implement a data classification standard. [They describe] how data are analyzed to produce a classification" (FGDC 1996: 8). Classification methodology standards specify how to develop a classification rather than specifying the categories of the classification. The 2008 FGDC NVC Standard provides "…a process standard to be used to create a dynamic content standard for all vegetation types in the classification [i.e., the NVC]. The content standard will provide hierarchical groups and categories of vegetation" (FGDC 2008: 1)

In 2008, the FGDC updated the NVC Standard, in part motivating the update to this technical guide.

> The structure of the revised NVC hierarchy is a substantial revision of the 1997 hierarchy. The revised hierarchy addresses the following issues, among others: a) uses vegetation criteria to define all types (de-emphasizing abiotic criteria, such as hydrologic regimes in wetland types), b) provides a clear distinction between natural and cultural vegetation wherever these can be observed from broad growth form patterns (rather than combining natural and cultural vegetation initially and separating them at lower levels), c) for natural vegetation, defines the upper levels based on broad growth form patterns that reflect ecological relationships (rather than detailed structural criteria, which are more appropriate lower down in the hierarchy), d) provides a new set of middle-level natural units that bridge the large conceptual gap between alliance and formation, e) integrates the physiognomic and floristic hierarchy levels based on ecologic vegetation patterns, rather than developing the physiognomic and floristic levels independently and then forcing them into a hierarchy, f) provides detailed standards for plot data collection, type description and classification, data management and peer review of natural vegetation, and g) for cultural vegetation provides an independent set of levels that addresses the particular needs of cultural vegetation (FGDC 2008: 8).

The 2008 NVC Standard is documented in detail at http://www.usnvc.org. As of October 2013, 8 classes, 18 subclasses, 38 formations, 77 **divisions**, 214 macrogroups, 430 **groups**, and 6,105 **associations** have been documented. Mid and lower levels are expected to continue to be defined for several years. Table 1-2 compares the 1997 NVC Standard with the 2008 NVC Standard; only the 2008 NVC Standard should be used.

Relationship to Forest Service Physiognomic Units

Level 1 of the NVC hierarchy, **Formation Class**, corresponds well to Forest Service physiognomic units, an adapted version of the NVC hierarchy that meets agency business requirements for existing vegetation classification (see appendix A for descriptions and keys for Forest Service physiognomic units; see also table 1-3). The unit "cultural forest," for example, is a Forest Service physiognomic unit that accounts for highly manipulated forest plantations that the Forest Inventory and Analysis (FIA) program considers forest. Sparse and **nonvascular** vegetation account for alpine and boreal tundra, and the unit "no dominant **life form**" accounts for areas with more than 10 percent vegetation without any one life form dominating the vegetation. As required by the NVC Standard, these units crosswalk to the NVC Standard and nest within conceptual categories 1 and 2 as shown in table 1-3. Forest Service crosswalks may be developed to describe only general relationships, such as those at the physiognomic unit level, until more specific keys are developed and adopted by FGDC.

Table 1-2.—*Comparison of 2008 FGDC NVC Standard hierarchy with the 1997 NVC hierarchy.*

1997 FGDC NVC hierarchy	2008 revised FGDC NVC hierarchy
Upper	
Division – Vegetation vs. Non-vegetation	
Order – Tree, Shrub, Herb, Nonvascular	
Level 1 – Formation Class	Level 1 – Formation Class
Level 2 – Formation Subclass	
Level 3 – Formation Group	Level 2 – Formation Subclass
Level 4 – Formation Subgroup – Natural / Cultural	
Level 5 – Formation	Level 3 – Formation
Mid	
	Level 4 – Division
	Level 5 – Macrogroup
	Level 6 – Group
Lower	
Level 6 – Alliance	Level 7 – Alliance
Level 7 – Association	Level 8 – Association

Table 1-3.—*Comparison of conceptual categories, Level 1 of the NVC hierarchy, and Forest Service physiognomic units.*

Conceptual category 1	Conceptual category 2	NVC Level 1: formation class	Forest Service physiognomic unit
Vegetated areas	(Semi) natural vegetation	Forest and woodland	FW – Forest and woodland
		Shrubland and grassland	SH – Shrubland
		Semi-desert vegetation	HB – Herbland
		Polar and high montane vegetation	
		Aquatic vegetation	AQ – Aquatic vegetation
		Nonvascular and sparse vascular vegetation	SV – Sparse vegetation
			ND – No dominant life form
			NV – Nonvascular vegetation
	Cultural vegetation	Agricultural vegetation	AG – Agricultural vegetation
			CF – Cultural forest
		Developed vegetation	DV – Developed Vegetation
Non-vegetated areas	Not included in the NVC.		NO – Non-vegetated

*The NVC Forest and Woodlands Formation Class, when finalized, may not fully correspond to the Forest Service Forest and Woodland Physiognomic Unit. The NVC Forest and Wood lands Formation Class may include krummholz and other stunted tree communities, while the Forest Service physiognomic classification places stunted tree communities in shrublands.

1.5.2 Relationship Between Existing and Potential Natural Vegetation

Potential natural vegetation, or PNV, "…is the vegetation that would become established if all successional sequences were completed under present climatic, edaphic, and topographic conditions without major natural disturbances or direct human activities" (adapted from Küchler 1973 and from Tüxen 1956, as translated by Mueller-Dombois and Ellenberg 1974: 422). PNV classifications are based on existing vegetation, successional relationships, and environmental factors (e.g., climate, geology, soil) considered together. This approach requires an understanding of species autecology and successional dynamics of plant communities. PNV classification uses information about structure and composition similar to that needed for existing vegetation classification, but it places greater emphasis on composition and successional relationships.

Both existing and PNV classifications and maps are important for assessing resource conditions and evaluating management options. Because these two sets of information address different questions, they are considered complementary, not mutually exclusive. Existing vegetation information alone cannot answer questions about successional relationships, historical range of variation, productivity, habitat relationships, and expected responses to management actions. An existing vegetation classification inherently lacks information about the topics in the previous section because it describes the vegetation present at the single point in time in which the classification was completed. Existing and PNV classifications can be performed simultaneously as demonstrated by Mueggler's (1988) classification of aspen forests in the Intermountain Region.

1.5.3 Relationship to Terrestrial Ecological Unit Inventory

The Terrestrial Ecological Unit Inventory (TEUI) process classifies ecological types and develops terrestrial ecological units (TEUs) to a consistent standard on NFS lands. The process also develops and describes ecological land units, where response to disturbance processes and land management actions are expected to be similar based on PNV and physical characteristics (e.g., geology, climate, soil, and topography). Existing vegetation classification, maps, and inventories describe current vegetation composition, structure, and patterns. To provide the ecological context for making land management decisions, use sections 2, 3 and 4 of this technical guide and the TEUI protocol (Winthers et al. 2005) together. TEUI includes nationally accepted protocols for sampling vegetation, sampling soil pedons and **site** characteristics. TEUI data can augment a design-based inventory (described in section 4 of this technical guide). Because the **plot** locations are typically purposively (rather than randomly) selected, however, these data cannot be used to generate a statistically valid estimate.

Existing vegetation classifications and maps, when combined with ecological type classifications and ecological unit maps, provide land managers a context for evaluating ecological conditions and resource values (e.g., wildlife habitat, forage, watershed conditions, and timber) and selecting appropriate land management practices based on ecosystem capability and expected responses. Bourgeron et al. (1994) consider relationships between biotic components and **abiotic** factors important for predicting management response of ecosystems and landscapes under various management scenarios. Bailey et al. (1994) describe the importance of combining existing vegetation maps with ecological unit maps delineating land areas with similar potential for management to effectively assess ecosystem health in land use planning. Information derived from combining existing vegetation classifications, descriptions, and maps with TEUI provides the basis for selecting suitable areas for land use activities, identifying and prioritizing areas for restoration activities, evaluating various land management alternatives, and predicting the effects of a given activity on ecosystem health and resource condition.

1.5.4 Relationship to Ecological Site Descriptions

The *Ecological Site Description* (ESD) handbook (USDA NRCS et al. 2013) provides a standardized method to be used by the U.S. Department of the Interior, Bureau of Land Management and USDA Forest Service and Natural Resources Conservation Service to define, delineate, and describe terrestrial ecological sites on rangelands. Ecological site classifications and descriptions provide a consistent framework for stratifying and describing rangelands and their soil, vegetation, and abiotic features, thereby delineating units that share similar capabilities to respond to management activities or disturbance processes. An ecological site is a conceptual division of the landscape that is defined based on recurring soil, landform, geological, and climate characteristics and differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and its ability to respond to management actions and natural disturbances (USDA NRCS et al. 2013). Ecological sites are roughly equivalent in scale and landscape context to TEUs at the land type phase, and correspond with PNV plant associations and **habitat type** phases, which are commensurate with soil series and soil series phase taxonomic units.

The objectives and methods for classifying and mapping existing vegetation are different from those used for ESDs, although both systems benefit from the other and are complementary. ESDs are classes of land, with class limits based on physical factors and consideration of vegetation, successional trajectories, and productivity. Existing vegetation is classified and mapped based solely on current vegetative conditions, not the environmental factors influencing vegetation. Existing vegetation types can be used to represent plant community phases in state-and-transition models, which are part of an ESD.

FSM 2060 (Ecosystem Classification, Interpretation, and Application) directs the Forest Service to use the National Hierarchical Framework of Ecological Units in resource assessments, planning, management, and monitoring, and to cooperate in developing ESDs in rangelands. Similar to TEUs, maps of ESDs, combined with maps of existing vegetation, enable the Forest Service to evaluate biotic distributions and ecological processes and can provide the basis for defining and mapping ecosystems.

1.5.5 Relationship to Forest Service Inventory and Monitoring Programs

Many national and regional inventory and monitoring programs exist in the Forest Service and other agencies. Coordination with tribes, States, and other Federal agencies is essential to understanding existing vegetation relationships and effects of management activities across landscapes managed by different organizations. Inventory and monitoring of natural resources provide the ecological information necessary to achieve the Forest Service mission.

Section 4 of this technical guide describes inventory methods for existing vegetation. It also describes how classification, mapping, and inventory can be used in a comprehensive monitoring program by producing basic information about ecosystems and/or individual resources. It does not provide detailed guidance for monitoring existing vegetation, however. Existing vegetation monitoring includes **dynamic sampling**, which measures changes in resources over time (Helms 1998), and **evaluation**, which compares these changes with management goals, threshold values for sustainability, or trigger points that initiate specific management actions. The body of knowledge produced by the inventory process is the basis for the evaluation criteria and the sampling methods.

Table 1-4 describes classification, mapping, and inventory activities, illustrates their relationships, and lists other related protocols and processes. Table 1-5 presents a generalized comparison of the sampling approaches used in existing vegetation classification, mapping, inventory, and monitoring. It describes the kinds of attributes collected, selection of sampling locations, and precision of sampling methods.

FSM 1940 defines inventory and monitoring as follows:

Inventory. To survey an area or entity for determination of such data as contents, condition, or value, for specific purposes such as planning, evaluation, or management. An inventory activity may include an information needs assessment; planning and scheduling; data collection, classification, mapping, data entry, storage and maintenance; product development; evaluation; and reporting phases (USDA Forest Service 2009a).

Monitoring. The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a resource or management objective. A monitoring activity may include an information needs assessment; planning and scheduling; data collection, classification, mapping, data entry, storage and maintenance; product development; evaluation; and reporting phases (USDA Forest Service 2009a).

Table 1-4.—*Relationships of Forest Service existing vegetation classification, mapping, inventory, and monitoring activities.*

	Existing vegetation classification	Existing vegetation mapping	Existing vegetation inventory	Vegetation monitoring
Basic questions	What is it?	Where is it?	How much is there?	Is it maintaining or moving toward desired conditions?
Task or activity	Develop and describe vegetation types; create keys to distinguish between types.	Delineate geographic distribution, extent, patterns, and juxtaposition of vegetation types or attributes.	Estimate the amount of each vegetation type or the values of vegetation attributes (e.g., species) in a specific area.	Detect changes over time in vegetation amount and distribution or values of vegetation attributes.
Relationships between processes	Classification is often a prerequisite for each of the other three processes. The other processes, especially mapping, can help validate and refine a classification.	Use a standard vegetation classification to design map units and develop a map legend. A classification system, however rudimentary (e.g., species x is present or not), is required for the map unit design process.	An inventory of vegetation types requires that a classification be developed first or that sufficient data are collected to later assign plots to a classification. A map-based inventory can be generated by summing acres of map units or components.	Knowledge gained through classification, mapping, and quantitative inventory helps develop evaluation criteria and monitoring methods. Repeated mapping or inventory can provide monitoring data.
Related activities or processes	- PNV classification - Ecological type classification - Ecological site classification	- PNV mapping - Land type association (LTA) mapping - Land type mapping - Land type phase mapping - Fire regime condition class mapping - Range or non-forested vegetation mapping	- FIA - Common stand exam - Riparian/wetland inventory - Old growth inventory - Rangeland or non-forested vegetation inventory	- Forest health monitoring - Rangeland or non-forested vegetation monitoring - Riparian or wetland monitoring - Invasive species monitoring - Threatened and endangered plant species monitoring

Table 1-5.—*Comparison of sampling approaches for existing vegetation classification, mapping, inventory, and monitoring activities.*

	Existing vegetation classification	Existing vegetation mapping	Existing vegetation inventory	Vegetation monitoring
Task or activity	Develop and describe vegetation types; create keys to distinguish between types.	Delineate geographic distribution, extent, patterns, and juxtaposition of vegetation types and/or attributes.	Estimate the amount of each vegetation type or the values of vegetation attributes (e.g., species, ground cover, fuels) in a specific area.	Detect changes over time in vegetation amount and distribution or values of vegetation attributes.
Example attributes	• Physiognomy • Floristics • Composition • Structure	• Vegetation types • Plant size classes • Cover	• Vegetation types • Plant size classes • Cover • Productivity • Health indicators	• Vegetation types • Plant size classes • Cover • Productivity • Health indicators
Sample location method	**Subjective**— Uniform stand and site conditions, not ecotonal. **Objective**— Systematic placement geographically or along environmental gradients, or random placement.	**Subjective**— Representative of a polygon or map unit. **Objective**— Systematic or random placement in a polygon or map unit.	**Subjective**— Usually not appropriate. **Objective**— Random or systematic placement to provide statistical reliability.	**Subjective**— Located in key areas of concern. **Objective**— Located randomly or systematically in predefined key areas to provide statistical reliability.
Sampling methods	Reconnaissance or intensive. Vegetation and environmental data required for identifying relationships.	Reconnaissance or intensive. Vegetation and environmental data usually collected.	Quantitative and usually intensive. Methods depend on objectives.	Usually quantitative and intensive. Data collected depends on objectives and what is being monitored.
Species list type	Completed and quantified.	Indicator or Dominant species only.	Species with a minimum abundance plus indicators.	Only key species indicating the effects of management.

QA/QC processes are defined in FSM 1940 as follows:

Quality assurance. The total integrated program for ensuring that the uncertainties inherent in inventory and monitoring data are known and do not exceed acceptable magnitudes, within a stated level of confidence. QA encompasses the plans, specifications, and policies affecting the collection, processing, and reporting of data. It is the system of activities designed to provide officials with independent assurance that QC is being effectively implemented uniformly throughout the inventory and monitoring programs (USDA Forest Service 2009a).

Quality control. The routine application of prescribed field and office procedures to reduce random and systematic errors and ensure that data are generated within known and acceptable performance limits. QC involves using qualified personnel, using reliable equipment and supplies, training personnel, and strictly adhering to servicewide standard operating procedures for tasks such as information needs assessments, establishment of standards and methods, data collection, data processing, classification, mapping, analysis, and dissemination (USDA Forest Service 2009a).

1.6 Data Management

Data collected for vegetation resources should be managed and stored to be accessible for current and future use both within and outside the Forest Service. A tremendous investment of time and energy is typically made for sample design, data collection, and map development, and it is critical that this important last step of the process, data management, is properly completed. Forest Service corporate database applications provide a system that not only fosters data sharing but also ensures integrity, transparency of the data, and defensible analysis and reports. For cases in which corporate databases do not meet the need of the project, ancillary databases may be used, but these ancillary databases should also address standard data management and quality requirements.

The Forest Service supports the concept of data preservation, whereby data are stored electronically for future accessibility beyond the current use and the local management unit. Preserving resource information in a central repository rather than on local servers makes resource data broadly available, making it useful across boundaries and at other levels of analysis. For example, key management questions related to Forest Service business requirements and the Strategic Plan (USDA Forest Service 2007) can be addressed using centralized data.

1.6.1 Data Stewardship

Data stewardship is the oversight and management of data for the program area. This oversight is brought to bear throughout the data lifecycle (see FGDC 2010) from defining information needs and data requirements to use of data to support the agency mission. It includes many aspects of the roles discussed in section 1.7 for data acquisition, data management and analysis, and evaluation and response with an emphasis on taking the responsibility to ensure that data are consistent with USDA requirements for Information Quality Activities as described by the Office of the Chief Information Officer (http://www.ocio.usda.gov/policy-directives-records-forms/information-quality-activities).

Data stewardship is conducted in a geospatial context in which the geographic location and characteristics of natural or constructed features are integrated within GIS and related databases.

1.6.2 Quality Assurance and Quality Control

Data **quality assurance** and **quality control** (QA/QC) are mandated by the Data Quality Act, USDA, and by Forest Service policy. Oversight of data collection, transfer, and accuracy are essential to effective management and occur throughout classification, mapping, and inventory processes.

The classification, mapping, and inventory processes described in this technical guide are normally conducted as large projects or programs of work. Although each of these processes have unique QA/QC considerations discussed in their respective sections, it is useful to consider the overall QA/QC processes in the context of **project management**.

QA from a project management perspective is a *process-based approach* that ensures that data products produced by a given project conform to all stated requirements of that project. QA is a proactive process that starts with a project plan during project initiation to document requirements and expectations. QA/QC topics in the project plan include process definition, training of project personnel, and the use of reliable, defensible science in project methods. An emphasis on QA during the planning phase saves time and reduces costs later in the project.

Quality control is a *product-based approach* that starts after project work has begun. It is designed to find defects or errors in the data products and corrects the problems before data delivery. Quality control typically includes items such as crew training and oversight, inspection/review of data collection techniques and intermediate products, and testing data products relative to requirements. Items identified through QC activities provide feedback for the QA process for future projects.

1.6.3 Corporate Data Storage

Existing vegetation inventory and monitoring information should be stored in corporate database applications, including but not limited to Natural Resource Manager (NRM) and geospatial databases. Data products that do not readily fit in existing corporate applications should be stored in the appropriate Forest Service electronic filing system or an ancillary database (e.g., project file or administrative record).

Natural Resource Manager

NRM is a national Forest Service organization responsible for the management and software development activities of an application group whose data are accessible to Forest Service personnel and the public. NRM works with the national programs to implement database development and standardization, enhancing the integration of information across resource programs and organizations. The Forest Service designed NRM applications to meet the unique business requirements of the agency, but the applications follow standards of the FGDC and are therefore compatible in **metadata** standards with data compiled by other Federal agencies.

Most data collected for existing vegetation classification, mapping, and inventory will be stored in the Forest Service NRM (http://www.fs.fed.us/nrm/) in one of the following four applications.

1. *Field Sampled Vegetation*, or FSVeg. FSVeg stores data about trees, fuels, down-woody material, surface cover, and understory vegetation. FSVeg supports the business of common stand exam, fuels data collection, permanent grid inventories, and other vegetation inventory collection processes.
2. *Field Sampled Vegetation Spatial*, or FSVeg Spatial. FSVeg Spatial manages spatial and tabular vegetation data in one place, at one time. NRM is working with units to move vegetation data from forests into the FSVeg Spatial application. It contains the following three types of data:
    - The vegetation polygon feature class (required to use FSVeg Spatial).
    - The vegetation point feature class.
    - Non-stand-exam vegetation data associated with the polygon feature class.

3. *Inventory and Mapping*. Inventory and Mapping for Terrestrial Ecological Units, non-NASIS (National Soil Information System) Soils, and Potential Natural Vegetation is a spatial application that supports sampling, mapping, characterization, interpretation, and classification of terrestrial natural resources. It specifically supports TEUI project work and inventories for geology, soils, and PNV.
4. *Rangeland Inventory and Monitoring.* Rangeland Inventory and Monitoring supports national protocols for vegetation and ground cover sampling, general site characterization, and detailed soil pedon descriptions. The application supports site characterization, interpretations, and classifications; it also accommodates casual point observations with basic attributes. National vegetation sampling protocols supported by the application include Tree/Snag, Ocular Macroplot, Line Intercept, Cover Frequency, Nested Rooted Frequency, Robel Pole, Density, Paced Transect, Macroplot, Riparian Greenline–Winward, Riparian Cross-Section–Winward, and Riparian Woody Regeneration–Winward. Rangeland Inventory and Monitoring is a spatial application intended for defined projects with formal protocol- or program-driven inventories.

Geospatial Data and Geodatabases

Geospatial data identifies the geographic location and characteristics of natural or constructed features and boundaries on the earth (Executive Order 12906 1994). Geospatial data include spatial and attribute data stored in GISs and additional attribute data stored within related databases. Within the Forest Service, GIS data are stored corporately within agency geodatabases, consistent with the GIS Data Dictionary, at various organizational levels and within NRM applications where they have the capability to store GIS data. Related attribute data can be stored within the geodatabase, within NRM applications, or other within ancillary databases. Maintaining the integrity of the relationship between **spatial data** and related attribute data is vital to the effective use of geospatial data to support agency business needs.

Standards for geodatabase design and data relationships are established within the National GIS Data Dictionary and incorporated within NRM designs.

Ancillary Databases

In some situations, data products from an existing vegetation classification, map, or inventory may not fit into existing applications because the applications do not support the appropriate standards or protocols (e.g., the applications do not have the data fields needed for entering specific attribute data). The project team may need to create an ancillary database but should first consult database stewards and data managers at the national forest or grassland and regional office levels to (a) ensure that the proposed database does not already exist, (b) verify that it does not conflict with any existing databases, and (c) track new developments and new business requirements. Ancillary databases may be a long-term management investment. If an ancillary database is created, it should use codes and other features published in corporate standards and databases to the extent possible.

An ancillary database can be as simple as a Microsoft (MS) Excel spreadsheet or as complicated as an Access or Oracle relational database or ARCGIS geodatabase. Whatever the final format for the data, the project team should use best data management practices and follow FGDC and Forest Service data standards. The database should be saved to a corporate drive to ensure it is backed up regularly and available when an employee leaves the agency or unit. It is recommended that Forest Service personnel use corporate applications to the extent possible and only create ancillary databases when no other solution exists within the Forest Service corporate database structure.

1.6.4 Metadata Requirements

Metadata are information about data, that is, its history and changes, and are federally mandated by Executive Order 12906. Metadata provide the information people need to understand, trust, and correctly use data. From defining attributes and accuracy to providing information about projection and coordinate systems, metadata provide answers to many users' questions. Metadata also help to avoid wasteful duplication of effort, direct people to the data they need, and determine how best to use it. The Forest Service *Metadata Users Guide* (http://www.fs.fed.us/gac/metadata/) is designed to help users with this information.

FGDC standards should be implemented when creating and managing metadata. The Forest Service standards for archiving and managing **FGDC compliant metadata** should conform to retention and disposal requirements and schedules described in Forest Service Handbook (FSH) 6209.11 and to direction issued by the FGDC Historical Records Working Group of the National Archives and Records Administration.

Forest Service GIS Data Dictionary

The Forest Service GIS Data Dictionary contains information about Forest Service data standards for the collection and storage of geospatial data. For the existing vegetation **theme**, this set of standards includes data structure and spatial requirements for feature classes at the national, broad, mid, and base levels, data structure of related tables, domains of valid values, and sample geodatabase designs with standard metadata templates. The data dictionary also contains standard feature-level metadata fields to document changes to individual features consistent with this technical guide. The Forest Service GIS data dictionary is available on the Forest Service internal Web site at http://www.fsweb.datamgt.fs.fed.us/index.shtml.

1.6.5 Data Continuity and Quality

Although the methods described in this technical guide are highly recommended, a key consideration for any implementation effort is the effect of transition on data continuity and quality. Maintaining the ability to interpret and compare data across spatial and temporal scales is particularly important for long-term datasets (e.g., FIA data).

It may be that the tradeoffs associated with the need to maintain data continuity and quality overrides the desire to transition to a new system. Investing in a transition plan to address these issues may be warranted. A statistician or scientist well versed in this kind of data adjustment should be consulted to help develop transition plans.

1.7 Roles and Responsibilities

Roles and responsibilities for existing vegetation classification, mapping, and inventory are shared across multiple Forest Service Deputy Areas (primarily NFS, S&PF, and R&D).

1.7.1 National

National program responsibilities for existing vegetation classification, mapping, and inventory are shared across multiple Washington Office program staffs in the NFS, R&D, and S&PF deputy areas and International Programs. Roles and responsibilities associated with vegetation classification, mapping, and inventory include the following shared responsibilities coordinated among staff areas.

Data stewardship. Develop standards and protocols to provide consistent, credible approaches for vegetation classification, mapping, and inventory within the agency; coordinate implementation of standards, protocols, and data collection across the agency.

Data acquisition. Provide and manage funding for implementing existing vegetation classification, mapping, and inventory projects; ensure that existing vegetation classification is consistent with FGDC-adopted standards; oversee program implementation, including interagency classification, mapping, and inventory activities; develop and maintain any necessary agreements among NFS, R&D, S&PF, and International Programs; provide guidance in the development of regional plans; support, monitor, and evaluate implementation of regional plans; assist regions in providing training and oversight; and develop collaborative relationships with other Federal and State agencies to facilitate landscape management and conservation, including through NLCD map development and the FIA and Forest Health Monitoring (FHM) programs.

Data management and analysis. Work collabratively to integrate existing vegetation data and information standards into corporate databases; ensure that regions are collecting data using approved database codes; support and evaluate regional implementation of existing vegetation classification, mapping, and inventory to ensure compliance with national standards; correlate vegetation types among regions, and ensure compatibility of descriptions across regional boundaries; identify geospatial data requirements; emphasize the critical importance of location (GIS) information for all inventory protocols; assist regions in providing training related to data management and analysis; develop basic models for forest, region, and national evaluations; analyze and report the national status and trends; and ensure consistency and data quality among regions. In addition, collaborative work with the FIA and FHM programs will enhance consistency with national reporting such as Resource Planning Act (RPA) assessments, National Sustainability Reports, and National Insect and Disease Risk Mapping. Collaborative work with other Federal agencies (e.g., Multi-Resolution Land Characteristics Consortium on the NLCD tree canopy cover **layer**) will enhance data consistency across NFS boundaries.

Evaluation and response. Update protocols, technical guides, and directives, as needed, in response to results and experiences at the forest, regional, and national levels and provide guidance to forests and regions regarding the suitability of results, future needs and priorities, and opportunities to improve the efficiency and effectiveness of management activities and plans.

1.7.2 Regions, Area, and Stations

Region, area, and station responsibilities for existing vegetation classification, mapping, and inventory include coordinating program needs and availability of vegetation specialists and also include the following responsibilities.

Data stewardship. Coordinate implementation of standards, protocols, and data collection for vegetation classification, mapping, and inventory within the region, area, or station consistent with national guidance; participate in the development of agency standards and protocols, including the change-management process; and develop and maintain standardized code tables and domains within the context of the region, area, or station.

Data acquisition. Implement existing vegetation classification and mapping programs consistent with national guidelines and protocols, including compliance with FGDC process standards, and develop regional supplements as needed; design and implement protocols with coordination from forests, regional offices, national program staff, and research stations; develop, coordinate, and conduct training for field data collection and oversight; oversee and direct the overarching framework in which protocol implementation fits; direct protocol funds to appropriate parties and projects; coordinate data collection across the region by involving forests; identify GIS data requirements; and coordinate with broader Forest Service programs, including NLCD map development and the FIA and FHM programs, as needed.

Data management and analysis. Develop existing vegetation classifications and maps to support resource assessments, forest plan revisions, resource monitoring, and other business requirements as scheduled in the regional strategic inventory plan; oversee third-party review of classification reports; coordinate with external cooperators and neighboring regions to correlate vegetation types; correlate vegetation types within the region; maintain a list of types in appropriate corporate applications; track the status of vegetation classification and mapping in the region; conduct field reviews to ensure consistency and quality during accomplishment of performance measures; oversee data entry, management, and input in appropriate corporate applications; summarize and analyze regional and forest data; evaluate sampling efficiency and statistical validity; coordinate with local agencies and organizations to maximize collaboration; and provide support at the regional level to maintain database code tables so that local management units can enter inventory and monitoring data into the appropriate Forest Service corporate applications.

Evaluation and response. Design an inclusive process for evaluating results; conduct annual or periodic reviews to evaluate changes in conditions or identify when data have become inaccurate; apply data and results to inform forest and regional assessments; test hypotheses related to cause and effect relationships relevant to management; and adjust management activities and plans when necessary.

1.7.3 National Forests and National Grasslands

Forest and grassland supervisors are responsible for ensuring vegetation resources within the NFS are managed to sustain forest and grassland health, diversity, and productivity. National forest and grassland responsibilities for existing vegetation classification, mapping, and inventory include—

Data stewardship. Apply national and regional standards and protocols to meet on-the-ground resource management needs; oversee and coordinate data collection and use of the data within each unit; work closely with regional **data stewards** to help develop regional code tables and domains; and participate in the change-management process.

Data acquisition. Implement existing vegetation classification, mapping, and inventory programs and activities using national guidelines and protocols and regional supplements; collect appropriate field data to classify existing vegetation according to FGDC standards; implement field-level data collection; provide QA/QC of data collection for classification, mapping, and inventory projects; coordinate with local cooperators and neighboring Forest Service administrative units to correlate vegetation types and maps; correlate vegetation types and track the status of vegetation classification and mapping on the forest or grassland; participate in regional plan development, development of monitoring protocols, Forest Plan monitoring program, and broader scale monitoring strategies (identify and communicate forest specific needs); identify GIS data requirements; participate in multiforest and multiregion coordinated implementation; and ensure that funding is obtained to complete project needs and goals.

Data management and analysis. Participate in forest and regional data management and analysis tasks; ensure QA/QC; maintain confidentiality of sensitive information; communicate or complete forest-level analyses and assessments with regions; document local ecological and management interpretations for vegetation classifications; and ensure inventory and monitoring data are entered into appropriate corporate databases; and publish final reports for vegetation classification and mapping projects.

Evaluation and response. Ensure that vegetation classification and mapping information is used appropriately in forest planning, assessments, and project implementation; identify the forest or grassland's role in evaluating results and determining management and monitoring responses; specify how results should be incorporated into forest planning and assessment; and participate in future activities related to implementation of this protocol.

1.8 Change Management

As science and technology change our ability to classify, map, and inventory vegetation resources, an established change-management process allows for incorporating innovations with nationally supported methods.

Information presented in this technical guide and methods referenced are anticipated to change over time. Typically one or more changes will trigger or initiate a need to adapt or change the technical guide. The first possible reason for change is related to business requirements such as a new law, a new management issue, or a new requirement for inventory or monitoring. The second possibility is a change in how business requirements are met. The third trigger is a change in the conceptual framework used to frame the problem or business requirement. The second and third triggers are typically spurred by a change in science or technology.

In all cases, an update to the business requirements analysis should be done to identify where overlap exists between current and future requirements and methodologies. Information used to define business requirements for field methods described in subsequent chapters of this technical guide is posted at http://www.fs.fed.us/emc/rig/protocols/vegclassmapinv.shtml.

This technical guide will be updated as needed or as directed by Washington Office staff with the concurrence of the regional program leaders. The technical guide will be evaluated periodically to determine its efficiency, utility, sampling requirements, and cost effectiveness.

Coordination With Corporate Data Systems

NRM applications also have a change-management process that may not be fully synchronized with updates to this technical guide. Therefore, the rate of change in the technical guide should be fully coordinated with NRM through their program of work proposal process to ensure desired NRM applications are consistent with any technical guide changes.

The Forest Service GIS Data Dictionary also includes a change-management process to ensure that changes will meet the business needs of the agency and reduce the impacts to support systems (http://www.fsweb.datamgt.fs.fed.us/changemgt/index.shtml). This process is used to ensure consistency, currency, broad involvement, and consensus of interested and affected parties. Version 2.0 of this technical guide was developed in coordination with an update to the GIS Data Dictionary for existing vegetation. This process, however, may not be synchronized with future updates to this technical guide. As a result, changes in GIS standards may not be consistent with the current version of this technical guide and may not be consistent with NRM applications.

Regions, stations, or the Northeast Area may supplement the information in this technical guide with methods or guidance required for meeting specific needs of the region. In these instances, limited ability will exist to use NRM applications to support regional business needs.

2.0 Existing Vegetation Classification

This section includes an overview of classifying **existing vegetation**, guidance for completing the preliminary and iterative stages of a classification, and guidance for data storage.

2.1 Overview

Vegetation **classification** facilitates understanding and communication about the natural world. By organizing the landscape into discrete vegetation groups, resource management is more easily communicated and understood. This section begins with definitions, then describes the purpose of classifying existing vegetation, key concepts related to the classification of existing vegetation and compliance with the data and process standards of the **Federal Geographic Data Committee** (FGDC; FGDC 2008), and applications for classifications. The process of classification is then fully described, divided into preliminary and iterative stages, followed by a discussion of data storage.

The target audience for this section is primarily vegetation specialists who are involved in the process of classifying **vegetation types**. This audience includes specialists involved in the design, collection, and analysis of vegetation data to generate a classification and in the naming and describing vegetation types. The audience also includes specialists who use classified vegetation types in **inventory** and mapping efforts. These users and other users of vegetation classifications benefit from understanding how the classifications are generated and described.

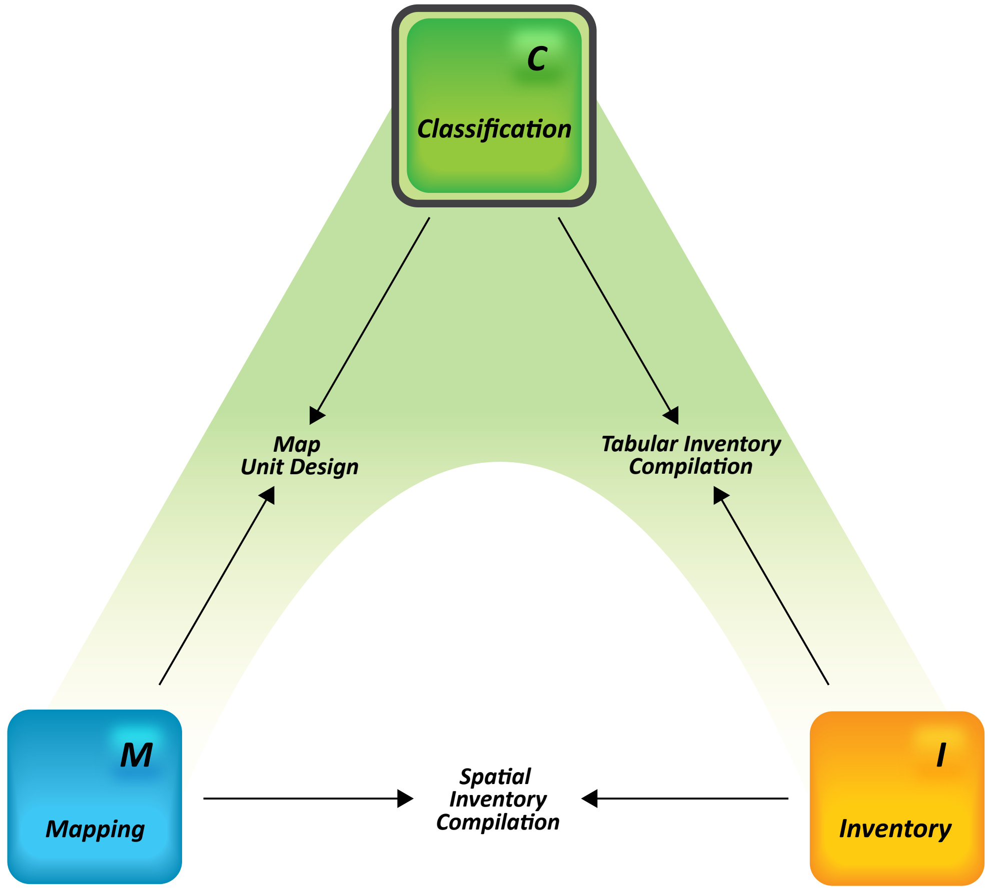
2.1.1 Conceptual Framework

Vegetation classification is the grouping of similar entities into named types or **classes** based on shared characteristics, answering the question, "What is it?" (see discussion in section 1.4.1). Vegetation classifications provide information and interpretations to support vegetation management and guide application of research results to management. Vegetation classification also has an important and interactive role in mapping (see section 3) and inventory (see section 4) activities. The relationships of vegetation classification to mapping and inventory procedures are illustrated in figure 2-1.

Classification and Mapping Process Relationships

Classification can provide valuable information for mapping, particularly in the **map unit design** process. Vegetation **map units** are designed to provide information and interpretations to support resource management decisions and activities. The map unit design process establishes the criteria used to aggregate or differentiate vegetation taxonomic units and technical groups. Vegetation classifications provide the ecological basis and **floristic** and structural information to guide this aggregation process. The criteria used to develop vegetation types and classes to form map units will depend on the purpose of, and the resources devoted to, any particular mapping project (Jennings et al. 2009; see Map Unit Design in section 3.2.4). This design process is often informed by understanding the proportional distributions of **dominance types** and age classes across a **map** project area. This understanding may come from inventory data (see section 4.6.5, Using Inventory Data in Vegetation Classification).

Figure 2-1.—*Relationships of classification to mapping and inventory.*



In general terms, the vegetation classification contributes the base units that are aggregated to establish map units that meet the objectives of the mapping project. This process should result in a set of map units that are exhaustive, mutually exclusive, useful for practical applications, ecologically relevant, and feasible for mapping project (technically and logistically).

The classification ideally should be developed and tested before conducting mapping projects so that the vegetation types developed through classification can be used in mapping. When developing the classification, it may be useful to consider how the classification will relate to **vegetation mapping**. Classification and mapping efforts are sometimes coordinated due to time and budget constraints. This effort works better at broader levels of mapping and higher levels of vegetation classification because fewer taxonomic units exist per map unit. At finer levels of detail, the limitations of mapping can limit the inherent value of the classification to managers.

Classification and Inventory Process Relationships

The process of classifying vegetation types consists of a preliminary stage and an iterative stage (each of which are described in the following section). Inventory data can contribute to development of vegetation classifications when appropriate data are collected. Inventory is very useful for applying vegetation classification to many management issues. In the preliminary stage (see section 2.2.2, Evaluate Available Vegetation Data), some inventory data may be useful to help stratify the area for reconnaissance or sampling.

The classification ideally should be developed and tested before conducting inventory projects so that the types in the classification can be used to describe vegetation during the inventory process. Following the completion of a vegetation classification, inventory data, classified to the taxonomic units of the vegetation classification, are commonly used to compile an unbiased quantification of the **composition** of vegetation for the inventory area. This process, referred to as **tabular inventory compilation**, is useful for obtaining estimates of **abundance** and composition for a variety of uses.

Relationship to Forest Service Physiognomic Unit Classification

The U.S. Department of Agriculture (USDA), Forest Service physiognomic unit classification (presented in appendix A) uses **physiognomy, structure**, total vegetation cover, and natural or cultural condition to define the units. The classification has 11 mutually exclusive classes: (1) forest and woodland, (2) cultural forest, (3) shrubland, (4) herbland, (5) **nonvascular** vegetation, (6) aquatic vegetation, (7) sparse vegetation, (8) no dominant **life form**, (9) agricultural vegetation, (10) developed vegetation, and (11) **nonvegetated** (see appendix A for definitions of these classes). It provides a national framework within which regional and local classifications can be nested. It also provides a useful legend for preparing vegetation maps at the national, broad, mid, and base levels. The system was designed to include all **natural and seminatural vegetation** and modified or "cultural" vegetation (wheat fields, vineyards, etc.) in a manner patterned after the National Vegetation Classification (NVC; FGDC 2008). This system is a compromise between the United Nations Educational, Scientific and Cultural Organization (UNESCO; UNESCO 1973) system that excludes **cultural vegetation** and Anderson Level 1 Land Use/**Land Cover** (Anderson et al. 1976) that emphasizes land use (cultural) over land cover (natural). (See appendix A, table A-1 for a comparison of Forest Service physiognomic units and Anderson Level 1 classification units.)

Use of the Forest Service physiognomic unit classification allows for mapping of vegetation categories necessary to meet the **business needs** of the agency (see section 3). The classification is similar to the NVC (http://www.usnvc.org) in that it also uses physiognomy and structure as the primary criteria for the upper levels. The NVC is the ongoing effort to compile and summarize the vegetation type information developed according to the guidelines in FGDC (2008), also referred to as NVC Standard. Implementing the classification **standard** specified by the FGDC (2008) produces a data **classification system** consisting of a hierarchical list of vegetation types and their descriptions (see section 2.2.4). For the upper levels, the current **data classification standard** content has been published in Faber-Langendoen et al. (2012); the Forest Service physiognomic unit classification can be crosswalked to those types.

The Forest Service physiognomic unit classification is broad enough to be compatible with nearly any vegetation classification effort. It is a useful starting point for developing a regional dominance type or **alliance**-level classification system.

It can be used to organize pre-existing **plot** data and as a criterion to stratify large landscapes for reconnaissance and sampling.

2.1.2 Purpose

The purpose of this classification **protocol** is to enable consistent and relevant classification of existing vegetation across National Forest System (NFS) lands, thus meeting a critical business need of the Forest Service. The protocol is consistent with the data collection requirements of the FGDC NVC Standard (FGDC 2008). This protocol provides standards and guidelines for collecting, analyzing, and interpreting data to classify and describe **associations**, alliances, and dominance types, based on floristic data. Agency vegetation mapping efforts at the national and broad levels often use the **physiognomic classifications** described in appendix A and section 3.

2.1.3 Key Concepts

Vegetation classification consists of grouping a large number of sampled plant communities (often called stands or plots) into relatively few vegetation types. A vegetation type is a named category of plant **community** or vegetation defined on the basis of shared floristic and/or physiognomic characteristics that are distinct from other kinds of plant communities or vegetation (FGDC 2008). Defined vegetation types allow for meaningful descriptions and associated interpretations to be developed for each type, thus reducing complexity and simplifying communication, while maintaining meaningful differences among types (Pfister and Arno 1980).

FGDC (1997: 46) states, "Classification methods should be clear, precise, quantitative where possible, and based upon objective criteria… Classification necessarily involves definition of class boundaries." Although transitions across the landscape are often gradual, we put boundaries on entities to facilitate understanding and communication about them.

2.1.4 Applications and Use

To meet Forest Service **business requirements**, a **floristic classification** of existing vegetation should have the following qualities:

- The classification system should be based on inherent vegetation **attributes**, such as composition, **dominance**, physiognomy, and structure. **Abiotic** features alone cannot distinguish types.
- The classification system should be hierarchical with varying levels of detail available to address management issues and guide vegetation mapping at multiple levels.
- The classification system should employ a simple dichotomous key with unambiguous criteria so that users (with some botanical knowledge) can consistently identify the vegetation types.
- The classification categories should be based on the plot data collected and analyzed to ensure categories are precisely defined, mutually exclusive, and exhaustive. These qualities facilitate communicating and sharing information about the vegetation types.
- Each category should crosswalk to one or a few types at an appropriate level of the NVC Standard in FGDC (2008) to meet Federal requirements and ensure vegetation classification compatibility within and across agencies.

The requirements listed in the previous section constitute guiding principles for developing floristic vegetation types for use on NFS lands. These requirements are consistent with the FGDC's guiding principles for existing vegetation classification (FGDC 2008). In addition, any classification process should be efficient in terms of time, money, and staff. Thought should go into coordinating the work of existing vegetation classification, inventory, and mapping when the latter two processes collect the data necessary to develop the classification. The eventual goal is that vegetation classifications are done for all plant communities on NFS and immediately adjacent lands.

2.1.5 Overview of Vegetation Classification Process

The process of classifying vegetation types consists of a preliminary stage, ideally performed once, and an iterative stage, usually repeated until the classification project is completed. The process is outlined in the following section and in figure 2-2. Each step is explained (in sequence) in the remainder of this section.

Preliminary Stage

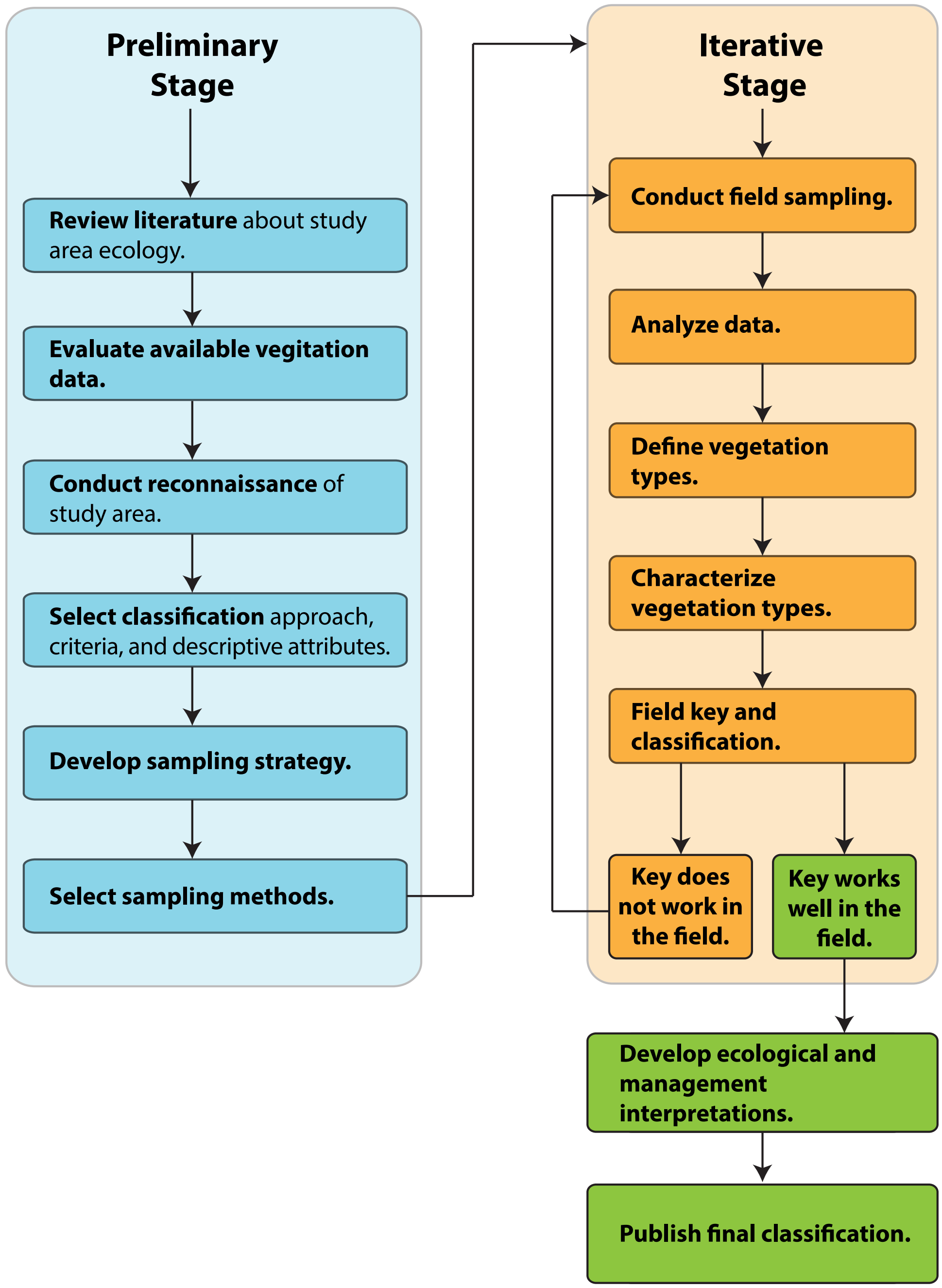
1. Review literature relevant to the ecology of the study area.
2. Evaluate available vegetation data for the study area.
3. Conduct reconnaissance of the study area.
4. Select classification approach, criteria, and descriptive attributes based on the purpose and taxonomic level of the classification.
5. Develop a sampling strategy consistent with the classification criteria that will encompass the full range of environmental conditions in the survey area.
6. Select sampling methods based on the classification criteria and descriptive attributes.

Iterative Stage

7. Conduct field sampling using the strategy and methods developed in the previous section.
8. Analyze data using techniques consistent with the classification criteria.
9. Define vegetation types by interpreting the analysis results and developing a diagnostic key.
10. Characterize vegetation types by summarizing floristic and environmental data.
11. Evaluate key and classification.
    Note: If the classification is inadequate, return to step 7 (or step 6 in some cases) and repeat the cycle. If the key works well and meets documentation standards, continue with step 12.
12. Develop ecological and management interpretations for each vegetation type.
13. Publish final classification.

The iterative stage of the classification process is often referred to as **successive refinement** because it involves repeated cycles of knowledge, questions, and observations. Successive refinement is the basic working approach of community ecologists (Gauch 1982, Pfister and Arno 1980). The preliminary stage of classification provides the knowledge for the first iteration of successive refinement.

Figure 2-2.—*Existing vegetation classification process.*



2.2 Preliminary Stage: Classification Project Design

The first part of a classification project is the planning and design stage. At the beginning of any classification project, it is important to do the following:

- Determine the geographical scope of the classification, using natural boundaries (e.g., watersheds) if possible.
- Determine whether all vegetation or certain types (forested, shrubland, alpine, riparian, etc.) will be classified.
- Document clear objectives for the classification.
- Work with partners and collaborators, as appropriate, especially other land and resource management agencies.
- Document the business needs the project is expected to meet.
- Determine the work required, how long it will take, and what it will cost.
- Determine who will be doing data collection, review, summarization, and analysis.
- Determine how data will be stored for long-term value.

Literature review, data **evaluation**, and reconnaissance (steps 1 through 3) constitute preparation for a classification project. These steps are essentially the same for associations, alliances, and dominance types, although this section focuses on developing plant association classifications. Steps 4 through 6 produce a project plan for classification development.

2.2.1 Review Literature

The first step in developing a vegetation classification is reviewing the ecological literature and other associated information relevant to the study area. Literature may be formally published or in reports, dissertations, theses, or filed information. The types of information to review include the following:

Synecological. Previous classifications of existing or potential vegetation from the study area or adjacent areas, and other data such as range analysis transects and timber inventory plots. Older literature often has descriptions of vegetation. Summaries of vegetation types for larger areas might also be available. Section 2.2.2 is an expansion of this step.

Autecological. Literature on the physiology and life history requirements of the dominant plant **species** and their responses to environmental factors, natural disturbances, herbivory, and management activities.

Vegetation history. Literature describing historical natural and human-caused disturbances (such as fire, grazing, timber harvest, etc.) to the vegetation in the study area or adjacent areas, ideally including information about the severity and extent of past disturbances, their effects on vegetation, and responses of individual species. This literature could include a review of old photographs and reports that include repeat photos that show change over time.

Botanical. **Floras**, taxonomic descriptions, and species lists for the survey area and adjacent areas, which should include synonymous plant names and plant reference (authority indicating who named the species) to facilitate consistent plant identification and reporting.

Climatic. Precipitation maps and data on precipitation, snowfall, air temperature, soil moisture, and temperature (if available).

Geologic. Literature on geologic parent materials, geomorphic processes, surficial geology, landforms, and physiography of the study area, including maps (if available).

Soils. Soil surveys, terrestrial ecological unit inventories (TEUIs), other soil data in the study area, and possibly data from adjacent areas, especially if they address soil-vegetation relationships.

Hydrologic. Studies of surface and subsurface water sources and flows in the study area.

Zoological. Natural history and current and historical distribution and abundance of vertebrates and invertebrates that may affect the distribution, abundance, and condition of vegetation in the study area; could include information about herbivores (e.g., ungulates), keystone species (e.g., beavers), and other species that influence vegetation.

2.2.2 Evaluate Available Vegetation Data

All vegetation data available for the study area should be reviewed and evaluated for usefulness to the vegetation classification project (this evaluation builds on the synecological literature review described in 2.2.1). Some vegetation data may be used directly to help develop the classification and to describe vegetation types; other data may only be useful to help stratify the area for reconnaissance or sampling. Plots may provide descriptive or ancillary data, such as for **site** index or forage production, but only if they can be assigned to a vegetation type *after* the classification is completed. Examples of such data include TEUI plots, wildlife **habitat** plots, range inventory and **monitoring** plots, **stand** exams, and Forest Inventory and Analysis (FIA) plots. Before using these data, it is important to consider the following: (1) specific purpose and intended use of these data, (2) criteria for sample location, (3) number of plots, (4) sample design, (5) sampling date, (6) methods used, (7) plot sizes, and (8) who sampled the vegetation. These factors will determine data quality and relevance and also which plots are appropriate for use in developing the classification.

2.2.3 Conduct Reconnaissance

Reconnaissance consists of rapidly traversing the study area looking for general features of the landscape and vegetation, such as dominant plant species, geologic parent materials, landforms, and climatic patterns (Daubenmire 1968). Reconnaissance provides an “on-the-ground” look at the same factors mentioned in the literature review. Reconnaissance may include field checking the

accuracy or relevance of available vegetation data (section 2.2.2). The reconnaissance effort can determine what intensity, or level of detail, and sampling strategies will be appropriate and most effective (Mueller-Dombois and Ellenberg 1974).

Reconnaissance should also include the use of satellite imagery, aerial photography, and existing maps to organize and stratify the eventual field sampling.

2.2.4 Select Classification Approach, Criteria, and Descriptive Attributes

The approach to classification and the criteria to be used should be selected at the outset of a project. These criteria must be compatible with each other and will help determine which specific analysis methods to use.

Two fundamentally different approaches are used to develop classifications. The "top-down" or divisive approach subdivides a group of objects based on differences among them. Most divisive classifications use differences that are readily apparent to define the categories. The "bottom-up" or agglomerative approach defines types by grouping objects together based on shared characteristics. This approach accommodates and often requires detailed observations of the objects to be classified. Table 2-1 compares these two classification approaches.

Table 2-1.—*Two approaches to hierarchical classification.*

Divisive approach (top-down)	Agglomerative approach (bottom-up)
• Subdivides a group of objects to create types. • Focuses on differences. • Generally uses one or few classification criteria. • Usually requires little observation of objects. • Usually based on a simple dataset. • Best suited for large sets of objects. • Works best over large areas; is less useful for small areas. • Upper level units are usually more clearly defined than lower level units. • Often used to express and clarify known relationships and patterns. • Resulting classification tends to be conceptual and a priori. • Useful to distinguish dominance types.	• Groups individual objects together to create types. • Focuses on similarities. • Often uses many classification criteria. • Often requires detailed observation of the objects. • Usually based on a complex dataset. • Best suited for small sets of objects. • Works best in small areas; often breaks down for large areas. • Lower level units are usually more clearly defined than upper level units. • Usually used to detect unknown relationships and patterns, or to quantify known relationships. • Resulting classification tends to be empirical and a posteriori. • Useful to distinguish associations.

Both top-down and bottom-up classifications can be either hierarchical or nonhierarchical. Both assign objects to classes based on shared attributes; hierarchical classifications also group those classes based on shared attributes. A hierarchy enables objects to be compared at various levels of detail and reveals relationships among individual objects. A simple hierarchy can assist in organizing and accessing information. A hierarchy may be better suited for describing and mapping vegetation at multiple geographic **scales** (FGDC 2008); however, the order in which criteria are used in the hierarchy greatly affects the usefulness of the classification.

Vegetation classification criteria should include attributes that are used to derive and describe species composition (see floristic criteria in the following section). The objectives of the intended classification should be considered in selecting additional classification criteria (e.g., density in addition to cover). These objectives will determine which vegetation attributes potentially will be classification criteria and what additional data are needed for descriptive purposes or to derive management interpretations. For example, if managers want timber productivity estimates for each vegetation type, timber productivity data should be collected on at least a subset of the plots.

In selecting classification criteria, it is necessary to determine the number of attributes that will be used to assign an object to a group. A single factor, a few factors, or many factors may be used to classify objects. Top-down (divisive) classifications are usually based on few attributes; bottom-up (agglomerative) classifications typically incorporate many attributes.

This step usually includes selecting analysis techniques appropriate for the classification criteria chosen.

Vegetation classification systems have generally used two types of criteria—physiognomic and floristic—which are described in the following section.

Physiognomic Criteria

Physiognomy is the overall appearance of a kind of vegetation (Barbour et al. 1980, Daubenmire 1968). Physiognomy is the expression of the **growth forms** (sometimes referred to as "life forms") of the dominant plants and vegetation type (Barbour et al. 1980, Gurevitch et al. 2002, Mueller-Dombois and Ellenberg 1974). Growth form is a characteristic of individual species, and includes gross morphology (size, woodiness), leaf morphology, life span, and phenological (or life cycle) phenomena (Barbour et al. 1980). **Structure** is "the spatial arrangement of the components of vegetation" (Lincoln et al. 1998: 287). Structure is a function of plant size and height, **vertical** stratification into layers, and **horizontal** spacing of plants (Mueller-Dombois and Ellenberg 1974). Physiognomy refers to the general appearance of the vegetation; structure describes the spatial arrangement of plants in more detail. "Physiognomy should not be confused with structure" (Mueller-Dombois and Ellenberg 1974: 140).

Physiognomic classifications subdivide vegetation into categories based on gross differences in growth form and vegetation structure. They are usually developed with a top-down approach and work best at broad scales. Physiognomic classifications typically have few factors and require relatively little data; physiognomic categories are inherently broad. Examples include terms such as *forest*, *shrubland*, and *meadow*. The Forest Service has developed a basic physiognomic classification that is exhaustive with only 11 categories (see key and class definitions in appendix A).

Floristic Criteria

Floristic classifications emphasize the plant species comprising the vegetation, not just the growth forms or structure. Floristic classifications are based on community composition, particularly **diagnostic species**. In practice, most floristic classifications incorporate growth form or vegetation **layers** to some degree. Floristic classifications can be developed by using a top-down (e.g., dominance types) or bottom-up (e.g., associations) approach, but the latter is more commonly used (see discussion in section 2.3.2, Analyze Data). Floristic classifications work better than physiognomic classifications at finer scales and generally require more data to develop.

Community composition is a description of the kinds and amounts of plant species present in a given area or stand. Community composition can be described qualitatively or quantitatively.

A qualitative description would be a species list (see definition of floristic composition in the following section and the glossary). A quantitative description would use either absolute amounts or proportions of the plant taxa present. The qualitative and quantitative approaches to describing community composition are differentiated based on the following terms and definitions.

Floristic composition is "a list of the plant species of a given area, habitat, or association" (Lincoln et al. 1998: 116). Because floristic composition includes only presence and not abundance, it provides a qualitative description of a plant community.

Absolute composition is a list of the absolute amounts of each plant species present in a given area (such as a plot). The amount of each plant taxon is typically reported as absolute percentage of cover (FGDC 2008, Jennings et al. 2003).

Relative composition is a list of the proportions of each plant species relative to the total amount of vegetation present in a given area (such as a plot) (Jennings et al. 2003). The proportion of each plant taxon is reported as relative percentage of cover. The sum of the relative cover values for all species in a plot is 100 percent.

Floristic composition alone provides less ecological information than a quantitative description of community composition (Daubenmire 1968, Greig-Smith 1983). Absolute composition is more informative than relative composition, which is derived from absolute composition. As Daubenmire (1968:44) states—

> It is more important to know that species A has 12 percent coverage in a stand than that it provides 75 percent of the total plant cover. Only the absolute values give an insight into the capacity of the environment to support vegetation.

Plot data that include absolute composition provide the greatest flexibility for developing a floristic vegetation classification. A list of plant species (floristic composition) can be derived from absolute or relative composition; however absolute and relative composition cannot be derived from floristic composition. Relative composition can be derived from absolute composition, but not vice versa.

Diagnostic species are "any species or group of species whose relative **constancy** or abundance differentiates one vegetation type from another" (FGDC 2008:57, Jennings et al. 2006). Constancy is the percentage of plots where a species occurs. This definition implies diagnostic species should be determined empirically through analysis of plot data (Mueller-Dombois and Ellenberg 1974). Identifying diagnostic species is an important part of classifying associations and alliances. Diagnostic species include dominant, differential, constant, character, and **indicator species**, which are defined in the following paragraphs.

Dominant species is a "species with the highest percent of cover, usually in the uppermost dominant layer. In other contexts, dominant species can be defined in terms of biomass, density, height, coverage, etc." (Kimmins 1997 as cited in FGDC 2008:58). Dominant species represent a quantitative difference in composition between vegetation types. Two stands or types may have identical floristics (i.e., the same species) but differ in dominant species (different abundances).

> **Differential species** is a “plant species that is distinctly more widespread or successful in one of a pair or group of plant communities than in the other(s), although it may be still more successful in other communities not under discussion (Bruelheide 2000, Curtis 1959). The more limited a species is to one or a few plant **community types**, the stronger its differential value” (FGDC 2008:58).
>
> **Character species** is a “species that shows a distinct maximum concentration, quantitatively and by constancy, in one well-definable vegetation type; sometimes recognized at local, regional, and general geographic scales” (Bruelheide 2000, Mueller-Dombois and Ellenberg 1974; as cited in FGDC 2008:58).
>
> **Indicator species** is a “species whose presence, abundance, or vigor is considered to indicate certain site conditions” (Gabriel and Talbot 1984 as cited in FGDC 2008:60).
>
> **Constant species** are “species that are present in a high percentage of the plots that define a type, often defined as those species with at least 60 percent constancy” (Mueller-Dombois and Ellenberg 1974, as cited in FGDC 2008:57).

Dominant species, in general, are self-evident. Other diagnostic species are typically determined empirically through analysis of species abundances and environmental data; however, they may be selected a priori if their ecology is well understood. The diagnostic value of a species may change across its geographic range due to genetic variation, compensating environmental factors, or changes in associated species.

Although vegetation data are primarily used to create the classification, environmental variables such as elevation and aspect are useful in the analysis to identify temperature-moisture gradients and diagnostic species that might otherwise have been missed. This information is useful for describing the environmental range of a vegetation type. Habitat has been defined as “the combination of environmental or site conditions and disturbances that influence community composition” (Jennings et al. 2003:23). The distributions of diagnostic species along environmental gradients may be used to evaluate the utility of a classification.

Association Criteria

An association is “a vegetation classification unit 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 2008:56). Associations are classified primarily based on species composition and diagnostic species. Physiognomy and structure are secondary criteria that are often correlated with floristics because growth form is constant for most species. Association is the lowest (most specific) level in the vegetation levels of the NVC (FGDC 2008), which are described in table 2-2.

Classifications that strike a balance between being too general and too specific are most useful to resource specialists. An association with broad ecological amplitude may be of little interpretive value for conservation and management. On the other hand, narrowly defined types can lead to a large number of types, which may be confusing and cumbersome for the user. Finding the right balance is a function of the business needs of the classification. Note that ecological amplitude is not the same as area covered; associations at the same level may cover small (riparian areas) or large (many upland forests) areas. How well the classified vegetation correlates with environmental gradients is more critical in potential rather than existing vegetation classifications.

The relationship of existing to potential vegetation has important implications. Potential vegetation is defined with a focus on land capability, and hence its types are more a function of environmental gradients (e.g., temperature and moisture), directly related to the site potential. Potential vegetation establishes a framework in which existing vegetation varies along a sere (set of seral stages) based on disturbance regimes. These seres typically occur in predictable **patterns**, and these patterns can be used to estimate the historical or natural range of variability, which is a useful tool in assessing ecological sustainability. Existing vegetation is thus affected by disturbance and inherent environmental attributes.

Because diagnostic species are determined empirically through numerical analysis, vegetation plot data for classification of associations should include a complete species list with **canopy cover** (i.e., absolute composition as described in the previous section) for every species by layer (as described in section 2.3.1). Physiognomic data should also be collected so that associations can be grouped later into alliances and related to the physiognomic levels of the NVC Standard (FGDC 2008, Jennings et al. 2009).

Alliance and Dominance Type Criteria

An alliance is "a vegetation classification unit containing one or more associations, with a characteristic range of species composition, habitat conditions, physiognomy, and diagnostic species, typically at least one of which is found in the uppermost or dominant **stratum** of the vegetation" (Jennings et al. 2006 as cited in FGDC 2008:56). Because an alliance is a grouping of associations (FGDC 2008), plot data need to be collected and analyzed and associations classified before alliances can be defined. Classification of alliances requires the same vegetation plot data as classification of associations. Alliance is the second lowest level in the vegetation levels of the NVC (FGDC 2008), which are described in table 2-2.

The standard approach to classifying alliances is to aggregate associations with similar floristics (i.e., bottom up) based on plot data (FGDC 2008). When immediate business needs require alliance-level information before completing classification of associations, a top-down approach should be used to classify dominance types.

A dominance type is a recurring plant community "defined by the dominance of one or more species which are usually the most important ones in the uppermost or dominant layer of the community, but sometimes of a lower layer of higher coverage" (Gabriel and Talbot 1984, as cited in FGDC 2008:58). Dominant species are the diagnostic species generally used to determine an alliance, so dominance types provide a similar level of vegetation information without the expense of first developing associations.

Dominance types are typically defined by the single species with the greatest amount of canopy cover in the uppermost layer. Dominance types based on multiple species require more rigorous data analysis. Classification of dominance types requires canopy cover values for the species in the uppermost vegetation layer and the physiognomic attributes of the NVC Standard (FGDC 2008). These data are relatively easy to acquire and may be obtained from existing information, such as ecology plots, range plots, stand exams, or FIA plots. Observational or anecdotal information can be used to develop dominance types, but by itself is inadequate to define differentiating criteria. Dominance types are the primary way the Forest Service describes existing vegetation to meet agency business needs. A dominance type can serve as a provisional NVC alliance (FGDC 2008).

Table 2-2.—*Levels of the vegetation type hierarchy in the NVC Standard (FGDC 2008).*

Level	Definition
Upper level (physiognomic-ecological) units	
Formation class	A vegetation classification unit of high rank (1st level) defined by broad combinations of dominant general growth forms adapted to basic moisture, temperature, and/or substrate or aquatic conditions.
Formation subclass	A vegetation classification unit of high rank (2nd level) defined by combinations of general dominant and diagnostic growth forms that reflect global macroclimatic factors driven primarily by latitude and continental position, or that reflect overriding substrate or aquatic conditions.
Formation	A vegetation classification unit of high rank (3rd level) defined by combinations of dominant and diagnostic growth forms that reflect global macroclimatic conditions as modified by altitude, seasonality of precipitation, substrates, and hydrologic conditions.
Middle level (physiognomic-floristic) units	
Division	A vegetation classification unit of intermediate rank (4th level) defined by combinations of dominant and diagnostic growth forms and a broad set of diagnostic plant taxa that reflect biogeographic differences in composition and continental differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.
Macrogroup	A vegetation classification unit of intermediate rank (5th level) defined by combinations of moderate sets of diagnostic plant species and diagnostic growth forms that reflect biogeographic differences in composition and sub-continental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.
Group	A vegetation classification unit of intermediate rank (6th level) defined by combinations of relatively narrow sets of diagnostic plant species (including dominants and co-dominants), broadly similar composition, and diagnostic growth forms that reflect biogeographic differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.
Lower level (floristic) units	
Alliance	A vegetation classification unit of low rank (7th level) containing one or more associations, and defined by a characteristic range of species composition, habitat conditions, physiognomy, and diagnostic species, typically at least one of which is found in the uppermost or dominant stratum of the vegetation. Alliances reflect regional to subregional climate, substrates, hydrology, moisture/nutrient factors, and disturbance regimes.
Association	A vegetation classification unit of low rank (8th level) defined on the basis of a characteristic range of species composition, diagnostic species occurrence, habitat conditions and physiognomy. Associations reflect topo-edaphic climate, substrates, hydrology, and disturbance regimes.

Published dominance types that are national in scope and that may meet some agency business needs include the following:

- Society of American Foresters (SAF) forest **cover types** based on plurality of basal area (Eyre 1980). SAF types apply only to stands with 25 percent or more canopy cover of **trees**.
- Society for Range Management (SRM) rangeland cover types (vegetation types) based on "the present vegetation that dominates the aspect or physiognomy of an area," (Shiflet 1994:xi). SRM types apply primarily to nonforested vegetation.

The utility of these dominance type classifications should be evaluated locally. If none are suitable, a local dominance type classification should be developed.

Classification Standards

Establishing a new association, alliance, or dominance type requires that the vegetation type be adequately sampled and clearly distinguished from other vegetation types using a diagnostic key and written type description. Proposed associations, alliances, and dominance types should be evaluated through peer review and correlation (see section 2.3.5); they may then become established through approval of the regional vegetation ecologist, or another qualified resource specialist.

When associations or alliances are developed, cooperation with the Ecological Society of America (ESA) Panel on Vegetation Classification (http://www.esa.org/vegweb2) and FGDC Vegetation Subcommittee (http://www.fgdc.gov/participation/working-groups-subcommittees/vsc/membership) is strongly encouraged so that types can be correlated and incorporated into the NVC.

2.2.5 Develop Sampling Strategy

The sampling strategy determines how sample points will be distributed across the study area and what criteria will be used to locate sample plots. Random or systematic sampling across a study area could be inefficient and costly if a large set of sample **points** is required to encompass the variation across the landscape (Gauch 1982, Mueller-Dombois and Ellenberg 1974). The study area can be stratified to optimize the distribution of samples and reduce the number of samples required.

Stratification of Study Area

Stratification of the study area is a useful way to subdivide the area, making it easier to search for and identify repeating patterns of vegetation. The use of strata will facilitate finding more of the vegetation types that are present in the study area. Strata may be based on environmental factors, vegetation patterns, or a combination of both. Environmental factors are preferred because they are more stable than vegetation and can be used to stratify the study area in an objective manner. Stratification based solely on vegetation cover is not recommended because the attribute being described and classified (existing vegetation) can be altered through disturbance, successional development, management, and other factors. It is therefore subject to change and not a reliable criterion for stratification. When using vegetation to stratify, it should be limited to obvious physiognomic types and dominance types.

Major environmental gradients identified through literature review and reconnaissance can be used to stratify the survey area for sampling. Environmental factors useful for stratification include elevation, slope, aspect, landform, geologic parent materials, soils, hydrologic conditions, and climatic factors. Many of these factors can be generated from **digital elevation models** (DEMs). Maps of climatic factors created by the Parameter-elevation Regressions on Independent Slopes Model (PRISM) or Daymet models are available on line; for PRISM, visit http://www.ocs.orst.edu/prism/prism_new.html, and for Daymet, visit http://www.daymet.org.

Plot Location

The purpose of field data collection for vegetation classification is to identify vegetation types that occur repeatedly across the landscape. To identify these vegetation types, it is necessary to find and sample **patches** of relatively homogeneous vegetation. These plots may be located using either the preferential or representative sampling approach (see Gauch 1982, Jennings et al. 2009, Mueller-Dombois and Ellenberg 1974). **Preferential sampling** locates plots in areas with relatively uniform physiognomy, floristic composition, and environmental conditions. **Representative (or probabilistic) sampling** locates plots systematically or randomly, usually within predetermined strata.

In general, preferential sampling is the preferred method for obtaining an efficient sample of a large number of plots to develop a vegetation classification. Ecologists have learned by experience that representative sampling is very inefficient for developing a classification (although it is appropriate for inventory or monitoring). The key point is that a classification effort is intended to describe vegetation types and *not* to derive a statistical estimate of abundance and distribution of vegetation across the landscape.

Inclusion and rejection criteria are used in both preferential and representative sampling approaches. Such criteria need to be (1) established a priori, (2) written in a clear manner, (3) well defined and identifiable, (4) tied to the purpose of the classification, and (5) rigorously followed. For example, an otherwise acceptable plant community could be rejected for sampling if a major disturbance occurred, such as thinning, fire, insect infestation, or disease. Crew safety should be a criterion for rejecting certain plots.

Preferential sampling, the recommended method, involves locating plots subjectively without preconceived bias (Mueller-Dombois and Ellenberg 1974, Peet and Roberts 2013). Using this method means plots are carefully selected for homogeneity of vegetation and environment, but *not* selected because they "fit" into a preconceived vegetation type. This method of plot selection is guided by a high level of reconnaissance—using maps, aerial photos, and personal knowledge—to identify areas with homogeneous vegetation, and is augmented by additional areas with homogeneous vegetation that are encountered during fieldwork. Most experienced ecologists who have done reconnaissance in a given area are qualified to identify homogeneous vegetation.

Ecologists have no completely objective way to evaluate homogeneity, but for many years they have successfully used the following guidelines (Gauch 1982, Mueller-Dombois and Ellenberg 1974):

- The plot should not include any obvious change in physiognomy.
- The dominant taxa in each vegetation layer should be consistently distributed across the plot.
- The plot should not encompass any abrupt changes or obvious gradients in environmental factors, such as slope, aspect, geologic parent materials, or soil (depth, moisture, or texture).

Efforts should be made to ensure that areas distant from roads and trails are included in preferential sampling, where stratification of the study area indicates a need.

Representative sampling employs systematic or random location of plots within strata, and rejection criteria to avoid sampling obvious **ecotones**, which are of limited use for classifying vegetation. The "gradsect" technique, or gradient-directed sampling, is one example of this approach (Austin and Heyligers 1991). This technique is a form of stratified random sampling that may be cost effective for sampling vegetation patterns along environmental gradients (Gillison and Brewer 1985). Representative sampling may be useful when the stratification units are large or where vegetation patterns are not distinct to the observer (Mueller-Dombois and Ellenberg 1974).

2.2.6 Select Sampling Methods

Sampling methods are selected based on the classification criteria and descriptive attributes chosen for the project. The major considerations in plant community sampling are plot size and shape, and methods for quantifying species abundance. If similar vegetation has been classified in adjacent areas, seriously consider the sampling methods used in those studies and determine whether they are appropriate for your classification. Use of the same methods will facilitate comparisons of types with the adjacent classification(s). Additional attributes could be collected to meet specific needs, as noted in section 2.2.4. If possible, keep additional attributes to a minimum as they increase the time needed to sample a plot, thereby reducing the number of plots available to develop the classification.

The ocular macroplot (OCMA) or relevé (Mueller-Dombois and Ellenberg 1974) sampling method is the fastest and most efficient sampling approach for vegetation classification (Jennings et al. 2009). Instructions for vegetation sampling and example field forms are in the *Ocular Macroplot Field Guide* (USDA Forest Service 2008). OCMAs work well in all vegetation types. The plot size and shape can be altered to fit the size, pattern and spacing of the vegetation. Plot sizes and shapes used in various vegetation types are listed in table 2-3.

Table 2-3.—*Commonly used plot sizes for vegetation sampling.*

Standard plot area	Equivalent plot area	Radius of circular plot	Side of square plot	Default plot dimensions or shape	Temperate vegetation types where commonly used
50 m^2	~1/80 ac	4.0 m	71. m	5 x 10 m	Riparian shrubland Riparian herbland
		13.1 ft	23.2 ft	rectangular	
100 m^2	~1/40 ac	5.6 m	10.0 m	10 x 10 m	Alpine vegetation Grassland
		18.5 ft	32.8 ft	square	
375 m^2 (legacy only)	~1/11 ac	10.9 m	19.4 m	circular	Low-diversity forest Shrubland Grassland Riparian forest and woodland Riparian large shrubland
		35.9 ft	63.5 ft		
400 m^2	~1/10 ac	11.3 m	20.0 m	20 x 20 m	
		37.0 ft	65.6 ft	square	
1/10 acre	~405 m^2	11.4 m	20.1 m	circular	
		37.2 ft	66.0 ft		
500 m^2	~1/8 ac	12.6 ac	22.3 m	circular	
		41.4 ft	73.3 ft		
800 m^2	~1/5 ac	16.0 m	28.3 m	20 x 40 m	Forests with widely spaced large trees
		52.4 ft	92.7 ft	rectangular	
1/5 ac	~810 m^2	16.1 m	28.4 m	circular	
		52.7 ft	93.3 ft		
1,000 m^2	~1/4 ac	17.8 m	31.6 m	20 x 50 m	high-diversity forests
		58.5 ft	103.7 ft	rectangular	
2,500 m^2	~3/5 ac	28.2 m	50.0 m	50 x 50 m	old growth forests with very large trees
		92.5 ft	164.0 ft	rectangular	

Vegetation Cover Concepts

Abundance of plant species can be determined in numerous ways, but the standard measure for vegetation classification purposes is percentage of cover. Cover is a meaningful attribute for nearly all plant growth forms; it enables their abundance to be evaluated in comparable terms (Daubenmire 1968, Mueller-Dombois and Ellenberg 1974). Percentage of cover can be defined generically as the vertical projection of the crown or shoot area to the ground surface expressed as…percent of the reference area (Mueller-Dombois and Ellenberg 1974). The use of crown or shoot area results in the following types of cover:

- **Foliar cover** is the percentage of ground covered by the vertical projection of the aerial portion of plants. Openings in the canopy and intraspecific overlap are excluded (FGDC 2008, SRM 1989).

- **Canopy cover** (recommended for vegetation classification purposes by FGDC [2008]) is the percentage of ground covered by the vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings in the canopy are included as canopy cover (FGDC 2008).

Both types of cover cannot exceed 100 percent for a single entity (e.g., species, growth form, layer, or size class). Both foliar and canopy cover can each total more than 100 percent for all the entities in a plot, however, due to overlap among entities (Daubenmire 1968). Foliar cover is usually less than, and never greater than, canopy cover because it does not include gaps in the canopy between shoots and branches (Daubenmire 1968, SRM 1989, USDA NRCS 1997). Foliar and canopy cover can differ significantly from each other, but both are useful, depending on sampling objectives.

Canopy cover is recommended for vegetation sampling for classification purposes (FGDC 2008) for the following reasons:

- Canopy cover better estimates the "area that is directly influenced by the individuals of each species" (Daubenmire 1968:43).
- Canopy cover is more rapidly measured or estimated in the field than foliar cover.
- The vast majority of legacy data for vegetation classification has canopy cover instead of foliar cover.

Another cover measure is **cover from above,** which is primarily an attribute used in image-based mapping (see section 3.0, Existing Vegetation Mapping). It is usually remotely sensed or derived from other data; it can be difficult to determine from the ground, particularly in dense vegetation. Ground estimates are often cross-checked with photo interpretation. Cover from above is not appropriate for developing a vegetation classification.

Canopy Cover Estimation

Canopy cover can be estimated for each species, growth form, layer, or size class. Collecting cover data as a percentage, rather than a cover class, provides greater flexibility in the use of these data. Percent cover values collected in the field can be converted to cover classes during analysis, but cover class data collected in the field cannot accurately be converted into a percent cover value. Estimate percentage of canopy cover in a plot as follows:

14. Use 0.1 as "trace" for each entity (species, growth form, layer, or size class) present but less than 1 percent cover.
15. Estimate to the nearest 1 percent between 1 and 10 percent cover.
16. Estimate to at least the nearest 5 percent between 10 and 30 percent cover.
17. Estimate to at least the nearest 10 percent for values exceeding 30 percent cover.

Commonly used plot sizes and the dimensions of squares representing 1 and 5 percent of the plot area are listed in table 2-4. Estimate canopy cover by walking through a plot and counting the number of 1 or 5 percent units of a nonoverlapping species present in the plot. Canopy cover for growth forms, layers, or size classes can be similarly estimated. Cross-check estimates with other observers for consistency and to help account for overlap among layers in a growth form or species, species in a layer, and so forth. It is recommended that cover estimates for the FGDC growth forms (see Growth Forms and Layers in section 2.3.1) be completed before estimating cover for each species (see Species Canopy Cover in section 2.3.1). Keep in mind, you cannot sum individual species cover within a growth form to generate growth form cover, due to potential overlap among species within a growth form.

Table 2-4.—*Plot sizes and dimensions of squares equaling 1 and 5 percent of the plot.*

Plot size (area)	Side of a 1-percent square	Side of a 5-percent square
50 m^2	0.7 m (2.3 ft)	1.6 m (5.2 ft)
100 m^2	1.0 m (3.3 ft)	2.2 m (7.3 ft)
400 m^2 (0.1 acre approx.)	2.0 m (6.6 ft)	4.5 m (14.7 ft)
800 m^2 (0.2 acre approx.)	2.8 m (9.3 ft)	6.4 m (20.9 ft)
1,000 m^2	3.2 m (10.4 ft)	7.1 m (23.2 ft)

Field personnel should calibrate their cover estimates with one another and with the trainer. Ocular estimate calibration should be conducted at the beginning of field seasons and periodically (usually about once a week) throughout the field season or life of the project. Field personnel may calibrate their ocular estimates by sampling with cover-frequency transects or line intercept methods (USDA Forest Service 2004a and 2004b). When using the line-intercept method for calibration, measure canopy cover, not foliar cover (Daubenmire 1968). A quick comparison of cover estimates can be made by having the field crew independently estimate cover for a few species in a plot and then compare their results. If necessary, the process may be repeated until all field crew members produce similar results. Occasional verification plots by supervisors, with follow up review of results with field crews, also help maintain data quality.

Sample Size

No set number of plots is required to characterize a vegetation type, but some guidelines for sampling are summarized here. More plots generally improve the characterization of vegetation types, although time and resources are limiting factors. The plots should be well distributed over the geographical and ecological ranges of the type. Types that are broadly distributed or more heterogeneous may require more plots to adequately characterize the floristic variation associated with their geographical and ecological ranges. Increased variability with sampling may warrant subdivision of the type, however, depending on the type concept (section 2.3.4). Conversely, some plant communities are consistently homogenous (e.g., dominated by a single species with few associated species present at low cover). If additional sampled communities do not add new species or different cover values, it is possible to describe these types with a small number of plots. A thorough reconnaissance will aid in determining the within-type variability, but sampling is the only way to verify this determination.

2.3 Iterative Stage: Methods To Develop Classification

The iterative stage implements the project plan developed in the preliminary stage. A pilot study is recommended by Gauch (1982) to refine the sampling and data analysis methods. The first year of a classification project usually serves as a pilot study, even if this status was not intended. Refining the criteria and methods requires revisiting steps 4, 5, and 6 of the classification process and revising the project plan. It is important to carefully document any changes. Iterative refinement of a classification can continue or be reinitiated during vegetation mapping.

2.3.1 Conduct Field Sampling

Field sampling consists of collecting data in accordance with the sampling strategy and the chosen sampling methods. Data collection involves accurately describing the vegetation in each plot by identifying and quantifying the vegetation abundance using methods that are systematic and thorough. The OCMA sampling method, as described in the *Ocular Macroplot Field Guide* (USDA Forest Service 2008), is recommended.

Environmental data should also be collected in the field (and from **geographic information system** [GIS] sources) to facilitate detection and understanding of the relationships between vegetation and environmental attributes.

The location of all plots should be recorded by using a **global positioning system** (GPS) device, which allows for plots to be spatially identified on maps. In some cases it may also be desirable to permanently mark plot locations on the ground. The benefit of permanently marking plots is the ability to revisit them in the future to confirm or improve the data quality (e.g., to obtain missing data or to determine uncertain plant identifications), or to document changes. Some negative aspects of permanently marking plots are the cost and effort to install rebar or other marking materials and the impacts that permanent markings can have ecologically and aesthetically.

If possible, field data collection should be done electronically, using some type of electronic data recorder. Electronic data collection has many benefits, including putting constraints on data entry to limit errors and quick and complete transfer of data to a database—eliminating the step of manually transferring data from paper to electronic format.

The recommended steps for the vegetation data collection process are listed here and then explained in detail after the list.

1. Plot size and shape: Establish plot boundaries.
2. Environmental attributes: Record data about the setting and location of the plot.
3. Species list: Make a list of species on the plot.
4. Growth forms and layers: Record the canopy cover for growth forms and layers.
5. Species canopy cover: Record the canopy cover of each species.
6. Tree and **shrub** height and diameter: Record the predominant woody plant height and tree diameter.

Photos should be taken of each plot. These photos can be used to better understand the data and provide a resource that can be used in the published classification.

Plot Size and Shape

Plots should be small enough to be efficient, yet large enough to include most of the species present in the community. Presampling tests can be conducted by listing the species present in a set of nested plots of increasing area. The required minimum plot size is then determined from a species area curve (i.e., by plotting number of species against plot size). A plot meets the minimal area requirements when enlarging the plot adds no or very few new species. Plots larger than the minimal area provide acceptable data but are less efficient in terms of the time required to sample the plot. If plots are too small, floristic data will not be adequate for developing a vegetation classification.

Minimal area, as defined in the previous section, varies widely by general vegetation type (Barbour et al. 1980, Gauch 1982, Mueller-Dombois and Ellenberg 1974). Table 2-3 shows several common plot sizes and the temperate vegetation types in which they are commonly used. One of the sizes listed in table 2-3 should be used, unless minimum area determination indicates a larger plot is needed or the vegetation being sampled occurs in patches smaller than these sizes.

It is acceptable to adjust the plot shape to fit in the homogeneous area to be sampled. Staying in a homogeneous area is more important for classification work than the shape of the plot. The plot shape (square, rectangular, or circular) is up to the user, but the entire plot should fit in the vegetation stand. Plot size should not be adjusted on steep slopes because doing so would overestimate canopy cover as compared with plots on level ground (Mueller-Dombois and Ellenberg 1974). For instructions on recording plot area and dimensions, see the *Ocular Macroplot Field Guide* (USDA Forest Service 2008).

Environmental Attributes

Data that describe abiotic characteristics and disturbance processes are collected to understand landscape vegetation patterns, relationships among plant communities, and successional dynamics and pathways. Such data are also necessary if the vegetation classification is to be used to evaluate ecological status and resource conditions.

Environmental data are collected according to guidelines in the *Site General Field Guide* (USDA Forest Service 2009b). The guide characterizes certain data fields as required, which means they should be included in all field sampling, including for vegetation classification. Those required fields include elevation and slope (percent). Other environmental attributes that should be recorded for floristic classification of existing vegetation are slope aspect (in degrees azimuth) and ground cover. Slope aspect can be recorded with declination set or as an uncorrected (magnetic) azimuth and corrected later. In riparian vegetation, the fluvial geomorphic surface should also be described, and channel type and stream gradient recorded. Recommended additional information includes landform, slope position, slope shape, and geologic parent material. Basic guidelines for describing elevation, slope and aspect, ground cover, slope position, and slope shape are in *Site General Field Guide* (USDA Forest Service 2009b). Guidelines for describing landform and geologic parent material are in the *Terrestrial Ecological Unit Inventory Technical Guide* (Winthers et al. 2005).

Although climate attributes are not collected in the field, consider using them in data analysis and description of vegetation types; use national climate data such as Daymet and PRISM or local weather station data (for PRISM, visit http://www.ocs.orst.edu/prism/prism_new.html; for Daymet, visit http:// www.daymet.org).

Species List

A list of all identifiable **vascular** plant species from the time of sampling is required on all vegetation classification plots. Identifying vascular plants to the subspecies or variety level may be required for some projects. Include plants if their crowns overhang the plot area, even though their root systems may not be in the plot area.

In the species list, don't record species that do not occur in the plot, even if they are present in the larger plant community. Information from outside the plot can be recorded in field notes, but cannot legitimately be used in data analysis. A consistent plot size is important for most community data analysis procedures; using species data from outside the plot violates this assumption. If sampling consistently misses ecologically meaningful species, use a larger plot size or increase the sample size.

Floristic classification requires accurate plant identification. Overlooking or misidentifying a species is likely to be a more serious error than an error in estimating cover. Field crews should be well qualified or trained in species identification, use of accepted scientific floras, and proper collection of unknown species for later identification.

Botanical nomenclature should follow the USDA Natural Resources Conservation Service PLANTS database (USDA NRCS 2012; http://www.plants.usda.gov). Nomenclature recorded in the field can be based on a standard flora (with older plant names) for the geographic area being sampled, but in the office species names will need to be updated to the accepted names in the PLANTS database. The taxonomic authority (such as a published flora) should be listed in any products (e.g., publications, database) produced by the classification project and included in the project **metadata**. Because changes in taxonomic nomenclature occur, it can be useful to develop and maintain a crosswalk of PLANTS names to a locally stewarded plants list.

Any plant that cannot be identified to the species level should be collected for later identification. Assign a collection number to the specimen and record the number on the field form along with other required information (e.g., percentage of cover, growth form). Identifying unknown specimens should be done promptly so the specimens do not become forgotten or lost. In addition, it is strongly recommended that voucher specimens (for those species that are assumed to be properly identified in the field) be collected for dominant species and major associated species.

Growth Forms and Layers

Canopy cover of major growth forms (sometimes referred to as life forms) is estimated to describe vegetation structure, to crosswalk plot data and vegetation types to the hierarchy of the NVC Standard, and to meet additional Forest Service business needs (FGDC 2008, Jennings et al. 2009). Growth forms useful for Forest Service business needs are described in the following section. Additional growth forms required for FGDC compliance are described in FGDC Physiognomic Attributes in the latter part of this subsection.

Percentage of canopy cover should be estimated (as described in section 2.2.6) for each of the following growth forms: tree, shrub, dwarf-shrub, **herb**, graminoid, and **forb** (definitions of these and other growth forms are in FGDC Physiognomic Attributes in the latter part of this subsection). Percentage of canopy cover of any growth form is the percentage of the plot area included in the vertical projection of the outermost perimeter of the natural spread of foliage of plants of that growth form (as defined in section 2.2.6). Canopy cover of any single growth form cannot exceed 100 percent. Canopy cover of growth forms should be determined in the field; it cannot be derived from species cover data due to overlap of different species within a growth form. Instructions for recording canopy cover by growth form are available in the *Ocular Macroplot Field Guide* (USDA Forest Service 2008).

Tree growth form, canopy cover, predominant (most common) tree height, predominant crown height, and predominant diameter by layer are used to describe vegetation structure, to provide a general understanding of past stand dynamics, and to crosswalk to the hierarchy of the NVC Standard (FGDC 2008). For instructions on recording these attributes see the *Ocular Macroplot Field Guide* (USDA Forest Service 2008). Percentage of canopy cover, predominant tree height, predominant crown height, and predominant diameter (see section 2.3.1) should be estimated for the tree overstory and regeneration layers (described in the following section and summarized in table 2-5). Recognizing these layers depends the potential height growth of the tree species making up the stand. For this purpose, **dwarf trees** are defined as trees that are typically less than 39.4 feet (12 meters) tall at maturity due to genetic and environmental constraints (e.g., pinyons and junipers; FGDC 2008). The tree (T) growth form is divided into the following two layers:

> *Tree overstory (TO)*. Trees at least 16.4 feet (5 meters) in height that comprise the forest canopy or dwarf trees that have attained at least one-half of their (site-specific) potential height growth and comprise the forest canopy.

> *Tree regeneration (TR)*.Trees less than 16.4 feet (5 meters) in height or dwarf trees that have attained less than one-half of their (site-specific) potential height growth and are clearly overtopped by the overstory layer.

The TO layer may be subdivided into the following sublayers to describe vegetation structure in more detail:

> *Supercanopy (TOSP)*. Scattered overstory trees that clearly rise above the main canopy.

> *Main canopy (TOMC)*. Dominant and codominant overstory trees that receive direct sunlight from above.

> *Subcanopy (TOSB)*. Overstory trees clearly overtopped by, and separate from, the main canopy, but taller than the regeneration layer.

Use the divisions described in the previous section to mentally subdivide the overstory. Some sublayers may not be present. Record the percentage of canopy cover, the predominant or prevailing tree height, predominant crown height, and the predominant diameter of each sublayer. For example, a stand may have a main canopy of dominant/codominant trees mostly 65.6 feet (20 meters) tall and a subcanopy of younger trees predominately 26.2 feet (8 meters) tall.

The TR layer may optionally be divided into the following sublayers:

> *Saplings (TRSA)*. Regenerating trees less than 16.4 feet (5 meters) in height but taller than 4.5 feet (1.4 meters) *or* regenerating dwarf trees taller than 3.3. feet (1 meter).

> *Seedlings (TRSE)*. Regenerating trees less than 4.5 feet (1.4 meters) in height *or* regenerating dwarf trees less than 3.3 feet (1 meter) tall.

Some studies may choose to subdivide seedlings into established and nonestablished classes. The criteria for established seedlings may vary by species and region.

For the shrub (S) growth form, total percentage of canopy cover, predominant shrub height, and crown height may optionally be estimated for the following shrub layers:

> *Tall shrubs (ST)*. Shrubs greater than 6.6 feet (2 meters) in height (includes shrubs more than 16.4 feet (5 meters) in height but clearly multistemmed).
>
> *Medium shrubs (SM)*. Shrubs 1.6 to 6.6. feet (0.5 to 2 meters) in height.
>
> *Low shrubs (SL)*. Shrubs less than 1.6 feet (0.5 meter) in height.

The low shrub layer includes FGDC's dwarf shrub growth form in addition to shrubs that are less than 1.6 feet (0.5 meter) tall due to young age or disturbance/herbivory. Tall and medium shrubs are subdivisions of FGDC's shrub growth form (table 2-5). For definitions of growth forms, see FGDC Physiognomic Attributes in the latter part of this section.

Table 2-5.—*Summary of tree and shrub growth form layers.*

Growth form	Required layers	Optional sublayers
Trees (T)	Overstory (TO)	Supercanopy (TOSP) Main canopy (TOMC) Subcanopy (TOSB)
	Regeneration (TR)	Sapling (TRSA) Seedling (TRSE) - Established (TRSEE) - Nonestablished (TRSEN)
Shrubs (S)		Tall shrubs (ST) Medium shrubs (SM) Low shrubs (SL)

Species Canopy Cover

The total canopy cover of each species is determined using the procedure described in Canopy Cover Estimation (section 2.2.6). For a tree species, estimate its canopy cover in the overstory and regeneration layers (as separate estimates) in addition to total cover for the species. Assign each species in the plot an appropriate general growth form and specific growth form as defined in FGDC Physiognomic Attributes in the latter part of this section. Each species can be assigned to one growth form only, but a species could be in several layers within its growth form.

Estimating canopy cover for each tree species in each sublayer is recommended but not essential. Using sublayers provides approximate relative age distribution information for tree species (Daubenmire 1968, Mueller-Dombois and Ellenberg 1974), which can be used to roughly describe past succession in the stand. Because size-age relationships are not constant, interpret such data with caution and supplement them with actual age data (Harper 1977).

Tree and Shrub Height and Diameter

The predominant plant height and crown height, including unit of measure, are recorded for any tree or shrub layer present in the plot. Crown height for trees is the vertical distance from ground level to the lowest whorl with live branches in at least three of four quadrants around the stem. Crown height for shrubs is the vertical distance from ground level to the lowest live foliage or branches. The minimum and maximum heights of each layer may be collected. Predominant height is optional for the other growth forms listed in the previous section in Growth Forms and Layers. Predominant height for each species in each layer is also useful, but optional, information. For instructions on determining predominant plant height and crown for trees and shrubs, see the *Ocular Macroplot Field Guide* (USDA Forest Service 2008).

The predominant **diameter at breast height (DBH)** or diameter at root collar (DRC) should be recorded for each tree layer. Record the diameter to the nearest inch rather than using diameter classes; classes can be assigned later. For instructions on measuring and recording predominant diameter, see the *Ocular Macroplot Field Guide* (USDA Forest Service 2008).

Metadata

The term **metadata** means data about the data. Metadata include information about how the data were collected and the original intended use of the data. Metadata are necessary to support proper analysis and application of the data. Ecologists should review metadata for reliability and applicability before using data, and pay extra attention to data from other sources. In the past, metadata were often recorded in hard copy form, if written at all, and difficult to attain when sharing data. Now a minimum set of electronic metadata must accompany all plot data and be included for a project before any plot data can be entered into the Natural Resource Manager (NRM) database. This ensures basic metadata will always be stored with the **dataset** and is accessible to all users.

Project metadata describe how a set of data was collected and should include the following:

Project name. Assigns a specific name and purpose of the data gathering/data analysis project.

Protocol. Documents the protocol followed. Include references to specific floras used to support plant species identification and other references that may have been used, such as existing classifications, sample design references, and photography or imagery sets.

Method. Describes the specific sampling method used to collect the data. For example, the OCMA method may have been used for collecting vegetation attributes, and the cover-frequency or line-intercept methods may have been used for ocular cover calibration. A separate method may have been used to collect optional tree measurement data (e.g., variable radius plot sampling).

Sample design. Documents the sample design used for the plots in a specific project. Sample design attributes include how the sample units were selected and the size of the plot. Additional attributes to support cover-frequency and line intercept methods include number of transects, length of transects, and number and size of frames along the transects.

Plot metadata. Describes how data were collected at a plot; these metadata include examiners, plot dimensions, unit of measure (e.g., feet, meter), and aerial photo information. Instructions on recording those attributes are available in the Forest Service *Site General Field Guide* (USDA Forest Service 2009b).

FGDC Physiognomic Attributes

The FGDC NVC Standard requires that federally funded vegetation classification plot data include physiognomic attributes. This requirement allows for rapid characterization of the vegetation by growth form. The general growth forms (sometimes referred to as "life forms") described in table 2-6 and specific growth forms described in table 2-7 are intended to facilitate the assignment of plots to appropriate levels of the NVC hierarchy. In the field it is necessary to determine the cover by growth form; these data cannot be generated from species cover data due to overlap within a growth form.

Table 2-6.—*Required FGDC general growth forms (FGDC 2008).*

Growth form code	Name and definition
T	**Tree**—A woody plant that generally has a single main stem and a more or less definite crown. In instances where growth form cannot be determined, woody plants equal to or greater than 5 m in height at maturity shall be considered trees (adapted from FGDC 1997). Includes small trees or "treelets" (Box 1981).
S	**Shrub**—A woody plant that generally has several erect, spreading, or prostrate stems which give it a bushy appearance. In instances where growth form cannot be determined, woody plants less than 5 m in height at maturity shall be considered shrubs (adapted from FGDC 1997). Includes dwarf-shrubs (less than 30 cm), krummholz (wind-stunted woody scrub), low or short woody vines, and arborescents (woody plants that branch at or near ground-level but grow to low tree heights) (Box 1981).
H	**Herb**—A vascular plant without perennial aboveground woody stems, with perennating buds borne at or below the ground surface. (Whittaker 1975, FGDC 1997). Includes forbs (both flowering forbs and spore-bearing ferns), graminoids, and herbaceous vines.
N	**Nonvascular**—A plant or plant-like organism without specialized water or fluid conductive tissue (xylem and phloem). Includes mosses, liverworts, hornworts, lichens, and algae (adapted from FGDC 1997). Also called thallophytes or "nonvascular cryptogams," (that is, excluding the fern cryptogams) (Box 1981).
E	**Epiphyte**—A vascular or nonvascular plant that grows by germinating and rooting on other plants or other perched structures, and does not root in the ground (adapted from FGDC 1997).
L	**Liana**—A woody, climbing plant that begins life as a terrestrial seedling but relies on external structural support for height growth during some part of its life (Gerwing 2004). Typically exceeds 5 m in height or length at maturity.

Table 2-7.—*Definitions of required FGDC "specific growth forms" that are subdivisions of the "general growth forms" described in table 2-6 (FGDC 2008).*

General growth form code	Specific growth form code	Name and definition
T	TBD	**Broad-leaved deciduous tree**—A tree with a branching crown, leaves that have well-defined leaf blades that are generally of at least microphyll size (>225 mm², or 0.35 in²) and which seasonally loses all of its leaves and becomes temporarily bare-stemmed (Box 1981, adapted from FGDC 1997).
	TBE	**Broad-leaved evergreen tree**—A tree with a branching crown, leaves that have well-defined leaf blades that are generally of at least microphyll size (>225 mm² or 0.35 in²) and which has green leaves all year round (Box 1981, FGDC 1997).
	TBES	**Sclerophyllous tree**—A type of broad-leaved evergreen tree with leaves that are stiff and firm, and retain their stiffness even when wilted. The leaves are relatively small (microphyll to small mesophyll in size),and sometimes rather linear (Whittaker 1975, Box 1981, FGDC 1997).
	TN	**Needle-leaved tree**—A tree with slender, elongated leaves or with small overlapping leaves that usually lie flat on the stem. Includes scale-leaved and needle-leaved trees, deciduous and evergreen, needleleaf trees (FGDC 1997, Box 1981).
	TU	**Succulent tree**—A tree or arborescent plant with fleshy stems or leaves with specialized tissue for the conservation of water. (FGDC 1997) Includes cacti, Joshua trees, euphorbias, and others over 5 meters in height at maturity. Referred to as "arborescent stem-succulent" by Box (1981).
	TM	**Small-leaved tree**—A tree with very small leaves (<225 mm², or 0.35 in²), or even leafless, sometimes armed with spines. Includes both evergreen and deciduous small- leaved trees, such as Acacia greggii and Mimosa (adapted from Thorn tree by Whittaker 1975).
	TP	**Palm tree**—An evergreen, broad-leaved, flowering tree with a simple, unbranched stem and terminal, rosulate crown of large, pinnate or fan-shaped leaves. A type of rosette tree. Palms are the primary taxa (but see Draceanaceae, some Pandanaceae etc. in Box 1981).
	TF	**Tree fern**—An evergreen, broad-leaved, spore-bearing tree (or arborescent fern) with a simple, unbranched stem and terminal, rosulate crown of large fronds. A type of rosette tree, including taxa from Cyatheaceae and some Velloziaceae (Box 1981).
	TG	**Bamboo tree**—A woody-stemmed, arborescent grass that is equal to or greater than 5 m in height at maturity. Only applies to woody-stemmed bamboo graminoids. Includes the "arborescent grasses" of Box (1981).
S	SD	**Dwarf-shrub**—A caespitose, creeping, matted, or cushion-forming shrub that is typically less than 30 cm tall at maturity due to genetic and/or environmental constraints, and generally small-leaved. Does not include shrubs less than 30 cm tall due to young age (adapted from Mueller-Dombois and Ellenberg 1974).
	SBD	**Broad-leaved deciduous shrub**—A shrub that is typically more than 30 cm tall at maturity with leaves that have well-defined leaf blades that are generally of at least microphyll size (>225 mm², or 0.35 in²) and seasonally loses all of its leaves and becomes temporarily bare-stemmed (FGDC 1997).
	SBE	**Broad-leaved evergreen shrub**—A shrub that is typically more than 30 cm tall at maturity with leaves that are generally of at least microphyll size (>225 mm², or 0.35 in²) and with green leaves year round (Box 1981, adapted from FGDC 1997).
	SBES	**Sclerophyllous shrub**—A type of broad-leaved evergreen shrub with relatively small leaves that are stiff and firm, and retain their stiffness even when wilted (Whittaker 1975, FGDC 1997).
	SN	**Needle-leaved shrub**—A shrub that is typically more than 30 cm tall at maturity with slender, elongated leaves or with small, overlapping leaves that usually lie flat on the stem (FGDC 1997). Includes scale-leaved as well as needle-leaved shrubs, and deciduous as well as evergreen.
	SU	**Succulent shrub**—A shrub or shrub-like plant that is typically more than 30 cm tall at maturity with fleshy stems or leaves with specialized tissue for the conservation of water (adapted from FGDC 1997 and the Thorn shrub of Whittaker 1975). Includes cacti less than 5 m in height at maturity. Includes both the "typical stem succulents" and "bush succulents" of Box (1981). Includes aloe, agave.
	SM	**Small-leaved shrub**—A shrub that is typically more than 30 cm tall at maturity with very small leaves (<225 mm², or 0.35 in²), or even leafless, sometimes armed with spines, usually having compound, deciduous leaves that are often reduced in size. Includes Larrea tridentata, Prosopis glandulosa, Acacia neovernicosa, Senna, Calliandra (Whittaker 1975, Jennings et al. 2006)
	SP	**Palm shrub**—An evergreen, broad-leaved, unbranched shrub that is typically more than 30 cm tall at maturity with a simple stem and terminal, rosulate crown of large, pinnate or fan-shaped leaves. Includes palms, espelettia, etc.

Table 2-7. (continued)—*Definitions of required FGDC "specific growth forms" that are subdivisions of the "general growth forms" described in table 2-6 (FGDC 2008).*

General growth form code	Specific growth form code	Name and definition
H	HA	**Aquatic herb**— A flowering or non-flowering herb structurally adapted to live floating or submerged in an aquatic environment. Does not include emergent herbs such as cattails and sedges (FGDC 1997, Jennings et al. 2006).
	HF	**Forb**—A non-aquatic, non-graminoid herb with relatively broad leaves and/or showy flowers. Includes both flowering and spore-bearing, non-graminoid herbs.
	HFF	**Flowering forb**—A forb with relatively broad leaves and showy flowers. Does not include graminoids, ferns, or fern-allies.
	HFE	**Fern (Spore-bearing forb)**—A non-flowering, spore-bearing forb. Includes non-aquatic, non-woody ferns, clubmosses, horsetails, and quillworts.
	HFS	**Succulent forb**—A flowering forb with a fleshy stem and often with reduced leaves. Includes Salicornia and others.
	HG	**Graminoid**—A non-aquatic, flowering herb with relatively long, narrow leaves and inconspicuous flowers with parts reduced to bracts. Includes grasses, sedges, rushes, and arrowgrasses.
N	NB	**Bryophyte**—A nonvascular, non-flowering, photosynthetic plant that bears leaf-like appendages or lobes and attaches to substrates by rhizoids. Includes mosses, liverworts, and hornworts (Abercrombie et al. 1966).
	NA	**Alga**—A nonvascular, photosynthetic plant with a simple form ranging from single- or multi-celled to a filamentous or ribbon-like thallus with relatively complex internal organization (Abercrombie et al. 1966).
	NL	**Lichen**—An organism generally recognized as a single plant that consists of a fungus and an alga or cyanobacterium living in symbiotic association (FGDC 1997).
E	E	**Epiphyte**—A vascular or nonvascular plant that grows by germinating and rooting on other plants or other perched structures, and does not root in the ground (adapted from FGDC 1997).
L	L	**Liana**—A woody, climbing plant that begins life as a terrestrial seedling but relies on external structural support for height growth during some part of its life (Gerwing 2004). Typically exceeds 5 m in height or length at maturity.

2.3.2 Analyze Data

Data analysis consists of two distinct steps, data cleaning and data analysis, which are discussed in greater detail in the following section (also see sections 1.6.2 and 1.6.3). Assuring the accuracy of data before analysis is an essential part of the analysis process.

Data Cleaning

Before the data are analyzed, some data review and cleaning should be done. It is important to review data for completeness and obvious errors before entering them into the corporate database.

Currently accepted taxonomic names, according to PLANTS database (USDA NRCS 2012), should be used in the species cover tables. A query should be done to compare the species data table with approved codes and names in the PLANTS database, and unapproved names should be updated to the currently accepted names. NRM tables will not allow for the entry of a nonexistent species code. In addition, data analysts should look for species not known to occur in the study area, which may be have been erroneously recorded or identified. A challenging situation is one in which different taxonomic treatments create confusion about the meaning of a recorded species name; guidelines by Peet and Roberts (2013) may be helpful in addressing such issues.

Other types of data collected (e.g., plot slope, tree heights) should also be examined to find obvious data entry errors that would be permitted even with restrictions in data entry (such as lookup table). For example, one could enter a plot slope of 180 percent, but the reviewer may know that no plot in the study could possibly have a plot slope of 180 percent. Query the data table containing all the site identifiers against each table containing data about the site to see if these other tables contain records for all plots sampled.

If data were recorded on paper, typographic errors may occur in individual plots and would need to be visually checked against plot field form.

After data are entered in the NRM database, several common methods can be used to check data for additional errors. The NRM database makes extensive use of **data validation** techniques for standard codes, units of measure, range of values checks, and required fields that will also promote consistent data and error elimination.

Data Analysis

The analysis process used by community ecologists is designed to detect patterns and relationships in a dataset, which is facilitated by reducing **noise**, and identifying and possibly eliminating **outliers** (Gauch 1982). Patterns exist where there are multiple samples with similar species composition. The patterns reflect relationships among plant species or among species and environmental factors. Noise is variation in species abundances that obscures or contradicts patterns and relationships in the dataset. Sources of noise include chance distribution and establishment of species, disturbance effects, microsite variation, outliers, and misidentification of species. Regarding classification, an outlier is a sample with low similarity to all other samples in a dataset.

No particular analysis process or method produces a vegetation classification. The available techniques simply produce information an ecologist uses to help define vegetation types. The results of data analysis should be interpreted in light of knowledge of the biotic and abiotic factors influencing plant species distributions in the study area. An ecologist must integrate this information; the process cannot be automated.

Jennings et al. (2003:47) stated, "Various methods are available for identification of floristic patterns…" (e.g., Braun-Blanquet 1932, Gauch 1982, Jongman et al. 1995, Kent and Coker 1992, Ludwig and Reynolds 1988, McCune and Mefford 1999, McCune et al. 2002, Mueller-Dombois and Ellenberg 1974, Podani 2000). It is critical ecologists understand the concepts and mathematics of each method to appropriately interpret the analysis results (Pielou 1984) in their biological context.

Multivariate analysis techniques examine the behavior of more than one dependent variable in a set of parameters. In the case of vegetation analysis, both species presence and associated cover values may be used to compare and group individual plots. Floristic data are often correlated to environmental or other abiotic parameters, such as soil type, elevation, slope, azimuth, and mean annual or seasonal precipitation values.

Three fundamental approaches are widely used for vegetation analysis: (1) ordination, including direct and indirect gradient analysis; (2) clustering; and (3) tabular analysis (Jennings et al. 2009). All three methods are used iteratively and interactively until they achieve consistent groupings of species and plots. This consistent grouping of species and plots requires eliminating outliers and noise sources from the analyses through the successive iterations.

Ordination is used to perform either direct or indirect gradient analysis. Indirect gradient analysis uses only floristic data to arrange plots along gradients of species composition. These results are afterwards linked to environmental parameters to elucidate relationships among the species assemblages and abiotic conditions (Gauch 1982). When environmental parameters are included in the dataset, ordination techniques perform direct gradient analysis by examining species and abiotic data simultaneously to relate species and clusters of plots to environmental gradients. A variety of software packages provide these types of analyses in various combinations (e.g., PC-Ord).

Clustering methods may be divisive—separating the data into progressively narrower groupings through differences between plots—or agglomerative, deriving clusters of plots that share common species. Clustering can be used to group only species, only plots, or group species and plots simultaneously.

Tabular analysis involves sorting a matrix of plots and species in an effort to detect recurring groups of species, identify diagnostic species, and group similar plots together. The resulting table is called an **association table**.

Regardless of the analytical methods used, it is important to document proposed associations using association and **synthesis tables** to facilitate peer review and correlation of vegetation types (see section 2.3.5). An association table displays individual plot data for each vegetation type. A synthesis table displays constancy and average canopy cover for each vegetation type. Both are invaluable for diagnostic key development, vegetation type correlation, and peer review. Constancy is the percentage of plots where the species was observed. Mean cover is usually based on only the plots where the species occurred. Some classifications report mean cover based on all plots, however, including the plots where the species did not occur, which would have zero values.

Tables 2-8 and 2-9 show examples of association and synthesis tables using data from big sagebrush plant associations on the Bridger-Teton National Forest (Svalberg et al. 1997, Tart 1996). To save space, both examples represent only partial tables. Table 2-8 is a partial association table for six plant associations. It displays only the diagnostic species for the late seral plots in each association. The complete association table would display 140 plots and more than 300 plant species. Table 2-9 is a synthesis table that summarizes late and mid-seral plots for the same six plant associations. It displays diagnostic species and species with high constancy in at least one association, rather than a complete species list. These plant associations were developed using ordination of floristic data and tabular analysis of both floristic and environmental data (Tart 1996). Note that these example tables use legacy species names and codes that may not be up to date with the PLANTS database (USDA NRCS 2012).

Table 2-8.—*Association table for vegetation classification example.* "Grp" represents a group of plots. Six groups are listed, each of which shows data for a distinct plant association. "Plot no." is an identifier for each plot where vegetation data were recorded. The other columns are plant species and the percentage of cover of each species in that plot. This is a partial list of species for each association, showing only the diagnostic species. Note: this table includes legacy species names and codes.

Grp	Plot No.	BASA3	PUTR2	ARTRP	ELSP3	FEID	ARTRV	POGR9	ELTR7	GEVI2	ARTRS	TRSP2	CARA6
1	J1810V	6		40	35	0							
	J1811V	5	7	30	30								
	J1814B	4	8	10	20	3							
	J1817B	3	3	10	30		3						
	BLEL01		7	20	45								
	H2001V		20	25	40								
	K2102V		20	20	20	2							
2	H1608B	10		8	17	23							
	G1306V	2		25	22	28			0				
	F1225B	10		10	30	5				0			
	F1214B	1	1	20	10	25							
	G1316B	10	1	17	40	0							
	G1705B	7	8	11	15	8							
	H1804B	1	5	17	25	15							
	I1705V	10	0	30	20	10							
	I1706V	3	7	17	20	10							
	I1712V	0	8	27	12	25							
	I1720B	4	6	18	20	5							
	I1723B	5	2	10	0	40							
	K1901V	1	10	35	30	15							
	I1902V		30	45	19	12							
	I1711B			30	7	35				0			
3	E0704B			5	15	20	25	0					
	F1001V			1	15	35	24			1			
	F1220B				15	35	20						
	E0915B				20	15	35	0					
	E0507B				0	50	30	0		0			
	F1202V					40	35						
4	E0509B					45	25						
	R2805N					20	20	1	15				
	F1002B					40	30	1	3	1			
	F1204B					40	35	1	0	0			
	F0202V					40	30	0	0			0	
	E0703B					40	35	0	4	0			0
5	D0422B					40		1	10		37		
	D0218B					30		0	5		45	0	
	D0436N					25		4	5	2	12		

Table 2-8 (continued).—*Association table for vegetation classification example.* “Grp” represents a group of plots. Six groups are listed, each of which shows data for a distinct plant association. “Plot no.” is an identifier for each plot where vegetation data were recorded. The other columns are plant species and the percentage of cover of each species in that plot. This is a partial list of species for each association, showing only the diagnostic species. Note: this table includes legacy species names and codes.

Grp	Plot No.	BASA3	PUTR2	ARTRP	ELSP3	FEID	ARTRV	POGR9	ELTR7	GEVI2	ARTRS	TRSP2	CARA6
6	B0608B					30	10	1	10	2	15	2	2
	D0804B					30	5	2	20	25	25	2	2
	D0605B					40		0	15	0	11	4	2
	D0607V					35		2	6	4	29		
	Q2706V					10		1	25		30	5	

Group	*Association short name*	*Association long name*
1	ARTRP4-PUTR2/ELSP3	*Artemisia tridentata var. pauciflora—Purshia tridentata/Elymus spicatus*
2	ARTRP4/FEID-ELSP3	*Artemisia tridentata var. pauciflora/Festuca idahoensis—Elymus spicatus*
3	ARTRV2/FEID-ELSP3	*Artemisia tridentata var. vaseyana/Festuca idahoensis—Elymus spicatus*
4	ARTRV2/ELTR7	*Artemisia tridentata var. vaseyana/Elymus trachycaulus*
5	ARTRS2/ELTR7	*Artemisia tridentata ssp. spiciformis/Elymus trachycaulus*
6	ARTRS2/TRSP2	*Artemisia tridentata ssp. spiciformis/Trisetum spicatum*

Table 2-9.—*Synthesis table for vegetation classification example.* Columns are plant associations and rows are species (a partial list, showing diagnostic species and species with high constancy). “N” refers to the number of plots sampled that represent that association. “Con” represents constancy, which is the percentage of plots (n) where that species occurred. “Cov” represents mean canopy cover for the plots in which the species occurred. Note: this table includes legacy species names and codes.

	ARTRP4-PUTR2 /ELSP3 (n = 30)		ARTRP4 /FEID-ELSP3 (n = 60)		ARTRV2 /FEID-ELSP3 (n = 17)		ARTRV2 /ELTR7 (n = 16)		ARTRS2 /ELTR7 (n = 6)		ARTRS2 /TRSP2 (n = 11)	
Species	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**
Diagnostic species												
BASA3	**67**	**3**	58	3	24	1	6	tr				
PUTR2	**93**	**8**	**67**	**6**								
ARTRP4	**100**	**24**	**100**	**22**	18	2						
ELSP3	**100**	**25**	**88**	**14**	**88**	**7**						
ARTRV2	3	tr	5	tr	**100**	**26**	**100**	**29**	17	2	18	1
FEID	40	1	**97**	**17**	**100**	**28**	**100**	**30**	**100**	**31**	**100**	**26**
POGR9			7	tr	47	tr	**81**	**1**	**83**	**2**	**100**	**3**
ELTR7	3	tr	7	tr	18	tr	**88**	**3**	**100**	**4**	**100**	**10**
GEVI2			8	tr	41	tr	44	tr	50	1	**82**	**4**
ARTRS2									**100**	**27**	**100**	**24**
TRSP2			3	tr			6	tr	33	tr	**73**	**3**
CARA6							13	tr	17	tr	**73**	**3**

Table 2-9 (continued).—*Synthesis table for vegetation classification example.* Columns are plant associations and rows are species (a partial list, showing diagnostic species and species with high constancy). "N" refers to the number of plots sampled that represent that association. "Con" represents constancy, which is the percentage of plots (n) where that species occurred. "Cov" represents mean canopy cover for the plots in which the species occurred. Note: this table includes legacy species names and codes.

	ARTRP4-PUTR2 /ELSP3 (n = 30)		ARTRP4 /FEID-ELSP3 (n = 60)		ARTRV2 /FEID-ELSP3 (n = 17)		ARTRV2 /ELTR7 (n = 16)		ARTRS2 /ELTR7 (n = 6)		ARTRS2 /TRSP2 (n = 11)	
Species	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**	**Con**	**Cov**
Species with 50 percent constancy in at least one association												
POSE	50	1	45	1	35	1	6	tr				
PHLO2	57	1	32	tr	41	tr	19	tr				
SYOR2	57	tr	47	1	29	tr	13	tr			9	tr
COUMP2	**70**	**tr**	**63**	**1**	24	tr						
CHVI8	**63**	**1**	50	tr	29	tr	6	tr				
STCO4	**87**	**4**	53	2	47	2	6	tr				
HEUN	10	tr	17	tr	53	2	13	tr			9	1
ANMI3	37	1	45	1	**94**	**3**	**81**	**3**	**67**	**3**	55	1
ERUM	50	tr	**60**	**2**	**100**	**6**	**94**	**4**	**100**	**3**	**73**	**4**
STLE4	33	2	18	tr	24	1	50	2	50	1	9	tr
ARCO5	7	tr	40	tr	59	1	**63**	**1**	50	1	36	tr
KOMA			17	tr	**76**	**2**	**63**	**1**	50	1	9	tr
CAOB4	10	tr	12	tr	**65**	**2**	**63**	**1**	**67**	**2**	9	tr
TAOF	13	tr	13	tr	53	tr	38	tr	50	tr	36	tr
GETR			7	tr	53	tr	**88**	**2**	**83**	**1**	27	1
ACMIL3			8	tr	**71**	**1**	**75**	**1**	**100**	**1**	**91**	**2**
SWRA			3	tr	41	tr	**75**	**1**	**83**	**1**	**64**	**1**
DAIN			3	tr	29	tr	**69**	**2**	50	1	18	1
PHMU3	17	tr	20	tr	18	tr	56	1	33	tr	9	tr
ANSES	3	tr	7	tr	35	tr	50	tr	**83**	**tr**	45	tr
STNEN2	7	tr	20	tr	35	1	44	1	**67**	**1**	45	1
HEHO5					6	tr	13	tr	**67**	**1**	27	tr
LILE3			2	tr	24	tr	25	tr	50	tr		
BRAN	3	tr	3	tr	12	tr	44	tr	50	tr	18	tr
LIFI									17	tr	55	3

Bold text 60 % constancy, Black text 25–59 % constancy, Gray Text less than or equal to 24 % constancy

The process in the previous section includes the following recommended components of a vegetation classification analysis (FDGC 2008):

1. Ensure the plot records used are clearly referenced and accessible by others.
2. Provide an outlier analysis of the initial set of plots and the criteria used for identifying and eliminating outlier plot records.
3. Show that sufficient redundancy exists in plot composition to identify a threshold of significant pattern in compositional variation. That is, show that the dataset has the statistical power needed to be convincing. One example would be to explore a null hypothesis that a given collection of plots is more self-similar than would be expected of a random collection of plots.
4. Provide an exact description of the analysis procedure, including careful documentation of assumptions and limitations of the data, methods of dimensional reduction, and value transformations.
5. Present results in tabular and graphical formats and as narrative.
6. Specify criteria used to identify diagnostic species (described in section 2.2.4), such as constancy and **fidelity**, for mid and lower levels.
7. Specify criteria used to identify diagnostic growth forms and other physiognomic features, particularly for upper levels.
8. Provide a tabular summary of diagnostic and constant species, where appropriate.

2.3.3 Define Vegetation Types

Defining vegetation types requires interpreting the results of data analysis in light of the ecology of the species involved and the inherent limitations of the numerical techniques used. The analysis process (section 2.3.2) groups the samples in the dataset into tentative vegetation types. The vegetation types are named based on the dominant and diagnostic species. Use the attributes that distinguish each group to develop a diagnostic key for field identification of the preliminary associations. The key is tested on the entire dataset and revised as needed.

Naming Vegetation Types

The purpose of naming the taxonomic units in a classification is to create a unique, consistent identifier for the unit. Naming conventions for taxonomic units should include short name, scientific name, and common name. This approach facilitates communication and tracking about vegetation types in databases, maps and reports, and among a variety of potential audiences. Naming approaches should be coordinated at the regional and national levels (preferably by the regional vegetation ecologist) to provide consistency.

A combination of dominant and diagnostic species should be used to name the type. “The names of dominant and diagnostic taxa are the foundation of the association and alliance names…” (Jennings et al. 2004:55) and dominance type names. For names of associations and alliances, include at least one or more species names from the uppermost layer of the type. For alliances, use taxa from lower layers sparingly. Among the taxa chosen to name the type, those of the same growth form (tree, shrub, herb, or nonvascular) are separated by a hyphen (-); those of differing growth forms are separated by a slash (/). Taxa occurring in the uppermost layer are listed first, followed successively by those in lower layers. Within the same growth form, the order of names generally reflects decreasing levels of dominance, constancy, or diagnostic value of the taxa. Nomenclature and plant codes (i.e., plant symbols) for vascular plant taxa used in type names should follow the PLANTS database (USDA NRCS 2012). Table 2-10 provides several naming convention examples.

Table 2-10.—*Examples of vegetation type names for plant associations from the NVC Standard hierarchy (http://www.usnvc.org/explore-classification).*

Scientific name	Common name	USNVC Unique Identifier
Abies grandis / Linnaea borealis Forest	Grand Fir / Twinflower Forest	CEGL000275
Pinus strobus - Quercus (rubra, velutina) - Fagus grandifolia Forest	Eastern White Pine - (Northern Red Oak, Black Oak) - American Beech Forest	CEGL006293
Populus tremuloides - Pinus contorta / Juniperus communis Forest	Quaking Aspen - Lodgepole Pine / Common Juniper Forest	CEGL000537
Tilia americana - Acer saccharum - Acer nigrum / Laportea canadensis Forest	American Basswood - Sugar Maple - Black Maple / Canadian Wood-nettle Forest	CEGL006405
Salix boothii / Carex utriculata Shrubland	Booth's Willow / Northwest Territory Sedge Shrubland	CEGL001178
Artemisia tridentata ssp. tridentata / Festuca idahoensis Shrubland	Basin Big Sagebrush / Idaho Fescue Shrubland	CEGL001014
Carex lasiocarpa - Carex buxbaumii - Trichophorum caespitosum Boreal Herbaceous Vegetation	Woolly-fruit Sedge - Buxbaum's Sedge - Tufted Bulrush Boreal Herbaceous Vegetation	CEGL002500

Diagnostic Keys

A dichotomous key to the vegetation types, using vegetation characteristics (not environmental variables) is essential (see example in figure 2-3). A dichotomous key, with only two choices at each decision point, is used because it is easier to understand and apply than a key with multiple choices. Physiognomic characteristics generally are used in the first part of a key and then floristics are used to guide the user to groups of vegetation types (the key in figure 2-3 is an example of such a group). For physiognomic distinctions, the Forest Service physiognomic unit classification key (in appendix A) is a useful starting point (see related discussion in section 2.1.1). For floristics, dominant species and species with narrow amplitudes (indicator species) are used to distinguish vegetation types. Such keys will require field testing (see section 2.3.5) and refinement.

2.3.4 Characterize Vegetation Types

Characterization entails describing the properties and components of a vegetation type. After the vegetation types are defined, species composition and environmental data are summarized to characterize the types. A vegetation type description describes its key characteristics, including the central tendency and the range of variation in both vegetation composition and environmental variables. Such descriptions require several plots per type.

A necessary product of the vegetation classification process is a standardized taxonomic description of the alliance, association, or dominance type. A taxonomic description defines the physiognomic and/or floristic characteristics that distinguish it from other vegetation types. The description of a vegetation type includes the following **elements**.

Figure 2-3.—*Example of a dichotomous key of existing vegetation types for the Humboldt-Toiyabe National Forests of Nevada (Manning and Padgett 1995).* Note: this key includes legacy species names.

Key to alder- and birch-dominated community types of the Humboldt and Toiyabe National Forests		
1.	*Alnus incana* at least 25 percent cover. Tall Salix species occasionally share overstory dominance.	2.
1.	Not as above. *Betula occidentalis* at least 25 percent cover.	6.
2.	*Cornus sericea at least 25 percent cover.*	*Alnus incana/Cornus sericea c.t.*
2.	Not as above.	3.
3.	*Acconitium columbianum, Smilacina stellata, Equisetum arvense, Actaea rubra, Mertensia ciliata, Urtica dioica, Pteridium aquilinum, Cicuta maculata, Veratrum californicum* and/or other Mesic Forbs either individually or combined at least 25 percent cover.	*Alnus incana/*Mesic Forb c.t.
3.	Not as above.	4.
4.	*Carex lanuginosa, C. microptera, C. simulata, C. nebrascensis, Agrostis stolonifera, Poa palustris, Glyceria striata, and/or Deschampsia cespitosa*, either individually or combined at least 25 percent cover or dominant undergrowth species.	*Alnus incana/*Mesic Graminoid c.t.
4.	Not as above.	5.
5.	*Alnus incana* dominates the overstory with a typically depauperate undergrowth.	*Alnus incana/*Bench c.t.
5.	Not as above.	Miscellaneous Unclassified Low Deciduous Tree-Dominated Communities.
6.	*Cornus sericea* at least 15 percent cover.	*Betula occidentalis/*Cornus sericea c.t.
6.	Not as above.	7.
7.	*Equisetum spp. dominate* a dense herbaceous layer.	*Betula occidentalis/Equisetum arvense c.t.*
7.	Not as above.	8.
8.	*Acconitium columbianum, Smilacina stellata, Actaea rubra, Mertensia ciliata, Urtica dioica, Veratrum californicum* or other Mesic Forbs either individually or combined at least 25 percent cover.	*Betula occidentalis/*Mesic Forb c.t.
8.	Not as above.	9.
9.	*Carex lanuginosa, C. microptera, C. simulata, C. nebrascensis, Agrostis stolonifera, Poa palustris, Glyceria striata, Deschampsia cespitosa* and/or other Mesic Graminoid species either individually or combined at least 25 percent cover or dominant undergrowth species.	*Betula occidentalis*/Mesic Graminoid c.t.
9.	Not as above.	10.
10.	*Poa pratensis* dominates a dry graminoid undergrowth with at least 25 percent cover.	*Betula occidentalis*/Poa pratensis c.t.
10.	Not as above.	11.
11.	*Betula occidentalis* dominates the overstory with a typically depauperate undergrowth.	*Betula occidentalis*/Bench c.t.
11.	Not as above.	Miscellaneous Unclassified Low Deciduous Tree-Dominated Communities.

Type concept. Provides a concise paragraph describing the overall concept of the vegetation type based on the structure, species composition, environmental setting, and geographic range (FGDC 2008). These attributes are described in more detail in the subsequent elements.

Geographic distribution. Describes the geographic data for the type, such as where it has been identified in the State or forest and its geographic distribution, if known from other sources.

Vegetation. Specifies the main growth forms in each type, including percentage of cover of each growth form or layer. Provide a table (may be in an appendix) with the principal plant taxa (diagnostic, dominant, abundant, and/or common) for the type by growth form or layer. The table should include constancy (percentage of plots in which a given species occurs), average percent canopy cover, and range of percent canopy cover for each taxon. Each species in the table should be referred to by its binomial Latin name (accepted name in PLANTS database) and a common name. The sample size for the type should be included. If the principal species table is placed in an appendix instead of the description, then provide a brief narrative in the type description.

Environmental description. Provides information about site conditions, such as elevation, slope aspect, slope steepness, slope shape, topographic slope position, landforms, geologic parent materials, soils, and climate. Describe the range and central tendency of these attributes as applicable (see also Environmental Attributes in section 2.3.1). The central tendency for categorical attributes, such as landform, parent materials, and soils, may be best described by the predominant value or mode. The central tendency for quantitative attributes can be presented using mean, median, or mode. In addition to the full range for quantitative attributes, it may be useful to provide a confidence interval around the mean or a percentile range around the median (e.g., the 10th to 90th percentile). Such values describe environmental conditions typical of the vegetation type, rather than the extremes of its range.

Vegetation dynamics. Describe successional and disturbance factors that influence the type. Note its successional relationship to other types, if known. Criteria for assessing successional status, such as species groups, can be explained here, when available.

Management interpretations. Describe information relevant to management options and limitations (see also section 2.3.6, which is step 12), such as timber productivity, wildlife habitat values, forage productivity, fire behavior and ecology implications, species diversity, and structural diversity. Relative cover of functional or interpretative species groups can be discussed here when they provide the basis for management recommendations.

Hierarchy. States the placement of the association, alliance, or dominance type in the FGDC physiognomic hierarchy from **division** through **group**.

Supporting data. Specify plot data used in the analysis of the type, including the number of plots used and the method of analysis used for determining the vegetation type.

Comparison with other types. Describes how the vegetation type compares with other similar described types. Include references for those types.

2.3.5 Evaluate Key and Classification

Field testing of the classification is done using a key (see example in figure 2-3) and descriptions in the field to identify vegetation types. This testing is often performed concurrently with field sampling during the next iteration of the classification process. The iterative stage of the classification process is complete when the descriptions and keys work well in the field for a variety of end users and each type is adequately documented. The relationships between vegetation types and environmental factors and disturbances ideally are also verified. Correlation by the regional vegetation ecologist and peer review by other ecologists should be incorporated into this step. These processes are described in the following section.

When using a key in the field it is important to remember that the key alone is not the classification. After using the key to identify a vegetation type in the field, it is necessary to read the type description to confirm the observed plant community closely matches the vegetation type described in the classification. The range of plant species present, along with their cover, should be compared with the plant community (refer to the constancy/average cover table), along with the range of environmental variables. If these plant species and variables do not closely match the classified community, it is advisable to go back to the key and check to be sure the right choice was selected at each couplet in the key. If the plant community does not closely match any of the classified types, it would be considered an unclassified plant community. Because classifications do not include every possible assemblage of plant species in the geographic area of that classification, observed plant communities can be unclassified. This lack of classification is not uncommon. It is important to acknowledge this situation rather than to try to fit a plant community into a type that it does not fit.

Correlation of Vegetation Types

The regional vegetation ecologist should evaluate the correlation among associations, alliances, and dominance types and ensure that new vegetation types are added to the corporate database. This process requires a manuscript that at a minimum includes vegetation type descriptions, a diagnostic key, and descriptions of sampling and analysis methods. The following information is required for correlating associations, alliances, and dominance types:

- Association tables (individual plot data) for each type.
- Synthesis tables (summaries of constancy and average cover by species) for each type.
- Summary tables (average and range) of environmental variables for each type.
- A **map** showing all plot locations for each vegetation type.

Regional vegetation ecologists may require additional information for correlation at their discretion.

Peer Review

To provide scientific credibility, peer review of the final manuscript is required, which should include a field review by agency ecologists, university, and/or Forest Service research station ecologists. The regional vegetation ecologist should oversee the peer review process. Peer review should focus on the adequacy of the data set, the appropriateness of the analysis methods and interpretation of their results, the completeness of the type descriptions, and the utility of the diagnostic keys. If vegetation types are going to be submitted to NVC, then the peer review steps listed in FGDC (2008) should be followed.

It is also recommended that the classification manuscript be reviewed and field tested by end users; in particular, by field-going resource specialists. They will be able to detect problems and suggest solutions, particularly with the diagnostic key.

2.3.6 Develop Ecological and Management Interpretations

Vegetation classification publications typically include ecological and management interpretations for each vegetation type based on research and literature, field observations, and management experience. These interpretations aid managers in making decisions on land use and land management. Some interpretations depend solely on attributes of the existing vegetation, and others are a function of successional relationships to other vegetation types.

As land managers use the classification in conducting projects, they will learn more about how each vegetation type responds to various treatments, along with natural processes and disturbances. That information could be incorporated into updates or revisions of the classification.

2.3.7 Publish Final Classification

After the classification is complete, it is published as either a paper or electronic (or both) report that includes association and synthesis tables (section 2.3.2), vegetation type names and diagnostic key (section 2.3.3), vegetation type descriptions (section 2.3.4), and documentation of the sampling and analysis methods used to develop the classification. The final document should be available in electronic form, and possibly hard copy, through the regional vegetation ecologist, or other appropriate specialist, and posted on a publicly accessible Forest Service Web site. The document should also be archived in the Forest Service national library.

2.4 Data Storage

Existing vegetation data should be managed and made available within the agency and to the public, when possible, in both the short and long term. Well-maintained data are an invaluable resource.

Project data and metadata, including plot data and vegetation type information collected or derived as part of this existing vegetation classification protocol should be stored in Forest Service NRM applications (see section 1.6.3). Follow formats and procedures for data storage developed in coordination with NRM and the region. Classification plots and the associated data are stored primarily in the NRM Inventory and Mapping Application. Ancillary **geospatial data** should be stored in a geodatabase on a corporate database drive, when feasible, and incorporated with map products according to the GIS Data Dictionary for Existing Vegetation.

It is anticipated that all attributes labeled as optional or required found in this protocol will be supported in NRM and follow national standards. Data entry forms will include lookup lists of standard codes. Applications and reports that use this information will be developed and maintained. Data entry screens, database fields and standard codes to hold this information will be available. Corporate tools, however, will be determined largely by corporate or required data. Data collected at a region's discretion beyond the required and optional attributes listed in this technical guide may not necessarily be accommodated in NRM and may not follow a national standard. Coordinate with regional and national stewards on such matters.

For cases in which a corporate database is not available, local ancillary databases may be developed in coordination with local and regional **data stewards** (see section 1.6.3). Archival materials associated with the classification project, (e.g., maps, photos, reports, plot data sheets), should be labeled with the project name and plot identification and stored together in an accessible and protected location, such as the appropriate project-level Forest Service file system.

In addition, it is recommended that the complete dataset for a given classification (the set of vegetation types) be submitted to a database that is accessible to the public, such as VegBank (http://www.vegbank.org).

3.0 Existing Vegetation Mapping

This section includes a discussion of the conceptual framework for mapping **existing vegetation**, guidance for designing a map project, a discussion of methods for conducting the mapping process, map maintenance guidance, and a discussion of spatial and thematic map guidelines.

3.1 Overview

Section 3 introduces methods for designing and creating base-, mid-, broad-, or national-level maps and **map** products. This overview demonstrates the links among mapping, **classification**, and **inventory**; the purpose of the guidance provided; key concepts related to **vegetation mapping** in the context of this technical guide; and applications of and uses for existing vegetation maps.

The target audiences for section 3 are **remote sensing** and **geographic information system** (GIS) specialists and associated professionals involved in vegetation mapping projects. Although a thorough treatment of remote sensing science and **image interpretation** is beyond the scope of this technical guide, appendix B introduces more detailed methods for designing and implementing an **accuracy assessment** of existing vegetation map products; appendix C presents principles of remote sensing for vegetation mapping; and appendix D provides background on the basics of image interpretation.

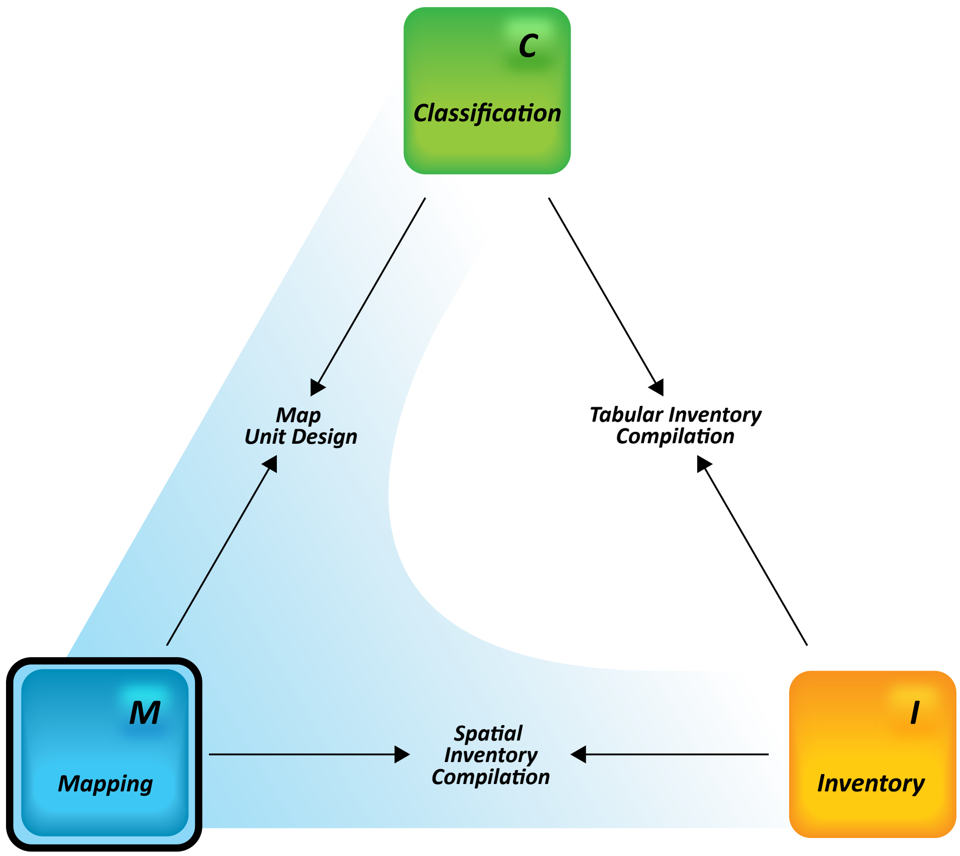
3.1.1 Conceptual Framework

Figure 3-1 presents a conceptual model depicting the general relationships among classification, mapping, and inventory processes. The corners of the triangle represent classification, mapping, and inventory processes while the sides of the triangle represent the major process relationships that provide feedback and integration among them (Brewer et al. 2006). As stated in section 1.4, vegetation mapping is the process of delineating the geographic distribution, extent, and landscape **patterns** of **vegetation types** or **attributes**, answering the question, “Where is it?” Maps are the most convenient and universally understood means to graphically represent the spatial arrangement and relationships among features on the earth’s surface (Brewer et al. 2006, Mosby 1980). A map is indispensable for recording, communicating, and facilitating analysis of such information relating to a specific area. Maps are commonly used to help with inventorying, **monitoring**, and managing numerous resources on national forests (Brewer et al. 2006). Classification and inventory information greatly improve vegetation map development.

Mapping and Classification Process Relationships

The primary and essential relationship between classification and mapping is the **map unit design** process. Vegetation **map units** (or vegetation groups that share a common definition and label based on their vegetative characteristics) are designed to provide information to support resource management decisions and activities. The map unit design process establishes the criteria used to aggregate or differentiate vegetation taxonomic units and technical groups. Vegetation classifications, which are generally developed by ecologists using field data, provide the ecological basis and floristic and structural information to guide the map unit design process. The criteria used to aggregate or differentiate within physiognomic types, floristic types, or structural **classes** to design

Figure 3-1.—*Classification, mapping, and inventory conceptual framework.* Mapping is related to inventory through spatial inventory compilation, and integrated with classification through the map unit design process.



map units will depend on the purpose of, and the resources devoted to, any particular mapping project (Jennings et al. 2003; section 3.2.4, Map Design Considerations: Spatial and Thematic Characteristics). The design process is often informed by local knowledge of patterns of vegetation **composition** in the area under study. Compiling vegetation inventory data that have been classified into taxonomic units and technical groups based on structural characteristics can also inform the design process (section 4.6.5, Using Inventory Data in Vegetation Classification); the compilation process provides some measure of the relative **abundance** of the taxonomic units in the mapping project area. Compiled inventory information can also suggest classes that are major components of the vegetation versus taxonomic units that are relatively rare and may not be abundant enough to warrant inclusion in the mapping project.

Vegetation classification contributes the base taxonomic units that are aggregated to establish the vegetation map units that meet project objectives. The resulting map units should be—

1. Exhaustive.
2. Mutually exclusive.

3. Field applicable.
4. Ecologically relevant.
5. Feasible for mapping project (technically and logistically).

These characteristics are discussed further in Map Unit Design, a subsection of section 3.2.4.

Mapping and Inventory Process Relationships

The primary relationship between mapping and inventory is **spatial inventory compilation**, or the intersection of inventory data with vegetation map products. In this process, the inventory must be a **probabilistic sample** within the geographic area depicted on the map. Spatial inventory compilation allows for the use of map information as classification (domain) variables; the inventory data are then summarized to quantify various vegetation characteristics for each map class. For example, volume by **species** or snags per acre (from the inventory data) can be calculated for each **dominance type** (from the map data). Due to variations in map **accuracy** and the inherent variability and number of inventory **plots** within the map units, map unit-based estimates calculated in this way can have high variance (see section 4.6.2, Spatial Poststratification, for more discussion).

3.1.2 Purpose

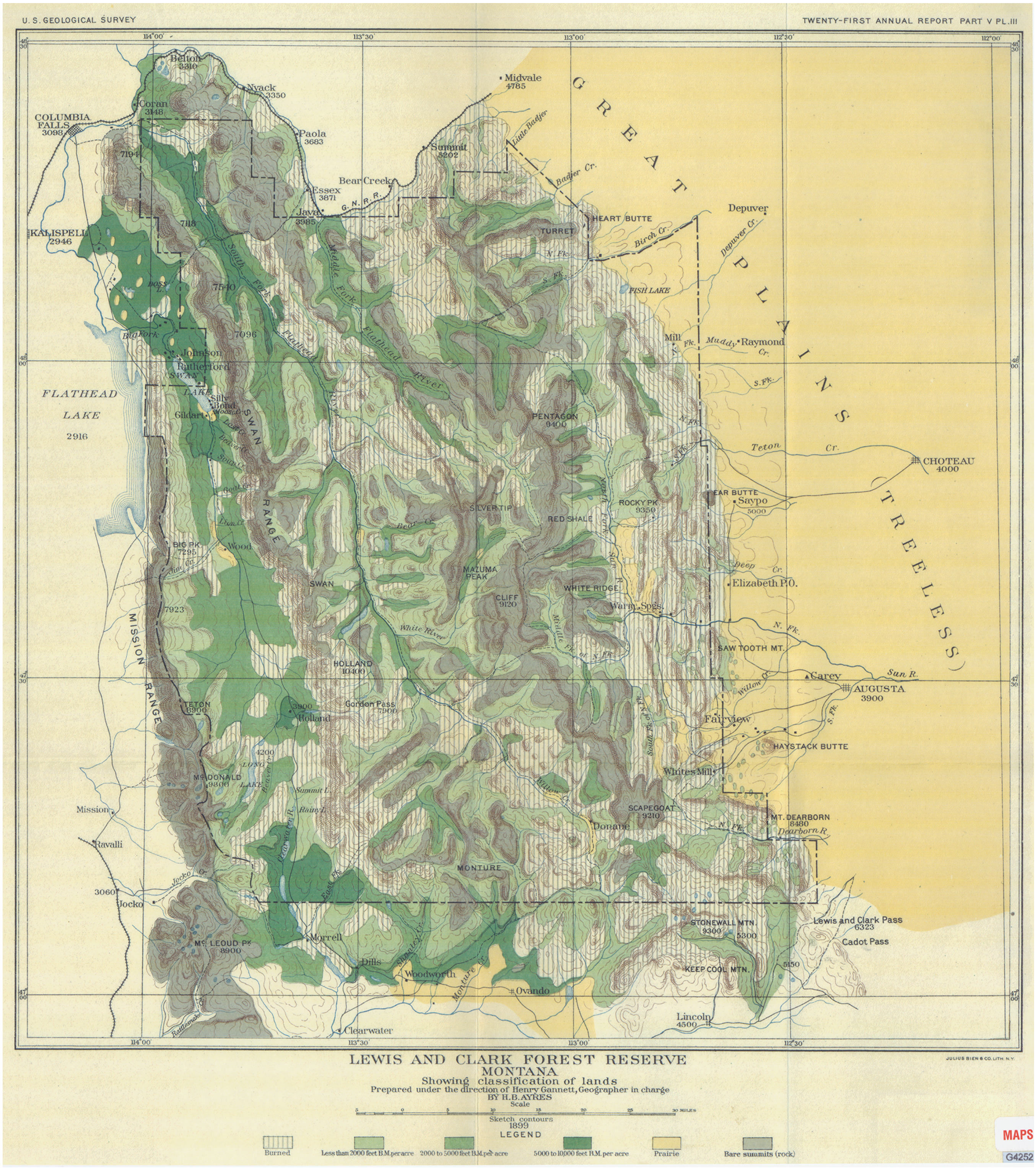
The purpose of this vegetation mapping **protocol** is to—

1. Provide guidelines for developing consistent and continuous existing vegetation map products at the national, broad, mid, and base levels. Successful implementation of these guidelines will allow for compatibility and consistency of existing vegetation maps nationally across forests and regions. Compatible, consistent vegetation maps meet agency **business needs** by providing a foundation for consistent, science-based management. This technical guide is based on an extensive **business requirements** analysis (Spencer and Solem 2011). Table 1-1 summarizes existing vegetation **map levels** (national, broad, mid, and base), business requirements, and applications.
2. Identify guidelines for map project planning and implementation and for map data storage, delivery, and updating. The intent of this protocol is not to be prescriptive regarding methods for project planning and product development; rather, suggested steps and methods serve as references for planning and implementing the mapping process. It is the role of program and project managers to determine the most cost-effective and appropriate methods to meet existing vegetation information needs.

3.1.3 Key Concepts

Vegetation mapping is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types or structural characteristics. The Forest Service, an agency of the U.S. Department of Agriculture (USDA), historically has placed a high value on vegetation and **land cover** maps, particularly when they were integrated with inventory data. The original establishment reports for the forest reserves contained maps and tabular estimates of timber volume classes (e.g., Ayres 1899, figure 3-2). The maps were based on ocular estimates of fairly large map-feature delineations and represented years of field reconnaissance, while the tabular reports summarized the map unit estimates. Together they represented the first maps and inventory estimates of forest

Figure 3-2.—*Lewis and Clark Forest Reserve in western Montana ca. 1899 (H.B. Ayres).*



condition for the forest reserves, which would become the National Forest System (NFS). In more recent times, the timber type atlas efforts of the 1950s and 1960s and the timber stand atlas efforts of the 1970s through present served similar functions.

In the past few decades, the agency and its partners have broadened the scope of vegetation and land cover mapping activities to respond to increasingly complex information needs and business requirements. During the same time period, remote sensing **datasets** and more sophisticated computing capabilities have resulted in a wide variety of vegetation mapping projects with substantial variation in approaches and products. Although these approaches and products have improved responsiveness to different analysis objectives and user groups, they have also resulted in inconsistent terminology and methods. The following key concepts and associated terminology build on those described in section 1.4 and apply specifically to the vegetation mapping activities presented in this protocol.

A vegetation map unit is a collection of taxonomic units or technical groups that share a common definition and label based on their vegetative characteristics (adapted from USDA Soil Conservation Service 1993). Vegetation map units can be based on physiognomic or **floristic** taxonomic units (e.g., dominance types or plant **associations**) and structural technical groups (e.g., **tree cover from above** classes or **overstory tree diameter** classes). Selecting the taxonomic units and structural technical groups to be depicted by the map is accomplished through the **map unit design** process (section 3.2.4).

Modeling units are the elemental modeling entities for the mapping process. Modeling units can be polygons (manual delineations or regions of raster cells) or individual raster cells. Polygons are used if spatially cohesive map features that depict vegetation patterns are needed; individual raster cells are used if the mapping objectives require **raster data** surfaces (see section 3.3.2, Identify Modeling Units; see also figure 3-6 for illustration).

Map features are individual areas or delineations that are nonoverlapping and geographically unique and are derived from modeling units. Specific map features combine adjacent modeling units characterized by the same map unit to form the polygons or regions on a map (see section 3.2.4, Map Design Considerations: Spatial and Thematic Characteristics, and section 3.3.2, Identify Modeling Units; see also figure 3-6 for illustration).

Map assessment is a critical part of the mapping process that provides information about the reliability of the mapping methods and products. Although quantitative accuracy assessment can be time consuming and expensive, it should be completed for every mapping project to refine modeling methods and remote sensing techniques and document the reliability of map information used in decisionmaking (section 3.3.7, Produce a Map Accuracy Assessment, and appendix B, Map Assessment).

3.1.4 Applications and Use

The mapping process generally yields a geospatial database and associated **Federal Geographic Data Committee** (FGDC) **compliant metadata**, a project report, and digital maps. Guidelines for map products and map attributes are described in section 3.3.8, Deliver Map Products, and section 3.5, Map Guidelines. Data sources and other deliverable products of a mapping process may include remotely sensed data (i.e., satellite imagery and aerial photography), topographic **layers**, interim map products (e.g., **image classifications**, delineated polygons), or a variety of field **reference data**.

Existing vegetation maps are invaluable for communicating the status of the vegetation resource. They can be used to meet a variety of communication, collaboration, planning, research, and management needs, including resource quantification, resource analysis, and resource status depiction. The following examples illustrate these types of applications:

1. Assessing resource conditions, determining capability and suitability, and evaluating forest and rangeland health and aesthetic values.
2. Designing and laying out forest management projects, including timber harvest and fuels reduction.
3. Identifying avoidance areas for threatened, endangered, or sensitive species and **habitats**.
4. Documenting vegetation resources, such as old growth forests or endangered species habitat.
5. Assessing risks for invasive species, fire, insects, and disease.
6. Demonstrating change in vegetation resources, such as following a fire, storm, insect outbreak, or other disturbance.
7. Facilitating modeling efforts to predict future vegetation and habitat conditions.

3.2 Project Design

This section provides a basic approach for map project planning. It includes guidance on using project management principles and practices for identifying business requirements and associated information needs, mapping objectives and management questions, map extent, thematic and spatial characteristics, and mapping constraints, and for project plan development.

3.2.1 Project Management Principles and Practices

Vegetation mapping projects are complex and require considerable financial investments in staff and technical resources. They also represent substantial time commitments. Given the complexity of these projects and their importance to agency business needs, projects should be managed in an efficient manner.

Project management is the discipline of planning, organizing, securing, and managing resources to achieve specific goals. The Forest Service increasingly is implementing more rigorous project management processes, tools, and techniques to promote successful project outcomes. Even within a broader program of work, a vegetation mapping project is a temporary endeavor with a defined beginning and end (usually time constrained and often constrained by funding or deliverables). Mapping objectives and management questions comprise the fundamental information needs affecting the map design process and influence many other aspects of the project.

A detailed discussion of project management is beyond the scope of this technical guide, but the *Guide to the Project Management Body of Knowledge* (Project Management Institute 2008) provides an extensive source of project management information that readily applies to vegetation mapping projects. The following activities represent major considerations in project plan development.

- Identifying business requirements and associated information needs that form the basis for the mapping objectives and identifying the management questions the map will address.
- Addressing the various needs, concerns, and expectations of the stakeholders through project planning and implementation. From a planning perspective, this activity is primarily accomplished through collaboratively identifying the appropriate geographic extent for the map and managing the map unit design and map feature design processes.
- Defining and sequencing activities, estimating activity duration and resources, assigning responsibilities for accomplishing activities, and scheduling activities to identify constraints and dependencies.
- Balancing the competing project constraints common in most vegetation mapping projects. Many constraints can be managed with proper planning and effective communication. Some of the major project constraints include scope, quality, schedule, budget, resources, and risk management.

These activities comprise the basis for developing a thorough project plan that conforms to professional project management principles. A well-documented project plan is the primary basis for the **quality assurance** aspects of a vegetation mapping project.

3.2.2 Business Requirements and Associated Information Needs

Business requirements originate from laws, regulations, and policy and from management issues and concerns. The business requirements analysis process provides an opportunity to reexamine management requirements, specific management questions, and priorities in a comprehensive manner over time should requirements, questions, or priorities change (Spencer and Solem 2011).

The initial steps of the analysis process focus on identifying agency business requirements, which serve as a basis for the remainder of the process. After agency business requirements are documented and understood, the next steps are to determine management's priorities for addressing these requirements and how new and existing data will be used to address them.

3.2.3 Mapping Objectives and Management Questions

The business requirements analysis process forms the basis for identifying project objectives and the management questions the map data will address. Clear statements of mapping objectives and specifications for the management questions provide the analytical basis for the map design and a framework for evaluating data quality requirements. Efforts should be made to identify how managers and decisionmakers will use the map product(s). This process includes the following general steps:

1. Specify the broad objectives of the project (e.g., developing maps that enable users to monitor forest plan compliance or maps that will be used to plan fieldwork; see table 1-1 for examples).
2. Identify and rank by importance the specific uses for the map products. These uses should directly relate to business requirements and management questions. Examples include—
    a. Tabular summaries for area of different map units by dominance type, tree cover from above classes, and overstory tree size classes inform forest plan development and monitoring.

b. The locations of map units or map features of interest inform specific management activities and planning activities.

c. Maps inform managers and the public about general patterns and extent of different map units.

3.2.4 Map Design Considerations: Spatial and Thematic Characteristics

Geographic Extent

The first element of the spatial aspect of map design is identifying the geographic extent of the map. Map extent is usually defined by business requirements and associated information needs. For example, business requirements that require consistent and continuous vegetation data across the United States are national in extent and will be national map products (e.g., National Land Cover Database [NLCD] land cover layer [Homer et al. 2007] and NLCD tree **canopy cover** layer [Coulston et al. 2012]). The business requirements define both the geographic extent and the data for the project. The extents of map products at other levels of the hierarchy are not always as easy to identify, but should be based on the business requirements for making the map. For example, a mid-level map covering NFS lands will need to cover some area outside the NFS boundary to provide context for vegetation planning and management activities (e.g., watershed analyses). This need is particularly evident when the Forest Service has agreements with adjacent entities, such as State, tribal, or other Federal partners. In some cases, a formal agreement with State partners provides for an efficient mapping project (e.g., California and Pacific Southwest Region). With increasing emphasis on an "all lands approach" to forest resource planning and management, broader extents and partnerships warrant consideration. As with all other project decisions, the extent should meet the objectives of the mapping project and be feasible within project resources and constraints.

Map Unit Design

Map units are designed to depict taxonomic or technical groups and provide information that supports resource management decisions and activities. The map unit design process establishes the criteria used to aggregate or differentiate vegetation taxonomic units and technical groups. The criteria used to aggregate or differentiate within physiognomic types, floristic types, or structural classes to form map units will depend on the purpose of and the resources devoted to any particular mapping project (Jennings et al. 2003). The design process is more complex for vegetation taxonomic units (e.g., dominance types) than for structural technical groups (e.g., tree canopy cover classes).

To maintain consistency and compatibility of Forest Service maps, mapping guidelines for vegetation cover, tree cover from above, and overstory tree diameter were developed (section 3.5). These guidelines represent general-purpose map unit designs for each structural characteristic at all map levels, and may be exceeded to meet project needs (e.g., subdividing the tree cover from above classes to meet local needs as long as they aggregate back to the original classes). In some cases, the information needs may be better served by mapping these variables as continuous/pseudo-continuous variables (e.g., NLCD tree canopy cover layer [Coulston et al. 2012] maps tree canopy cover in 1 percent increments from 0 to 100 percent). Tree canopy cover is particularly well suited to map as a continuous/pseudo-continuous variable because canopy cover classes vary considerably for different analysis applications (e.g., wildlife cover or fire and fuel modeling).

The following steps are useful in the map unit design process.

1. Research what vegetation taxonomic units and structural technical groups occur in and near the study area. Examining existing data (e.g., Forest Inventory and Analysis [FIA] data or **stand** exam data) and existing floristic and taxonomic classifications (e.g., regional dominance types or nearby national park classifications) provides an initial assessment of the vegetation communities and can be used during the map unit design process.

2. Compare the existing vegetation information with the vegetation needs identified in the mapping objectives and questions and create a lookup table accounting for each existing vegetation **taxonomic unit** and each map unit. At a minimum, a map unit design should—

    a. *Be exhaustive*. The map units that result from the design process should account for the full range of conditions of interest found in the project area. In addition to the vegetation classifications, other land cover and land use classes needed to meet analysis objectives should be included (e.g., urban, agriculture, barren, and water).

    b. *Have mutually exclusive classes*. Any vegetation taxonomic unit must be assignable to one and only one map unit at any given map level.

    c. *Be field applicable*. The logic in the map unit design must be applicable to field observations and, or, field-sampled data so that it can be observed or sampled.

    d. *Be ecologically relevant*. Map units should reflect a biologically meaningful condition on the landscape.

    e. *Be technically feasible*. Map units developed from a vegetation classification that cannot feasibly be implemented using available **geospatial data** or mapping technology will not provide useful results. Map unit design may require an iterative process to test alternative map units' feasibility for modeling.

    f. *Meet Forest Service map attribute guidelines and any regional supplements*. See tables 3-2 through 3-7 and related text for a summary of these guidelines and the mapping level (spatial **scale**) at which map units should apply.

    g. *Be capable of reclassification to Anderson Level 1 classes*. Reclassification allows for compatibility with other land cover classification systems based on the Anderson system (table 3-5; Anderson et al. 1976). *Note: Map units should either equate to an Anderson 1 class or, when aggregated, match up with an Anderson 1 class*.

Map keys define relationships between the taxonomic units or technical groups from vegetation classifications and the map units identified in the map unit design process. Map keys are developed as a part of the map unit design process and included in project **metadata**. They can also be used to support field activities and photo interpretation. Map keys define mutually exclusive and exhaustive map units, and can be depicted in the form of a lookup table or dichotomous key (e.g., appendix A). Although this process applies to all map keys, the technical groups associated with structural characteristics, such as tree cover from above and overstory tree diameter, may not need a formal map key because they are simply groupings of physical characteristics (e.g., 10 percent tree cover from above classes). Physiognomic and floristic map units, however, normally need map keys for consistency.

Modeling Unit and Map Feature Design

Modeling units and map features serve two separate but related functions in a mapping project. Modeling units function as the elemental modeling/mapping entities to which map units are assigned during the mapping process, while map features depict various map units on finished map products (described in section 3.3 and depicted in figure 3-3).

Polygon-based modeling units can be created by either manual delineation (e.g., image interpretation) or automated delineation (e.g., **image segmentation**). For raster data surfaces the basic structure of the data defines the modeling units. The approach for creating modeling units will dictate much of the remaining project planning and implementation steps. For polygon-based modeling units, manual delineation is an intuitive and generally accepted approach. It has a long history of use within the natural resource community, enabling the interpreter to use expert knowledge, logic, and context that is difficult to replicate in an automated method. It is, however, time consuming and is often inconsistent given the subjectivity of the interpretation process. Image segmentation exploits multivariate relationships and local variance structure in the imagery to delineate polygons. Advances in automated delineation, such as image segmentation procedures, allow for the incorporation of contextual information into modeling unit delineation, in much the same way a human interpreter might employ experience-based knowledge when drawing lines on a map. The automated approach normally has greater repeatability and can be completed much faster. Section 3.3.2 describes automated methods for delineating modeling units in greater detail.

Modeling unit design should consider the source imagery and ancillary data sources that are required for the modeling process within the context of project budgetary and time constraints. The spatial and temporal scales of the data sources for the modeling process should be reconciled with the type and size of the modeling units. It is important to match the **spatial resolution**, or "grain" of the source data with the landscape elements intended for mapping. If the **spatial data** are too coarse, then small area landscape elements and vegetation patterns may not be adequately modeled. Conversely, if the grain of the imagery is very fine, modeling units and the resulting map features could be made so small that the level of detail is too great and the map becomes difficult to interpret. It is thus imperative to use source imagery that has spatial resolution appropriate to the desired modeling unit design.

Map features depict various map units (e.g., Ponderosa pine dominance type or 10 to 30 percent tree cover from above class) on finished map products. The designer can use polygons for map features if spatially cohesive map features are needed, or individual raster cells if the mapping objectives require raster data surfaces. Final map products can be delivered as raster data, **vector data**, or both to fill a variety of analysis needs independent of the form of the data during the production of the map (e.g., a polygon map can be converted to raster data for analysis).

If the final map product will display spatially cohesive map features (i.e., polygons) then a **minimum map feature** will need to be specified in the design phase and a process identified to meet the requirement. The minimum map feature is the smallest map feature delineated in the final map product; requirements vary for different map levels. (Note: The term *minimum map feature*, as used in this technical guide, is analogous to the term *minimum mapping unit*, which is widely, although imprecisely, used in the mapping literature.) The minimum map feature size is based on the integration of users' needs, map unit composition, and the Forest Service guidelines described in section 3.5. The minimum map feature generally will depend on the scale at which the map will be used and the intended analysis application.

In summary, the geographic extent is the area covered by the mapping project, map units are the classes depicted on the map, modeling units are the geospatial elements (polygons or raster cells) that are assigned a map unit, and map features describe the geospatial format (polygons or raster cells) of the completed map product.

3.2.5 Project Work Plan

Mapping Project Constraints

All vegetation mapping projects face some form of financial constraints, particularly in times of reduced budgets and limited personnel. Other constraints include technological and data limitations. Many of these challenges can be managed with proper planning and effective communication. Managing expectations about data quality and project scope is a key aspect of success for vegetation mapping projects.

Federal agencies have responsibilities under the Data Quality Act (DQA) for ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information). In general practice for mapping projects, data are deemed of high quality if they correctly represent the real-world construct to which they refer and are fit for their intended use. In this context, a tradeoff generally exists between various levels of thematic detail and the resulting levels of thematic accuracy. The tradeoff between information content and accuracy is not always predictable during the map unit design process and sometimes is not apparent until draft map products are reviewed or a preliminary accuracy assessment is conducted. The best approach to solving this problem is to evaluate the map unit design iteratively in the context of the business requirements, mapping objectives, and the management questions. Identifying the amount and types of error and acceptable levels of uncertainty is a difficult but important aspect of map product development.

Managing the scope of a mapping project normally consists of limiting the geographic extent of the map and the number of taxonomic units to the data requirements identified for the mapping project. Larger map areas and more detailed taxonomic levels will require more project resources and can be costly to include when the information is not required. Partnership agreements with other Federal and State agencies or tribal governments can help with cost, but they require additional coordination of business requirements and mapping objectives.

The taxonomic units included in the map unit design process should reflect the vegetation types that occupy the area to be mapped. FIA data and any similar design-based inventory data can be used in the map unit design process to help determine the vegetation dominance types or structural characteristics that occur within the map extent. The designer will need to summarize the aerial distribution of vegetation characteristics, such as dominance type, canopy cover, and tree size, for all taxonomic units or other characteristics across the geographical extent of the mapping area. This approach not only provides the list of dominance types, but also can provide relative proportions of each dominance type or other characteristic. Understanding the proportions of dominance types can be useful in determining which classes occur with adequate extent to be depicted adequately on the map, and to assist in sample design and sample size determinations.

Limits on time, funding, and access to critical resources such as key team members are often constraints for vegetation mapping projects. These constraints occasionally limit the feasibility of a project or seriously compromise the quality of the products. Mapping project team members, forest resource specialists, and resource managers and leadership need to understand these constraints in advance. The project sponsor and other agency leadership need to be informed of the constraints and any problems that develop.

3.3 Methods for the Mapping Process

This section presents the general sequence for producing existing vegetation maps across national, broad, mid, and base levels (figure 3-3). Please keep in mind that variation in mapping methods and availability of existing data and resources may alter the specific sequence in a given project. These steps assume that mapping objectives and intended map uses have already been determined from the information needs assessment completed in the design phase (see section 3.2). They assume that the spatial and thematic characteristics of the map have been determined in the design phase (see section 3.2.4). Two of the principle considerations related to mapping objectives are modeling unit design and map feature design. One major difference resulting from these design processes is whether the resulting map is a polygon map or a raster data surface. Within the general methods presented in this section these approaches are similar enough to present together with differences discussed within individual steps.

The following steps are detailed in this section:

1. Acquire and prepare geospatial data.
2. Identify modeling units.
3. Assemble and collect reference data.
4. Assign attributes to modeling units.
5. Assess draft maps.
6. Produce final map product.
7. Produce map assessment.
8. Deliver map products.

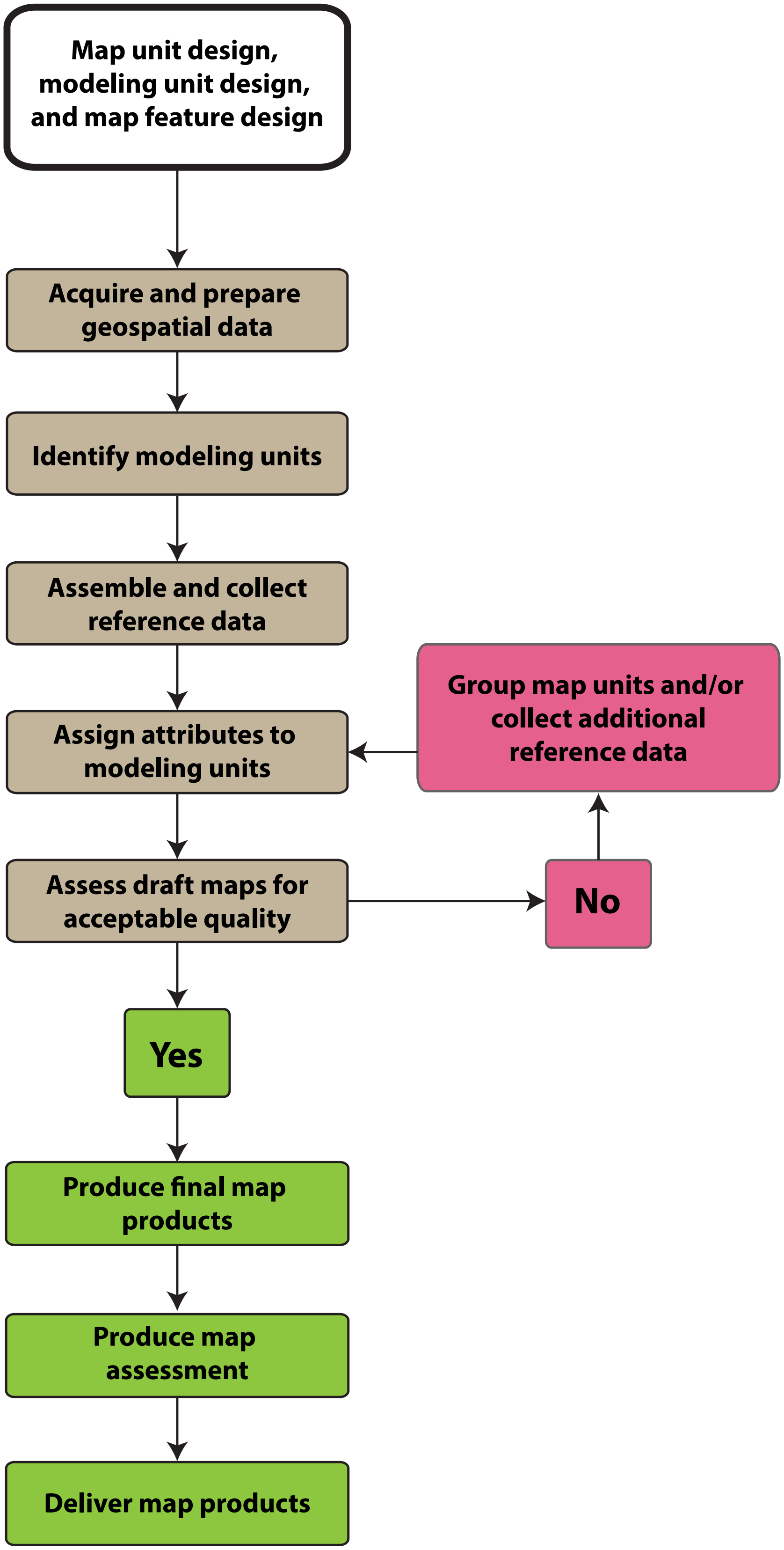
3.3.1 Acquire and Prepare Geospatial Data

Acquiring geospatial data for any mapping project begins with determining what geospatial data are available and whether they are appropriate (i.e., of the necessary quality, cost, and currency) for meeting the goals and objectives outlined in the project plan. Data selection should consider the potential for developing a statistical modeling approach to create and label modeling units. Examples of geospatial data include remotely sensed images, topographic data, and other ancillary information, such as soils and climate data.

Assemble Data

Vegetation mapping is primarily accomplished through the use of remotely sensed image data. These data can be acquired from airborne or space-borne **platforms**. Appendix C provides supplemental information about the basic principles and processing steps for using remote sensing data for vegetation mapping. It also includes descriptions of common satellite-based data with their

Figure 3-3.— *Mapping process steps.*



spatial, temporal, radiometric, and spectral characteristics. Appendix D discusses the minimum photographic scales that are required by photo interpreters for detecting and measuring various vegetation characteristics.

When selecting remotely sensed imagery, it is important to consider the relationship between the grain, or minimum resolvable landscape **element** on the image (Turner et al. 1989), and the size and shape of the vegetation/landscape elements of interest on the ground. When the landscape pattern of interest is finer than the grain of the data, the pattern cannot be detected (Wiens 1989). Conversely, when the landscape pattern of interest is coarser than the grain of the data, the pattern can often be identified. This condition is particularly true when the pattern is composed of spectrally homogenous units organized in predictable shapes and sizes, which partition the entire landscape into exclusive and exhaustive areas.

It is also important to consider the temporal and spectral characteristics of the imagery. Sometimes multiple image dates, referred to as multitemporal imagery, are necessary to identify specific map units, such as deciduous forest types, that have spectral similarity during certain times of the year but have different seasonal senescence (or seasonal foliage variation) at other times. In a similar way, additional spectral information is needed to distinguish between various vegetation types. For example, "natural color" images lack the information in the near-infrared range of the **electromagnetic spectrum** that is useful for distinguishing between evergreen and deciduous broadleaf vegetation. Spatially detailed imagery often has limited spectral data and does not contain the information needed to separate various map units.

Remotely sensed data such as Light Detection and Ranging (LIDAR) or Interferometric Synthetic Aperture RADAR (InSAR) may also be available. Derivatives from these and other sources are often effective in conjunction with traditional continuous optical data sources (e.g., space-borne or airborne imagery). LIDAR and InSAR sources can be expensive and are often available only for small areas. Therefore, they may be more suitable for modeling structural characteristics or developing finer scale vegetation maps such as those produced at the base level. Appendix C provides a more detailed discussion of the basic principles associated with remotely sensed data for vegetation mapping.

Many ancillary data are also available to support vegetation mapping. These data include **digital elevation models** (DEMs), climate layers, hydrological data, historical vegetation maps, and other ecologically related data and maps, such as soils, geology, and **potential natural vegetation**. Ancillary data regarding management practices and natural disturbances, such as insect infestations, wildfires, timber harvests, threatened and endangered species locations, and invasive species treatments, assist in many steps of the vegetation mapping process.

Ancillary data also include administrative layers, such as forest and district boundaries, landownership, natural resource areas, roads and trails, motor vehicle use maps, and urban areas, that will be used in map design and production.

Consider the effective scale of information associated with an ancillary data source relative to the desired level of detail in the map product. For example, it may not be appropriate to rely on a 1:250,000 scale hydrographic **layer** to help map riparian vegetation types at the mid level (approximately 5-acre [2-hectare] map features). Conversely, at the mid level, topography derived from a 98.4-feet (30-meter) or finer scale DEM can greatly enhance one's ability to map the distribution of vegetation types that are affected by slope or aspect gradients. In general, it is important to be aware of differences in spatial and information content when using different data sources for a mapping project.

Prepare Data

After the appropriate data sources have been identified, the data should be prepared for the mapping process. Preparation commonly includes projecting all geospatial data layers into a common projection and coordinate system, checking imagery for anomalies like clouds and cloud shadows or damaged scan lines, and clipping the data to the project area extent. **Digital imagery** might require additional processing steps that include **radiometric correction, geometric correction**, and **terrain correction**. Spatial coregistration of different data sources may also be necessary when multiple layer types, or adjacent layers of the same type, are used. The process of spatial coregistration insures that static features from corresponding layers are in alignment.

Additional vegetation indices and topographic derivatives may also be produced. For spectral data these indices and derivatives can include Normalized Difference Vegetation Index (NDVI), tasseled cap transformations, texture metrics, and others (Huete and Jackson 1987, Jensen 1996, Lillesand and Kiefer 1994). Topographic derivatives often include; slope, aspect, curvature, solar radiation and absorption, hill shade, topographic wetness index, and others (Evans 2004, Horn 1981, McCune 2007, Murphy et al. 2009, Zhou and Liu 2004).

Extensive nationwide datasets, including many of these layers, have been assembled for projects such as the NLCD Tree Canopy layer and Monitoring Trends in Burn Severity (MTBS). These data are available through the Remote Sensing Applications Center at http://www.fs.fed.us/eng/rsac/.

3.3.2 Identify Modeling Units

As stated in section 3.1.3, modeling units are the elemental entities used in the mapping process, while map features are the nonoverlapping map units represented on the final map. Modeling units can be polygons (manual delineations or regions of raster cells) or individual raster cells. If the minimum map feature size is at the **pixel** or cell level, then the individual image pixels or raster cells are the modeling units.

Because most vegetation mapping completed by the Forest Service historically has been conducted through delineation of forest stands, it is important to review the terms stand and **patch**. The term *patch*, as defined in Helms (1998:132), is "an ecosystem element, e.g., an area of vegetation, that is relatively homogeneous internally and differs from surrounding elements." This definition is consistent with other common reference texts, including Pickett and White (1985), Forman (1995), and Forman and Godron (1986). This definition is also consistent with the common use of the term in the landscape ecology literature (Hartgerink and Bazzaz 1984, Scheiner 1992). Patch can describe forested patches or any other homogenous land cover feature.

In contrast, the term *stand* has long been used to refer to the basic unit of forest management (Toumey 1937). It also has been used as the basic unit of mapping and inventory (Graves 1913). A stand is described as a "contiguous group of trees sufficiently uniform in age class distribution, composition, and **structure**, and growing on a **site** of sufficiently uniform quality, to be a distinguishable unit, such as mixed, pure, even-aged, and uneven-aged stands. A stand is the fundamental unit of silviculture reporting and record-keeping. Stand may be analogous to Activity Unit." This definition from the Society of American Forester's *Dictionary of Forestry* (Helms 1998:174 and formerly in Ford-Robertson 1971) is consistent with definitions in a variety of reference texts, including Toumey (1937), Smith (1986), Oliver and Larson (1990), and Lincoln et al. (1982), and with the definition provided in FSM 2400.

In the context of the mapping protocol in this technical guide, the terms "patch" and "stand," in general, are synonymous, depending on the degree to which management considerations are incorporated into stand delineations along with compositional and structural characteristics. Because many past stand delineations contain multiple vegetation conditions and map units, they would be multiple map features in any new mapping effort. Patches and stands historically served as both the modeling units and the final map features, particularly photo interpretation-based efforts.

It is important to consider that patches or modeling units identified by a mathematical model used in image classification, or a heuristic technique used in manual interpretation may not be ecologically significant; an organism and a computer algorithm might see the landscape in very different ways. It is critical that ecologists or resource specialists and image interpreters communicate throughout the map design and validation process.

Manual Delineation

Manual delineation is the process of visually inspecting images and, either digitally or on a paper map or photograph, digitizing polygons based on feature shape, texture, pattern, tone/color, location, and context, using the interpreter's expert knowledge. An advantage to manual delineation methods is the ability for the interpreter to visualize and comprehend complex vegetation and ecological patterns that are difficult or impossible to model through automated computer processes. Manual delineation has been applied for many years and is considered a reliable approach. Because interpretation is more of a heuristic technique, however, it is often difficult to replicate precisely and is a time consuming activity.

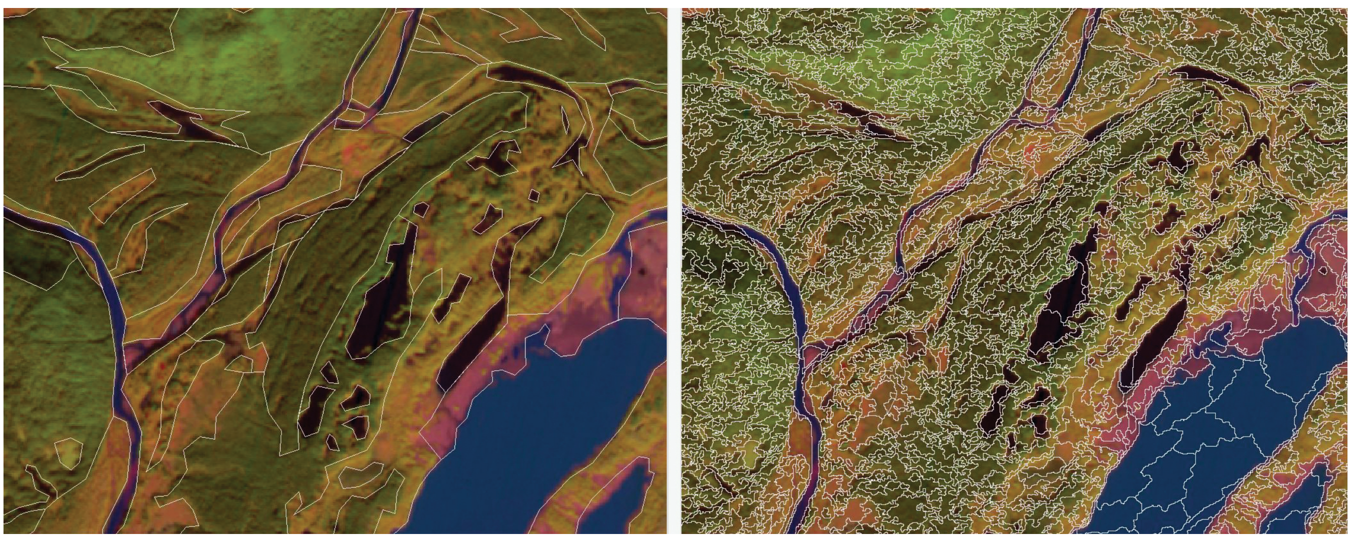
Manual delineation often involves other supporting materials, such as maps and field observations (Lillesand and Kiefer 1994), and relies on visual discontinuities in image characteristics, which generally reflect differences in **life form** composition, tree crown size, or apparent tree height (Stage and Alley 1972). The process historically used stereoscopic, **vertical** aerial photography and involved transferring the photo delineations to a base map and converting them to a digital form. More modern techniques involve interpretation and delineation of digital stereo pairs directly on screen with software that creates a digital product immediately. Image interpretation without stereoscopic viewing does not benefit from three-dimensional (3-D) interpretation of vegetation cover, but can be used if stereo pairs are not available. Image interpretation is the most intuitive form of map feature delineation but is also the most subjective and often the least cost effective (appendix D).

Automated Delineation

Automated modeling unit delineation is often referred to as image segmentation, the process of partitioning digital imagery into spatially cohesive polygonal segments or regions that generally represent discrete areas or objects on the landscape (Ryherd and Woodcock 1996). The goal of developing segments is to simplify complex images into more meaningful and mappable objects. The scale of the imagery being processed will determine the detail that can be captured in the modeling units or polygons. Spatially detailed imagery, such as National Agriculture Imagery Program[2] or other high-resolution image data, is often used with topographic information to develop modeling units. Most segmentation software uses scale, shape, and color parameters to delineate objects with similar properties based on the variance structure of the data.

The use of image segmentation recently has become the de facto approach for delineating modeling units. As opposed to manual delineation of patches or stands, image segments might not have ecological or management significance because a computer algorithm bases the delineations on local variance structure in the data (figure 3.4). In a typical mapping process, adjacent segments with the same map unit label will be merged into a single map feature (see section 3.3.6).

Figure 3-4.—*(A) Hand-delineated polygons on 5m SPOT 5 imagery (displayed shortwave color IR) near the Copper River Delta, Chugach National Forest. Manual interpretation and delineation are variable and generally capture only larger textural and tonal patterns. (B) Semiautomated segmented polygons produced in eCognition on 5m SPOT 5 imagery provide a finer and more meaningful delineation of landscape features.*



3.3.3 Assemble and Collect Reference Data

Reference data are representative samples of the map units that are to be depicted on the final map. They are used both as training data in model development and to assist with image interpretation. Reference data represent quantitative examples of vegetation characteristics and site conditions at specific locations throughout the project area. The information is used to assign map unit labels related to vegetation dominance type, structure, and cover to associated modeling units. Reference data have three primary sources: (1) newly collected field data, (2) legacy field data, and (3) image-interpretation data. Mapping projects most often use all three sources in combination with one another, depending on available resources.

[2]The National Agriculture Imagery Program (NAIP) acquires aerial imagery during the agricultural growing seasons in the continental United States. A primary goal of the NAIP program is to make digital orthophotography available to governmental agencies and the public within a year of acquisition. NAIP is administered by the USDA's Farm Service Agency (FSA) through the Aerial Photography Field Office in Salt Lake City. This "leaf-on" imagery is used as a base layer for GIS programs in the FSA's County Service Centers, and is used to maintain the Common Land Unit boundaries.

Reference data should represent the range of variability for each map unit and be consistent with the scale of the map being produced. The variability for each map unit depends on several factors, including the spatial extent of the project area, number and taxonomic complexity of the map units, and spectral variation of the imagery resulting from factors such as plant vigor, vegetation density, and topographic conditions (Lachowski et al. 1996). The number of reference sites needed for each map unit depends directly on these factors. Map units with high variance, such as those that occur in diverse topographic conditions (e.g., elevation, slope, aspect) or in various ecological settings (e.g., alpine, montane) may require more samples to enable accurate and comprehensive representation on the resulting map. Conversely, those map units found in more specific topographic/ecological settings or with lower spectral variability may require fewer samples. An initial assessment of the variance structure within map units can assist in determining how samples should be allocated.

The scale of the map being produced and its associated modeling units determine the scale at which the reference data should be collected or assessed. If the modeling units are image segments, the associated reference data should consider the context of the entire segment when assigning a map unit label.

Field Data

For most vegetation mapping projects, field data collection is a necessary task (figure 3.5). Due to high costs and limited time, it is important to consider what amount of information needs to be collected to accurately and consistently assign map unit labels to field sites. For this reason, an information needs assessment should be undertaken before beginning field campaign.

Figure 3-5.—*Reference field data collection.*

Mapping projects have historically tended to collect too much information on too few plots, and not enough general information on many plots to effectively develop predictive models or classification heuristics. For mapping and modeling purposes, having a larger number of reference sites with less detail is preferable to having fewer sites with more detail. The level of detail required for new data collection should be determined in advance of any new collection efforts and be within the project timeline and budgetary constraints. The amount of information ultimately collected at each reference site should include enough detail to correctly assign the site to a corresponding map unit, but not more information than necessary.

Legacy Data

Legacy data are reference data that already exist from other projects. They can be used as long as their spatial, floristic, and taxonomic information can be systematically and consistently crosswalked to the current project's map units. Legacy data should be compared with current, high-resolution imagery to verify that the site is correctly located, and that the land cover has not changed because the data were collected. It is also important to verify that legacy data adequately correspond to the modeling units identified for the project.

Two of the most common sources of existing data for mapping projects are common stand exam and FIA data. Historic stand exam data typically do not have precise locations for individual plots, and often were created for forest management purposes and not collected for nonforested areas. Because these exams were collected for purposes other than mapping existing vegetation, they often do not correspond to current modeling unit delineations.

FIA plots are a systematic random sample to quantify vegetation conditions as part of a State and, or, national assessment. FIA field plots are widely used for national and broad mapping applications and other purposes, but they may not be optimal for mid- and base-level mapping because they are randomly located and might not fall in all map units of interest. In a similar way, the FIA plot (an array of subplots distributed across roughly an acre area) often represents multiple conditions across multiple modeling units. A plot might not represent a single vegetation type or, if it does fall within one vegetation type, it might not effectively characterize the type as a whole. Therefore, these data might not serve as appropriate reference data in all cases.

Both stand exam and FIA data may introduce error into predictive models; however, both can be used to supplement field collection or photo-interpreted reference data and to assess model outputs during the draft map review process.

Image Interpretation Data

Image interpretation is also a useful and cost effective technique for collecting reference data. Photo interpretation captures the visible components of the canopy from an aerial or bird's-eye perspective, including areas that are inaccessible due to safety concerns or cost. Legacy and newly collected field information can sometimes be useful to help locate and subsequently label additional photo interpretation sites. Image interpretation is especially useful for determining tree cover on forested sites and for identifying dominance type classes, such as bare ground, water, deciduous tree, and others, that are easily interpretable from an aerial perspective.

Stereo photographic imagery has long been valued as a cost-effective planning tool because it provides a 3-D view of the terrain and increased image interpretability, while facilitating vertical landscape measurements such as the quantification of slope, elevation, vegetation height, and vegetation form.

Although resource specialists have used stereoscopes and aerial photography for decades to characterize terrain, digital imagery has recently opened up innovative, more efficient possibilities. New software tools like Stereo Analyst for ArcGIS by ERDAS provide access to digital stereo imagery. The Stereo Analyst interface not only enables the resource specialist to visualize the terrain in 3-D, but also to efficiently plan, measure, record, and characterize terrain in a way that, until recently, has been unavailable. For more information about image interpretation see appendix D.

3.3.4 Assign Attributes to Modeling Units

Numerous techniques can be used to assign map unit attributes to modeling units. These techniques include automated model development and manual image interpretation. Choosing the best technique for a particular set of objectives requires understanding the principles underlying each. Variation in land cover, spectral variation in the imagery, and the relationships between land cover and spectral variation should be considered when choosing an attribution technique (Lachowski et al. 1996).

Automated Model Development

Automated model development can range from simple **unsupervised classifications** to more complex **supervised classification** techniques. In general, automated classifications depend on having distinct signatures or response patterns for the classes being mapped (Eastman 2003). Supervised and unsupervised classification methods are often combined in the same workflow.

Unsupervised Classifications

Unsupervised classifications historically have been the primary method used to map vegetation conditions (Everitt et al. 2002, 2006; Stitt et al. 2006; White et al. 1995). Unsupervised classifications require only a minimal amount of initial input from the analyst and can be used without having prior knowledge of the current vegetation in the study area (Jensen 1996). K-mean and ISODATA [Iterative Self-Organizing Data Analysis Technique algorithm] clustering are among several algorithms. These algorithms generally work by grouping pixels found across the image into a preselected number of statistical clusters based on differences among within- and between-cluster spectral variability. These clusters are very spectrally homogenous; however, they are not always equivalent to actual vegetation map units and additional analysis is often needed to assign labels (Campbell 1987, Nie et al. 2001).

Supervised Classifications

Supervised classifications require prior knowledge of the existing vegetation in the study area. Unlike unsupervised classifications, supervised classifications enable the analyst to examine the data being used to develop predictive models, detect model errors, and augment or adjust the reference dataset to improve model performance. The **multispectral** data from pixels of known vegetation composition are used to build a supervised classification model (Kamaruzaman et al. 2009). After being built, the classification model can be applied to the entire study area by assigning unlabeled modeling units to a map unit class. Classification algorithms such as maximum likelihood and minimum distance to means have traditionally been used in image classification (Shupe and Marsh 2004).

Machine learning techniques, including classification and regression tree (CART) analysis, have recently become the most common methods to construct predictive models. CART analysis is a nonparametric approach used to uncover patterns in datasets (Breiman et al. 1984). Classification trees are used to predict categorical variables such as vegetation type, while regression trees are used to predict continuous variables such as tree cover from above. Some CART classifiers, such as See5 and Cubist, build models by recursively partitioning a dataset into homogenous subsets until a tree is constructed (Hansen et al. 1996). Others, such as Random Forests, combine the results of multiple tree classifiers into one single classification (Pal 2005).

Although the approaches discussed in the previous section are widely used when assigning a single map unit attribute to a modeling unit, nearest neighbor **imputation** approaches are used to simultaneously assign multiple attributes to a modeling unit (Ek et al. 1997, Eskelson et al. 2009, Hassani et al. 2004, LeMay and Temesgen 2005, McRoberts et al. 2002, Moeur et al. 1995, Ohmann and Gregory 2002, Ohmann et al. 2012, Temesgen et al. 2004). Nearest neighbor approaches have traditionally been used to estimate missing values in inventory applications and are described in more detail in section 4.6.4.

Manual Image Interpretation

In manual image interpretation, a skilled analyst examines satellite or photographic imagery using the elements of image interpretation: image tone, image texture, shadow, pattern, association, shape, and size. These elements are described in more detail in appendix D. Along with contextual clues, they allow for the direct assignment of map unit classes by the interpreter.

Depending on the thematic detail in the **classification scheme** for any given map product (i.e., plant associations vs. **alliances** vs. dominance types), the image interpretation task will involve various amounts of field validation sampling. This fieldwork may range from simple “ground truth” reconnaissance to a formal, two-stage sample design or a complete field data-based attribution of modeling units. Appendix D includes an example of a structured image interpretation data gathering protocol in operational use in the agency.

Campbell (1987) describes the following five general image interpretation strategies.

1. *Field observation*. Using field observations to identify features on the imagery. This strategy has been employed to greater or lesser degrees by nearly all photo interpreters and provides reference or training data for most supervised and unsupervised classifications of satellite imagery.
2. *Direct recognition*. Applying the interpreter’s accumulated experience, skill, and judgment to map features recorded on an image. An example would be recognizing a conifer forest or rocky area on aerial photographs.
3. *Interpretation by inference.* Using the visible distribution to infer a distribution that is not visible on the image. An example is aerial photograph interpretation of soil patterns, inferred from vegetation and topography. This strategy constitutes the vast majority of satellite imagery classifications.
4. *Probabilistic interpretation.* Typically relying on the relationship between some element of image interpretation and the probable interpretation. Collateral (nonimage) information is commonly used in probabilistic interpretation. An example would be the recognition of a riparian area on aerial photographs.
5. *Deterministic interpretation*. Tying image characteristics and ground conditions with quantitatively expressed deterministic relationships. A common example is using stereo photogrammetry to determine the height of an object on the photos.

3.3.5 Assess Draft Maps

Draft maps should be distributed to local resource specialists and other experts for comment and review. These draft maps may be digital or hardcopy products. This task provides an opportunity for local experts to assess the maps and give additional information needed to make improvements. Reviewers of draft maps should be familiar with the project area and include a variety of disciplinary resource specialists. Notations about whether the map accurately characterizes or mislabels the vegetation characteristics may be provided, based on field reviews or expert knowledge.

In large project areas associated with the mid, broad, and national levels, review of the draft map is usually a rapid assessment of the digital maps using high-resolution imagery and limited field visits. Base-level mapping projects may require walkthrough observations.

The draft maps are taken into the field as printed maps or as digital products on a portable electronic device. Field review vegetation maps are more easily used when they include road systems, hydrography, and terrain characteristics. U.S. Geological Survey 7.5-minute base series maps can serve as an effective overlay on vegetation draft maps to provide this ancillary information.

When assessing the maps, it is important to use the same parameters (e.g., map units, map keys) as were agreed upon during the project planning and reference data collection phases. It may be tempting for reviewers to express dissatisfaction in the map product. This dissatisfaction often relates to applying the map product at scales finer than those that were agreed upon or expecting it to address information needs that were not identified during the needs assessment. These situations highlight the importance of managing expectations and communicating throughout the process.

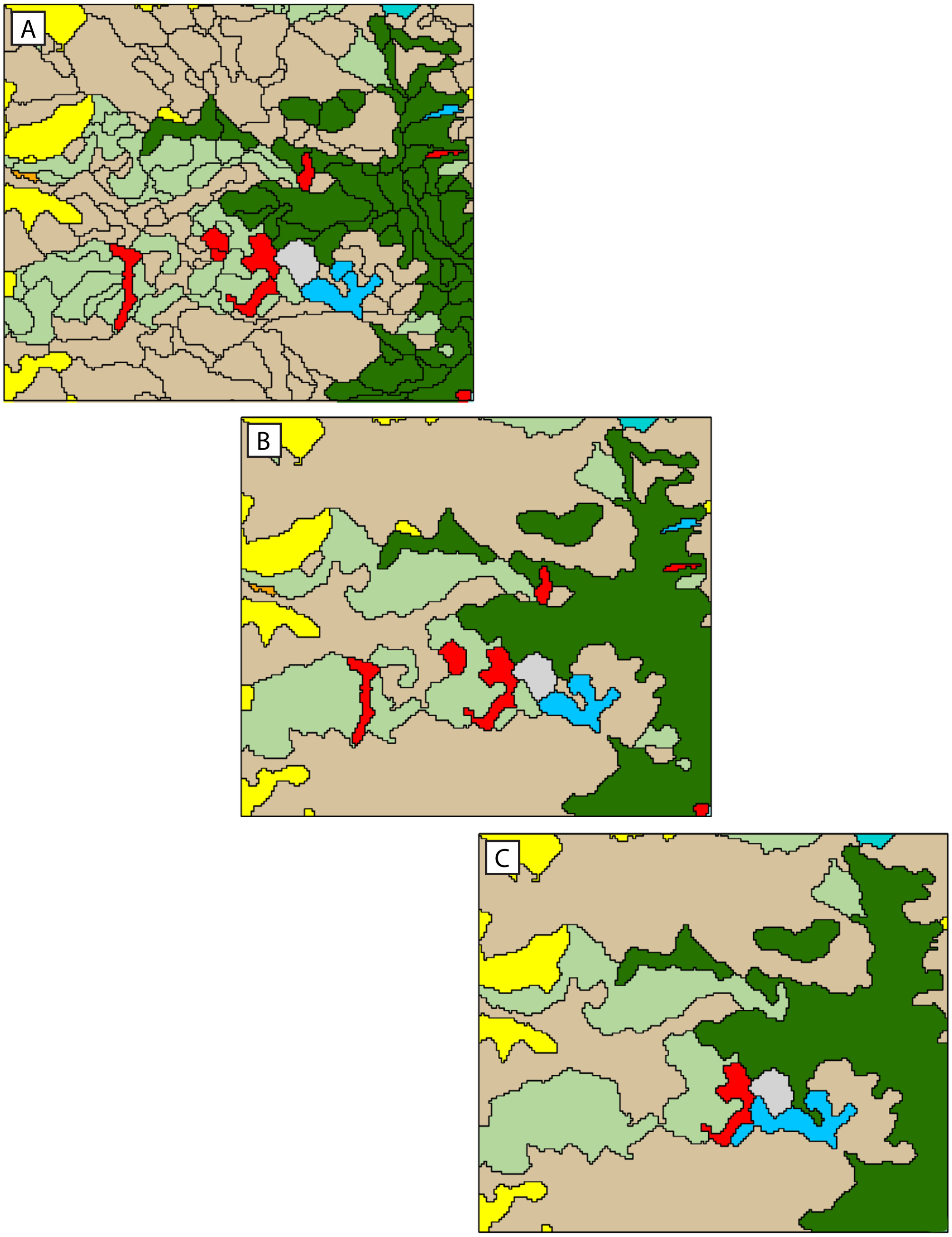
Comments and observations should be reviewed by the geospatial specialist and incorporated into the final maps. Draft map revisions include both simple manual edits to individual modeling units or revisions to the classification models. If certain classes are identified as poorly mapped, additional reference data from field visits or photo interpretation can be used to develop new models for assigning map units. If the classes are poorly mapped yet adequately represented in the reference data, consider grouping them into other map units or other redesign approaches to improve results.

3.3.6 Produce a Final Map Product

Finalize Maps

The final maps are produced when the modeling units are aggregated and filtered to the final map features outlined in the project plan. Aggregation is the grouping of contiguous modeling units that share common map unit classes (dominance type, tree cover from above, and tree diameter) into a single feature (figure 3-6B). Aggregation is applicable to polygon modeling units only, because raster surfaces retain their spatial structure throughout the mapping process. Filtering is performed to eliminate features less than the minimum map feature (figure 3-6C). Filtering rules should consider the thematic relationship of potentially merged features (e.g., the aggregation of two similar tree types is more desirable than the aggregation of a tree type and a **nonvegetated** class) and are ideally based on a hierarchical classification scheme rather than spatial rules such as longest shared perimeter. Base-level mapping presumes that no finer continuous map product exists for the intended purpose, and aggregation may not be an applicable technique.

Figure 3-6.—*Example of (A) map product with labeled modeling units, (B) aggregation/grouping of contiguous modeling units that share common map unit classes into map features, and (C) filtering to eliminate map features less than the specified minimum map feature size.*



3.3.7 Produce a Map Accuracy Assessment

An accuracy assessment for a mapped product can be defined as a statistical summary or metric, usually presented as a table, comparing the mapped classes with reference data or “truth.” An accuracy assessment should provide objective information on the quality or reliability of the map and can be used to determine the appropriate use of the map with respect to specific applications. The accuracy assessment is the primary **quality control** process for a vegetation mapping project. The following discussion is an overview of some of the main components of the theory, design, and implementation of accuracy assessments. A more detailed discussion is beyond the scope of this chapter. For a detailed treatment of any of these topics, please refer to the references listed herein and in appendix B.

An accuracy assessment is an important component of a remote sensing project for several reasons. First, during the planning process (see section 3.2.5), accuracy metrics and requirements establish the criteria for “quality” or usefulness of the desired product, and thus affect decisions about map design, methodology, and subsequent planning and implementation steps. Second, after the map products are produced, accuracy assessments enable the producer to compare different methods and **sensors** to determine the reliability and usefulness of remote sensing techniques. Finally, and most importantly, accuracy assessments support the spatial data used in decisionmaking processes by providing a measure of reliability of the map.

Conducting an Accuracy Assessment

The three basic components of an accuracy assessment are the sample design, the response design, and the analysis protocol (Stehman and Czaplewski 1998). The sample design determines both the plot design and the distribution of sites across the landscape; the response design determines how the sites are labeled or assigned to map units; and the analysis protocol summarizes the results of information obtained from the sampling and response designs. The three main components are discussed briefly here and in more detail in appendix B. Conducting an accuracy assessment is an important and complex endeavor and should be undertaken with expert advice.

Sample Design

The sample design should be statistically and scientifically valid. The sampling unit (i.e., polygon or **point**) should be identified early in the process because it affects much of the plot design. Whether the sampling unit is a point or polygon is often debated and is chosen after comparing benefits and costs associated with each (Janssen and van der Wel 1994). Choosing sampling units and data collection protocols for accuracy assessment similar to those used for the projects’ training samples is often recommended because it helps assure definitional similarity between map features and the areas chosen as accuracy sites. Although training data used for producing a map may be collected according to a **preferential** (purposive) **sampling** scheme, data used for accuracy assessment should be collected by using an unbiased (probabilistic) approach, however, where samples have a known probability of selection. Simple random and systematic sampling are commonly used equal probability sampling designs. Stratified random and cluster sampling can also represent equal probability sample designs depending on how they are implemented. Simple random sampling without replacement (each sample unit selected only once) ensures equal probability but may undersample rare types. Systematic sampling, where sample units are based on a fixed spatial interval, may provide a better spatial distribution of samples and usually results in better precision relative to simple random sampling when using the appropriate variance estimators (Stehman and Czaplewski 1998). When using **simple random sample** estimators with a **systematic sample**, however, the variance tends to be overestimated (precision is underestimated; Stehman and Czaplewski 1998). The FIA program is based on a systematic sample design.

The appropriate sample number and size are also important considerations. The number of sample sites should be large enough to be statistically sound but not larger than necessary for the sake of efficiency. If **overall accuracy** is to be considered, more samples will be needed to examine the nature of errors in individual categories such as for rare types. A general rule of thumb is that at least 20 sites are required for each category in the classification. Congalton (1991) suggests 50 sites for each category and 75 to 100 sites per map unit for large areas with many categories. Evaluating the frequency distribution of each class by each mappable attribute can support an estimate of the appropriate sample size.

Response Design

The response design includes procedures for collecting the accuracy assessment samples and protocols for assigning a map unit label to each accuracy assessment sample (Stehman and Czaplewski 1998). If an existing dataset is used, determine whether the existing information is sufficient for assigning a map unit label, or if additional information and interpretation is needed. When data collection protocols for the accuracy assessment samples are similar to those of the training samples, then assigning the appropriate map unit label to an accuracy assessment sample is straightforward. If plot designs or attribute definitions are dissimilar (e.g., if using FIA data to assess polygons), then developing a crosswalk and reinterpreting or verifying plot information using high-resolution imagery may be necessary for improving spatial and definitional compatibility.

Analysis Protocol

The analysis protocol summarizes the results of information obtained from the sampling and response designs (Stehman and Czaplewski 1998). One important objective of an accuracy assessment is to quantify the level of agreement between mapped and observed attributes. This quantification is most often performed for classified (categorical) maps by creating an error and contingency matrix, and deriving the accuracies from that matrix. The **error matrix** is the standard way of presenting results of an accuracy assessment (Story and Congalton 1986). This matrix is a cross-tabulation table (array) that shows the number of reference sites found in every combination of reference data category and map unit category (see table 3-1). Agreement can also be measured by comparing the similarity of the mapped and observed proportions of the attributes within the mapped area. Thus, agreement can be measured in at least two ways:

1. Agreement between map and ground map unit values at reference site locations, tallied in an error matrix.
2. The degree of similarity of the mapped and observed proportions of the attributes within the area as shown in a tabular comparison of marginal distributions.

In the first case, we are interested in the agreement for specific locations within the area. In other words, we are interested in determining the correspondence between map features and **accuracy assessment sites**. In the second case, we want to know if the proportions of observed and mapped types within the study area agree. Appendix B discusses both of these concepts in detail.

Table 3-1.—*Example of an error matrix.*

Reference data					
	Tree dominated	Shrub dominated	Herbaceous dominated	Sparsely vegetated	Row total
Tree dominated	65	4	22	24	115
Shrub dominated	6	81	5	8	100
Herbaceous dominated	0	11	85	19	115
Sparsely vegetated	4	7	3	90	104
Column total	75	103	115	141	434

Overall accuracy = 321/434 = 74%

Producer's accuracy/omission error:
Tree dominated = 65/75 = 87%
Shrub dominated = 81/103 = 79%
Herbaceous dominated = 85/115 = 74%
Sparsely vegetated = 90/141 = 64%

User's accuracy/commission error:
Tree dominated = 65/115 = 57%
Shrub dominated = 81/100 = 81%
Herbaceous dominated = 85/115 = 74%
Sparsely vegetated = 90/104 = 86%

Accuracy assessment sites are expensive and time consuming to delineate, characterize, and ground check. Often a tradeoff is made between strict statistical rigor and practical considerations of cost, and thus clear metadata are critical so that users of the map products can better assess the appropriate uses of the accuracy information. In determining the number of accuracy assessment sites to investigate, a tactical approach is recommended. For example, more image-interpreted sites may be collected than field sites.

Fuzzy Accuracy Assessment

A relatively recent innovation in accuracy assessment is the use of fuzzy sets for accuracy assessments. Traditional accuracy assessments often suffer from certain limitations. First, they assume that each accuracy site can be unambiguously assigned to a single map unit (Gopal and Woodcock 1994), when in reality it may be difficult to assign portions of a landscape found on a gradient to a discrete class. Second, the traditional error matrix makes no distinction between magnitudes of error. For example, in a traditional error matrix, misclassifying conifer forest as a deciduous forest carries the same weight as the error of misclassifying it as conifer/hardwood mix forest.

A fuzzy accuracy assessment is designed to handle ambiguity and, therefore, should be considered for an accuracy assessment of complex or potentially ambiguous classification. For example, misclassifications between ecologically similar sites can be assigned less weight in the overall accuracy assessment than misclassifications between very different classes (Gopal and Woodcock 1994). The resulting accuracy assessment can then rate the seriousness of errors and the absolute correctness and incorrectness. For a complete description of applying fuzzy sets to accuracy assessment, refer to Woodcock and Gopal (1992). Note: Fuzzy accuracy assessment approaches are particularly useful for variables modeled by using a pseudo-continuous and continuous map unit design such as 0 to 100 percent tree canopy cover.

Fuzzy accuracy assessment provides a quantitative approach for dealing with gradual membership assessment of classed data (Woodcock 1996, Zadeh 1965). In most classic accuracy assessment schemes, the mapped class is declared to be either correct or incorrect when compared with the ground observations of an expert. In fuzzy assessments, the correctness of a ground location is more a matter of degree. In either case, a map user is mainly interested in a metric for determining the quality or reliability of the map; the metric used is in support of the desired application. In the case of fuzzy sets, metrics support opportunities of class membership, and include contributions concerning spatial locations and boundary definitions.

Final Map Modification

The final map products can be modified as needed based on the map assessment results. Often the map assessment identifies map units with low accuracy. These map units may meet the desired thematic detail but not the desired thematic accuracy. By assessing the error structure, relative to the mapping objectives and management questions, map units can be combined into new, more generalized map units that better meet the accuracy requirements. Merging map units is not an edit or a correction to the final map; rather, this process is a generalization of the map legend to achieve an acceptable compromise between thematic detail and classification accuracy.

3.3.8 Deliver Map Products

The primary product at each level of mapping will be a geospatial database, consistent with the geodatabase design in the Forest Service existing vegetation GIS data dictionary, and FGDC-compliant metadata. Maps can be in vector or raster geospatial format. The map products should be geographically continuous in the area of interest and contain the appropriate data attributes identified and described in section 3.5.

Data assembled or generated for use in the mapping process should be included in the product delivery. These data include satellite imagery, aerial photography, DEMs, and byproducts such as vegetation indices, topographic derivatives, modeling unit segments, and other GIS layers. All reference data (field, photo, and existing legacy) used in the modeling process should also be delivered.

Project reports should provide an overview of the information needs and map design, a detailed explanation of the mapping methods, and a discussion of the accuracy assessment design and results. All associated information such as reference data collection procedures, field data forms, field keys, map unit crosswalks, and draft map review notes should be included in the final report.

3.4 Map Maintenance

Natural events and management activities can alter the landscape and change vegetation composition. Without maintenance, vegetation maps can quickly become outdated and not reflect current conditions. Maintenance activities can range from simply recoding incorrect map units to developing more complex models that use remotely sensed data, topographic data, and other ancillary data to assign updated map labels. Maps need to be updated and corrected because of the following variables:

- *Disturbance events*. Changes in vegetation composition, canopy, and structure due to an external agent. These events are different than those anticipated due to normal projected successional changes. Included are sudden natural cataclysms such as wildfires and wind events, management activities such as timber harvests or prescribed burn, and the occurrence of diseases and insect outbreaks. These changes are generally localized and may have a relatively distinct perimeter.

- *Successional change*. The natural change that occurs in vegetation communities over time without disturbance. These changes can be difficult to detect because they evolve over a longer time period and can be subtler than natural disturbances or management activities. Some successional changes, however, such as regrowth after a fire, can take place quickly and can be more easily assessed. These types of conversions need to be addressed at an appropriate spatial and temporal scale.
- *Thematic errors*. Errors that adversely impact the usefulness of the map can also be addressed under the continuous improvement process that falls within the general concept of map maintenance. Thematic errors are not the result of changing conditions; rather, they are inherent errors that occur in all mapping projects because of the fundamental issues of mapping complex landscapes with limited resources. The two general types of thematic errors are (1) site specific and (2) systematic. Site-specific errors are localized on the map and can include incorrect classification of map features. Systematic errors occur when areas of one map class are consistently labeled incorrectly across a large portion of the project area.

Map maintenance should not be confused with remapping. In the context of this vegetation mapping protocol, map maintenance involves making updates or minor revisions to an existing map and requires adherence to the original classification scheme, map units (vegetation type, canopy closure, and size class), and minimum map feature size. Maintenance activities can range from simple manual revisions, to more complex model revisions that use remotely sensed data, topographic data, and other ancillary data to update maps. Remapping (and major revisions) is a new mapping effort that may include changes to the original mapping design parameters. Remapping should occur when the original map inadequately represents current vegetation conditions on the landscape across large areas, does not meet the current business needs, or when major changes have taken place over a significant portion of the map. Remapping can incorporate information from previous mapping efforts where conditions have not changed. Correcting either one of these error types can affect the accuracy assessment results completed for the original map.

3.4.1 Prioritize Map Maintenance Needs

The business needs of the map user often determine which updates are the most important and consequently what resources are needed to perform the updates. Not all updates need to be made on the same frequency; some are more costly and time consuming than others, and not all updates may be essential to management or planning needs. Several factors need to be considered when developing a maintenance plan.

- Methods and type of updates being made.
- Severity and extent of disturbance.
- Acquisition of new reference data (field visits, photo interpretation, and new imagery sources).

- Availability of existing data for locating update areas and determining the updated map class.
- Personnel and skill requirements, and their availability.
- Monitoring schedule.
- Distribution strategy for updated maps.

Update Schedule

A map at a given level should be updated to account for changes in vegetation that typically occur within that temporal range. Map products with a hierarchical relationship should be on a coordinated schedule to ensure that updates in the most detailed map are incorporated into upper level maps in a timely fashion. Business needs and resource constraints will also play an important role in determining the update cycle. Identifying how the map is being used and what resources are available for map updates will ultimately determine the update schedule.

Disturbance events that are documented such as large wildfires and timber harvests can be made on a yearly basis because the data to locate and describe the event are readily available. Changes due to succession may involve advanced change detection methodology, however, and may need to be done on a coarser time scale, or only as part of a remapping effort, due to costs.

A programmatic update schedule for existing vegetation map updates may be developed for ensuring that map products are current, reflecting additional data collection efforts, new imagery sources, or improved modeling techniques. An update schedule should be prioritized on the need for updates, rather than a strictly temporal schedule. For instance, instead of updating maps only every 5 to 10 years from the initial map delivery, updates should be based on identifying changing conditions due to fire and disturbance or identifying changing business requirements in specific areas that necessitate the need for map updates in certain areas.

3.4.2 Implementation

Updating existing vegetation maps requires both ecological knowledge and geospatial (GIS and remote sensing) skills. Resource, GIS, and remote sensing specialists should work together in a cooperative multidisciplinary environment to identify where maps need to be updated, determine the correct labels, and select the most appropriate updating technique. To make the updates consistent with the original map it is important to be familiar with the original mapping project's objectives, **classification system**, geospatial techniques, and map units.

As described in section 1.6.2, a regional authority should ensure regional consistency, including coordinating update efforts, organizing resources, and facilitating communication between resource and geospatial personnel.

Locate Areas for Updating

Experienced personnel who are familiar with the local flora and vegetation communities are an essential resource for determining if and where map updates are needed. When locating update areas it is critical to keep in mind the minimum map feature size of the original map. For example, a burn area less than the 5-acre (2-hectare) minimum map feature size may not be an appropriate update for a mid-level map. The following resources and **image processing** techniques can be used to locate areas where the map needs to be updated.

- *Field observations*. As personnel perform other field-related duties within the forest, they may notice errors on the current vegetation map, or they may gather ground data for areas where a disturbance occurred.
- *Fire perimeters*. Personnel can assess vegetation conditions after a fire using data layers produced by several programs, include the following:
    - Monitoring Trends in Burn Severity. MTBS is a multiyear project to consistently map burn severity and perimeters of fires greater than 1,000 acres (404.7 hectares) in the West and 500 acres (202.3 hectares) in the East for the years 1984 to present.
    - Burned Area Reflectance Classification (BARC). BARC maps are generated by the Burned Area Emergency Response (BAER) program for use in developing postfire emergency assessments of erosion and runoff. BARC maps have four classes: (1) unburned, (2) low, (3) moderate, and (4) high.
    - Rapid Assessment of Vegetation Condition after Wildfire (RAVG). RAVG maps identify conditions such as basal area mortality and percentage of change in cover from above for forested areas after a fire. They are produced within 30 days following the containment of a fire that burned 1,000 acres (404.7 hectares) or more of forested NFS land.
    - Some regions produce and archive official fire history maps each fire season. These maps include fire perimeters and fire history, and they are typically stored in corporate geographic databases. These maps typically include smaller fire disturbance events that are not captured by other sources.
- *Forest Service Activity Tracking System (FACTS).* FACTS is a Natural Resource Manager application that provides an activity tracking system at the field level. It consists of an integrated set of reports and maps to support the entry, editing, and retrieval of activity information to support business process at the field level. FACTS tracks timber sales, fire history, and invasive weed treatments, and it also generates national, regional, forest, and district reports regarding treatment accomplishments. Because a time lag often exists between acquisition of activity data and its upload to FACTS, information on all forests and activities may not be available or temporally accurate.
- *Annual aerial detection surveys.* Each year, Forest Health Protection staff in each region map forest damage caused by insects, diseases, or other large area tree stressors or mortality, including wind (blow down). Areas that have “mortality” listed as an attribute can be more closely assessed to determine the change in vegetation.
- *Image interpretation.* Personnel often use satellite imagery or aerial photographs to assess vegetation condition, land use, and areas where vegetation alterations have occurred.
- *Change detection.* Personnel can use simple change detection analysis to examine vegetation conditions and evaluate the impact of disturbances. It involves multidate image processing to produce a change layer and reference data to calibrate the change layer to current vegetation conditions. Personnel can use it to monitor changes in vegetation cover by identifying increases and decreases in the spectral **reflectance** of and correlating those differences to changes in individual life. They should take care to minimize temporal changes due to imagery acquisition timing and the natural variation of seasonal spectral responses.

- *Original map accuracy assessment.* Personnel can identify thematic map errors by reviewing the map accuracy assessment. They can use the accuracy assessment to indicate which map units have low accuracies and to help prioritize updates and additional data gathering activities.
- *Qualitative map assessment.* Resource specialists who have intimate knowledge of the local flora and distribution of the vegetation communities locate thematic map errors. They evaluate the maps in the office using a systematic process to identify the most obvious errors. A more detailed field visit or photo interpretation may be necessary to determine the correct label.

Determine Correct Map Unit Label

After the areas to update have been located, personnel who are familiar with the original map's design and field classification key should determine the correct map label. Field visits are the ideal method for assessing vegetation conditions after a disturbance event. The data collected during these visits need to be consistent with the original mapping methods and procedures. For example, if the map represents a bird's-eye view, assess only the visible components of the canopy from an aerial perspective.

Postevent resource photography or imagery can be used to assess vegetation conditions if field visits are not practical. It is important when using remotely sensed imagery to consider the temporal and spatial resolution at which the imagery was collected. For example, "green up" times may vary by location, latitude, vegetation type, and topographic position, such as slope, aspect, and elevation. The type of imagery and available spectral bands should also be considered. True color imagery works best for desert and other dry environments, while a color infrared (CIR) band is critical when assessing mesic and wet environments.

The same resources that were used to locate the update areas can be also be used to determine the new map label. Harvest information from FACTS can be used to estimate the tree size and tree cover from above. MTBS data can be used to assess postfire vegetation composition and cover.

Occasionally additional supplementary labels can be developed to address disturbance events. This additional label development is primarily applicable to recently burned areas or other major disturbance. These areas should be revisited in future map updates and the labels revised.

Select an Updating Method

The type, extent, and complexity of map updates will determine the appropriate updating technique. Updating methods include manual GIS editing and modeling, including change detection and image processing. These techniques can be used individually or in combination. Some considerations should be given to the availability of data (i.e., imagery, field, ancillary) and the expertise of the GIS and remote sensing specialist. The following list discusses updating methods in more detail.

- Interactive or headsup GIS editing involves manually editing or relabeling map polygons. This technique can be used to correct localized site-specific errors or update areas where a uniform disturbance event with an easily defined border has occurred. This method is the simplest updating technique.

- GIS modeling is the process of creating new data from existing spatial data. Data layers such as burn severity, topographic data (i.e., slope, elevation, and aspect), or timber harvest information are used to derive current vegetation conditions. This technique should be applied to areas where multiple factors need to be considered to determine the correct map unit label.
- Change detection examines the change in vegetation conditions and evaluates the impact of disturbances. It involves multidate image processing to produce a change layer and reference data to calibrate the change layer to current vegetation conditions. It can be used to monitor changes in vegetation cover by identifying increases and decreases in the spectral reflectance and by correlating those differences to changes in individual life form types (Levien et al. 2002). This method is the most complex updating technique.

Make the Update and Documentation

Updates should be made to all appropriate map attributes, including dominance type, tree cover, and size class. Information on the type of update made and the GIS and remote sensing methods used should be noted in an update report along with other information that documents the process. These reports, metadata, and associated geospatial data can be stored in a map revision repository at the appropriate administrative level. The repository should include the following information:

- Data used to locate the update, including MTBS data, harvest activity information, and change detection layers.
- Field information (if collected).
    - **Global positioning system** (GPS) **coordinates**.
    - Species composition, canopy cover, and size class.
    - Ground photos of update field sites.
- Resource specialist and GIS and remote sensing personnel who identified the error, determined the correct map class, and performed the update.
- GIS and remote sensing methods used, including models, new datasets or imagery, processing techniques, and other tools developed specifically for the update process.

The attributes of the revised map should also be expanded to include update information. This expansion would enable map users to see which areas have been updated and when. New attributes should include the following update information:

- Update identification (ID). A unique ID should be used for each update or collection of updates (e.g., wildfires or timber harvests that occurred in a specific year) that could be used to track back to the more detailed information contained in the map revision repository.
- Update year. When were the updates done?
- Update type. Why was an update necessary? Was it because of a wildfire, timber harvest, or wind event? Or was it necessary to correct a thematic error?
- Event year. When did the disturbance event take place?
- Contact organization or person. Who should be contacted if someone needs more detailed information about the update? Most likely this person would be someone at the regional level, such as a map maintenance manager, who has access to the map revision repository and who was involved in the update process.

Map metadata that contain detailed information about the map layers will need to be updated to reflect the changes that were made to the map. The updated metadata should include revision dates, data sources and methods used, and a description of disturbance events.

3.4.3 Changes in Map Accuracy

Map updates typically make up only a small percentage of an overall map and thus only minimally affect the accuracy of the map. In this case, one can identify which mapped classes were most affected, and realize the accuracy assessment error matrix for those classes may no longer be valid. In most cases, the new updated map should be more accurate than the original because of the targeted nature of the updates. For cases in which the vegetation has changed across very large areas, however, such as with succession, insect mortality, or large fires, the updated areas on the map may affect the accuracy assessment to a greater degree. In conclusion, if maps are updated, a new accuracy assessment should be conducted.

3.5 Map Guidelines

The mapping guidelines presented here provide a baseline for high quality spatial products and suggestions for thematic consistency across administrative boundaries. With the exception of following the standards established by the FGDC, the Forest Service has not defined agency-wide mapping standards. Region, station, and area offices determine local standards (see section 1.6.2).

The spatial and thematic guidelines described in the following section are included in the GIS data dictionary and geospatial database design for existing vegetation (http://www.fsweb.datamgt.fs.fed.us/index.shtml).

3.5.1 Spatial Guidelines

Minimum Map Feature

If the final map product will display spatially cohesive map features (e.g., polygons), then specify a minimum map feature in the design phase (see Modeling Unit and Map Feature Design in section 3.2.4 for additional discussion about polygon vs. raster). *Minimum map feature* is the term used to describe the smallest area that can be mapped as a homogeneous unit on the landscape (table 3-2). Map features labeled with one class should not contain areas of land that could be labeled as a different class that are larger than the chosen minimum map feature size. Rather, a second map feature should be constructed around the inclusion. Depending on technical feasibility and business need, it may be necessary to map features smaller in areal extent than the minimum map feature **standard** (e.g., mapping water features down to 1 acre [.4 hectare] for base-level mapping). Note: These georegistration standards apply to the base data (aerial or satellite imagery) used in a mapping project. The spatial accuracy of the modeling units and subsequent map features derived from these images can be assumed to be the same as the input images (given no spatial transformations have occurred).

Table 3-2.—*Minimum map feature guidelines.*

	Map level			
	National	Broad	Mid	Base
Minimum map feature (acres)	500	20	5	5

Georegistration

Map projects are designed to address specific business needs. Geospatial position accuracy is a business requirement that is generally defined during the project planning process. Feasible spatial precision is generally determined by the data sources and map development methods.

In general, the geospatial positioning accuracy of geospatial datasets produced during a mapping project should be calculated according to the standard defined in Geospatial Positioning Accuracy Standards Part 3: National Standard for Spatial Data Accuracy (FGDC-STD-001.3-1998). If the map is based on aerial or satellite imagery, and the original images have not been subjected to spatial transformation (reprojection or other warping), then the positional accuracy of the derived map products can be assumed to be the same as that of the input imagery. If the imagery has undergone a spatial transformation, or if the maps are not based on satellite imagery with metadata on positional accuracy, then the procedures described in FGDC-STD-001.3-1998 should be used. If the positional accuracy of a dataset cannot be determined by the prescribed procedure, the FGDC (1998) identifies four alternatives for determining positional accuracy: (1) comparison to an independent source of higher accuracy (preferred), (2) deductive estimate, (3) internal evidence, and (4) comparison to source. **Digital orthophoto quads** are generally the best source of well-defined control points, short of using surveyed points or a high-precision GPS. Table 3-3 identifies the **horizontal** geospatial positioning accuracy standards for existing vegetation maps (datasets).

Table 3-3.—*Horizontal accuracy standards.*

	Map level			
	National	Broad	Mid	Base
Map scale	1:1,000,000	1:250,000	1:100,000	1:24,000
Horizontal accuracy	± 1,666 ft	± 416 ft	± 166 ft	± 40 ft

3.5.2 Thematic Guidelines

Physiognomic and Floristic Type Attributes

Physiognomic and floristic type attributes (as described in section 2) are two of the fundamental components of an existing vegetation map. Physiognomic types are based on the overall appearance of the vegetation as determined by the combination of **growth forms** present and their sizes; floristic types are based on plant species composition.

The FGDC National Vegetation Classification (NVC) Standard establishes physiognomic and floristic types so that classification efforts are consistent across all Federal agencies and classification and map data can be aggregated from all Federal agencies. The NVC defines a hierarchical system for arranging floristic and physiognomic types into taxonomic units (table 1-2) that can be useful for map unit design. The upper levels of the NVC—**formation class**, formation subclass, and formation—are physiognomic-ecological units. The middle levels—**division**, macrogroup, and **group**—are physiognomic-floristic units. The lower levels—alliance and association—are floristic units (e.g., figure 3-7). In practice, alliance- and association-level taxonomic units can sometimes be mapped individually but often must be treated as components of multitaxon map units.

The FGDC NVC Standard requires that Federal agencies crosswalk their classifications only to the most appropriate level of the NVC. Forest Service information should at a minimum identify the crosswalk between NVC formation class and Forest Service physiognomic units (table 3-4), as Forest Service map guidelines state that physiognomic units should be defined for all vegetation map units. Because of the nested nature of the NVC system, higher level classification labels (NVC levels 1, 2, and 3) can be automatically determined from lower levels.

Figure 3-7.—*NVC hierarchy example (NVC and NatureServe Explorer at* http://explorer.natureserve.org/classeco.htm*).*

Formation class/Forest Service physiognomic unit—forest and woodland
Formation subclass—temperate and boreal forest
Formation—cool temperate forest
Division—Western North America cool temperate forest
Macro group—Rocky Mountain subalpine and high montane conifer forest
Group—*Picea engelmannii—Abies lasiocarpa—Tsuga mertensiana* mesic-wet forest and woodland group
Alliance—(Under review by Ecological Society of America Vegetation Panel)
Association—*Abies lasiocarpa—Picea engelmannii/Acer glabrum* forest (subalpine fir—Engelmann spruce/ Rocky Mountain maple forest)

Table 3-4.—*Comparison of conceptual categories, NVC formation class, and Forest Service physiognomic units.*

<table>
<tr><th>Conceptual category 1</th><th>Conceptual category 2</th><th>National Vegetation Classification level 1: formation class</th><th>Forest Service physiognomic unit</th></tr>
<tr><td rowspan="10">Vegetated areas</td><td rowspan="7">(Semi) natural vegetation</td><td>Forest and woodland</td><td>FW—forest and woodland</td></tr>
<tr><td rowspan="2">Shrubland and grassland
Semidesert vegetation
Polar and high montane vegetation</td><td>SH—shrubland</td></tr>
<tr><td>HB—herbland</td></tr>
<tr><td>Aquatic vegetation</td><td>AQ—aquatic vegetation</td></tr>
<tr><td rowspan="3">Nonvascular and sparse vascular vegetation</td><td>SV—sparse vegetation</td></tr>
<tr><td>ND—no dominant life form</td></tr>
<tr><td>NV—nonvascular vegetation</td></tr>
<tr><td rowspan="3">Cultural vegetation</td><td rowspan="2">Agricultural vegetation</td><td>AG—agricultural vegetation</td></tr>
<tr><td>CF—cultural forest</td></tr>
<tr><td>Developed vegetation</td><td>DV—developed vegetation</td></tr>
<tr><td>Nonvegetated areas</td><td colspan="2">Not included in the National Vegetation Classification.</td><td>NO—nonvegetated</td></tr>
</table>

Maps depicting Forest Service physiognomic units and formation class should also be classified with the Anderson Level 1 Land Cover Classification system (table 3-5, Anderson et al. 1976) to ensure compatibility with this system and consistent classification rules for nonvegetated areas. For example, land cover classes such as water, barren land, or snow are particularly useful in sparsely **vegetated** and nonvegetated areas. Furthermore, land cover label assignments that identify urban and agricultural landscapes enable map users to interpret vegetative conditions more accurately and answer questions such as the amount and location of urban forests or agricultural vineyards. Anderson Level 1 forms the historic basis for current NLCD mapping (Homer et al. 2007), and provides a crosswalk to the NVC level 1 using a geospatial reference. See appendix A for the Anderson classification definitions.

As discussed in section 2, a dominance type is “a recurring plant **community** defined by the **dominance** of one or more species that are usually the most important ones in the uppermost or dominant layer of the community, but sometimes of a lower layer of higher coverage” (Gabriel and Talbot 1984 as cited in FGDC 2008:58). Many Forest Service regional vegetation and land cover mapping projects and programs have developed and use dominance type classifications that include some Anderson Level 1 or Level 2 classes. It is likely that these regional dominance type classifications will be in use for many years and the map products generated by these projects and programs may serve as the most efficient approach to crosswalk to the National Vegetation Classification Standard.

Table 3-5.—*Relationship between Anderson Level 1 and Forest Service physiognomic units.**

	Anderson 1 land cover								
Forest Service physiognomic unit	Urban or built-up land	Agricultural land	Range-land	Forest-land	Water	Wetland	Barren land	Tundra	Perennial snow or ice
Forest and woodland	X			X		X			
Cultural forest	X			X		X			
Shrubland	X		X			X		X	
Herbland	X		X			X		X	
No dominant life form	X		X			X		X	
Agriculture vegetation		X							
Developed vegetation	X								
Non-vascular vegetation								X	
Aquatic vegetation						X		X	
Sparse vegetation	X					X	X	X	
Non-vegetated	X	X			X		X	X	X

*“X” indicates where mapping both attributes would be appropriate because of overlapping conditions. Table developed by Ralph Warbington, USDA Forest Service, Pacific Southwest Region.

Structural Characteristic Attributes

Tree Cover From Above

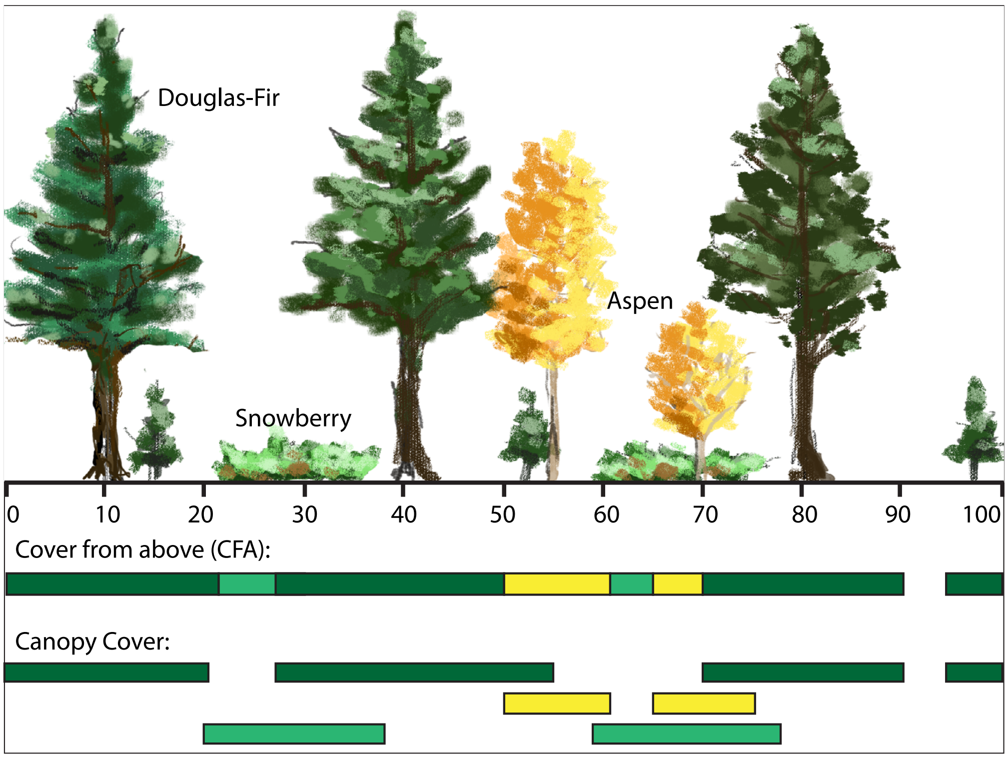
Tree cover from above is the total nonoverlapping tree canopy in a delineated area as viewed from above. (Note that tree cover as viewed from above is not defined by a hemispherical projection of tree cover viewed from below. The hemispherical projection of tree cover viewed from below is often used for describing the light environment of the forest floor and is common in wildlife literature. Tree cover as viewed from above is also not the same as the canopy cover described in section 2 and illustrated in figure 3-8.) Table 3-6 identifies tree cover from above breaks that are recommended for base-, mid-, and broad-level maps. Other class breaks or use of pseudo-continuous and continuous variables are also used within the Forest Service. Ten percent of class breaks and pseudo-continuous or continuous variables are all feasible categories for map units at the base level and allow for flexibility for aggregation into mid-level map units. The class breaks in tree cover from above map units (table 3-6) are also consistent with the class breaks for Forest Service physiognomic units. If a project at the mid or base level requires more detailed map units than those presented in table 3-6, design them to aggregate into the next higher level of tree cover from above map units.

Table 3-6.—*Tree cover from above map units.*

<table>
<tr><th rowspan="2">Tree cover from above map units (%)</th><th colspan="4">Map level*</th></tr>
<tr><th>Base</th><th>Mid</th><th>Broad</th><th>National</th></tr>
<tr><td>0</td><td>R</td><td rowspan="2">R</td><td rowspan="4">R</td><td rowspan="11">O</td></tr>
<tr><td>1–9.9</td><td>R</td></tr>
<tr><td>10–19.9</td><td>R</td><td rowspan="2">R</td></tr>
<tr><td>20–29.9</td><td>R</td></tr>
<tr><td>30–39.9</td><td>R</td><td rowspan="3">R</td><td rowspan="3">R</td></tr>
<tr><td>40–49.9</td><td>R</td></tr>
<tr><td>50–59.9</td><td>R</td></tr>
<tr><td>60–69.9</td><td>R</td><td rowspan="4">R</td><td rowspan="4">R</td></tr>
<tr><td>70–79.9</td><td>R</td></tr>
<tr><td>80–89.9</td><td>R</td></tr>
<tr><td>90–100</td><td>R</td></tr>
</table>

*R = Recommended; O = optional.

Figure 3-8.—*Comparison of cover from above (CFA) and canopy cover by species.* Horizontal bars indicate CFA and canopy cover of Douglas fir, snowberry, and aspen along a 100-ft line intercept transect. The species CFA values total 95 percent, which means that vegetation covers 95 percent of the transect. The species canopy cover values total 130 percent due to overlap among some individuals of different species. Douglas fir has 65 percent CFA but 70 percent canopy cover. The Douglas fir seedling under the aspen is counted as canopy cover but does not contribute to CFA. Aspen has 20 percent canopy cover but only 15 percent CFA because one-half of the aspen sapling is under a Douglas fir. Snowberry has 40 percent canopy cover but only 15 percent CFA because 25 feet of its intercept is under aspen or Douglas fir. Tree regeneration data (a measure of seedlings and saplings) are also very different between CFA and canopy cover. CFA for tree regeneration is 10 percent while for canopy cover it is 25 percent.



Overstory Tree Diameter

Overstory tree diameter class is any interval into which a range of tree diameters may be divided for classification (Helms 1998). In this protocol, the mean **diameter at breast height** of 4.5 feet (1.37 meters) above the ground is calculated for the trees forming the upper or uppermost canopy layer (Helms 1998). This mean may be calculated as the quadratic mean diameter or as basal area weighted mean diameter. Table 3-7 identifies tree diameter class breaks that are recommended for base- and mid-level mapping, based on classes commonly used by managers within the Forest Service. Other class breaks or use of pseudo-continuous and continuous variables are also used within the Forest Service. Tree diameter map units at the broad and national levels are optional. If a project at the mid or base level requires more detailed map units than those presented in table 3-7, design them to aggregate into the next higher level of diameter class map units.

Table 3-7.—*Overstory tree diameter map units.*

Tree diameter map units (dbh in inches)	Map level*			
	Base	Mid	Broad	National
0–4.9	R	R	O	O
5–9.9	R	R		
10–19.9	R	R		
20–29.9	R	R		
30–39.9	R	R		
40–49.9	R			
50+	R			

*R = Recommended; O = optional.

4.0 Existing Vegetation Inventory

This section introduces methods for assessing if available **inventory** data meet **existing vegetation** information needs. If inventory data do not exist to meet program needs, the design, implementation, and analysis of a new inventory are discussed. This section also demonstrates how to integrate inventory with **classification** and mapping activities and data products.

4.1 Overview

This overview demonstrates the links among inventory, classification, and mapping; the purpose of the guidance provided; key concepts related to vegetation inventory in the context of this technical guide; and applications and uses for existing vegetation inventories and information.

The target audience for this section is those who use, design, or implement base-, mid-, or broad-level inventories. Examples of individuals involved in base-level inventory activities are silviculturists, wildlife biologists, rangeland management specialists, and others who require base-level (project) vegetation information. At the mid and broad levels, planning staff, plan **monitoring** teams, those responsible for cumulative effects analyses for National Environmental Policy Act (NEPA) analyses, and regional resource specialists all use inventory data to help in decisionmaking.

4.1.1 Conceptual Framework

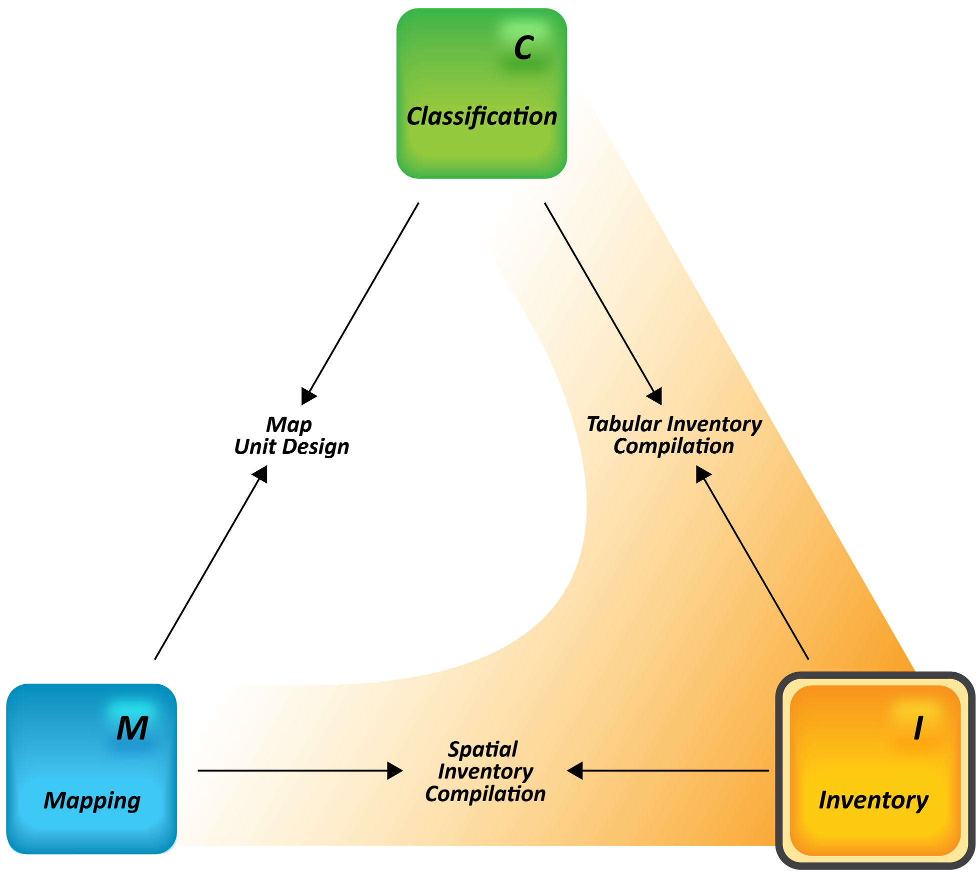
Figure 4-1 presents the conceptual model depicting the general relationships among classification, mapping, and inventory processes. The corners of the triangle represent classification, mapping, and inventory processes while the sides of the triangle represent the major process relationships that provide feedback and integration (Brewer et al. 2006). As stated in section 1.4 and defined later in section 4.1.3, a design-based vegetation inventory is the process of applying an objective set of sampling methods to quantify the amount, **composition**, and condition of **vegetation types**. In this context, an inventory needs to have a statistically valid sample design, be collected across a specified area of interest, be unbiased in how **plots** are placed and data are collected, and provide **population** estimates and an indication of their reliability (e.g., confidence intervals) to answer the question, “How much is there?” Inventories support vegetation management, development of desired conditions and management prescriptions, monitoring trends in vegetation over time, and research information needs. Vegetation inventories should be closely integrated with classification and mapping activities, where appropriate (Brewer et al. 2006).

Inventory and Classification Process Relationships

As discussed in section 2, Existing Vegetation Classification, vegetation classification is the process of grouping similar entities into named types or classes based on shared characteristics. In some situations, inventory data can contribute to the classification process. In the preliminary stage of classification, some inventory data may be used to inform development of the classification, while other inventory data may be useful to help stratify the area for reconnaissance or sampling.

Following the completion of a vegetation classification, inventory data, classified to the taxonomic units of the vegetation classification, are commonly used to compile an unbiased quantification of the composition of vegetation for the inventory area. This process, referred to as **tabular inventory compilation**, is useful for obtaining estimates of **abundance** and composition for a variety of uses. For example, the use of Forest Inventory and Analysis (FIA) program data classified to forest and woodland **dominance types** can help determine which dominance types are common enough to be mapped. The classification ideally should be developed and tested to ensure that the keys to vegetation types used in the classification relate to data that are commonly collected during the inventory process.

Figure 4-1.—*Relationships of inventory to classification and mapping.*



Inventory and Mapping Process Relationships

Mapping is the process of identifying the geographic distribution, extent, and **patterns** of vegetation types and structural characteristics. A primary relationship between mapping and inventory is **spatial inventory compilation**, which is the intersection of inventory data with vegetation **map** products. Spatial inventory compilation allows for the use of map information as classification (domain) variables; the inventory data are then summarized to quantify various vegetation characteristics for each map **class**. In this process, the inventory must be a **probabilistic sample** within the geographic area depicted on the map. At the simplest level, when the map is a delineated **stand** and the inventory is a stand exam, the spatial inventory compilation consists of the estimates derived from the Common Stand Exam (CSE) data. Inventory data can be used to calculate data summaries for each map class. For example, estimates of volume by **species** or snags per acre (from the inventory data) can be determined for each dominance type (from the map data).

In some cases, grouping inventory data by map classes can be used to improve the precision of estimates. Map class information can be used to group homogeneous vegetation together, to reduce the variance of the overall estimates derived from the inventory plots within the **stratum**. Only when the inventory was conducted as a probabilistic sample can this poststratification be investigated.

4.1.2 Purpose

Section 4, Existing Vegetation Inventory, outlines a process to assess existing vegetation inventories and, if needed, to scope, design, and implement a vegetation inventory. This section also provides guidelines for processing and interpreting inventory data and for evaluating and adapting **protocols** to meet information needs. The purpose of this section is to—

1. Inform U.S. Department of Agriculture (USDA), Forest Service employees about existing inventories, corporate protocols, and associated databases available to collect, warehouse, analyze, and understand the current condition of existing vegetation.
2. Educate inventory users about design-based, probabilistic inventories.
3. Articulate how probabilistic inventories can be integrated with national-level, broad-level, mid-level, and base-level classification and mapping systems to meet agency information needs.

4.1.3 Key Concepts

The key concepts discussed here build on those described in sections 1.4 and 1.5.5, including the basic definitions for classification, mapping, inventory, and monitoring and the conceptual model for the interrelationships of these concepts.

Inventory and Monitoring Definitions

This section focuses on vegetation inventory, recognizing that much of the content also applies to vegetation monitoring. Section 1.5.5 provides general definitions for inventory and monitoring and tables with examples of inventory and monitoring activities and sampling approaches. Here, we provide more specific definitions that highlight the importance of statistically valid sampling techniques. In this section, the term *monitoring* implies remeasurement of the inventory data over time and is used only when its application differs explicitly from that of an inventory. Regarding design, process, activities, and tasks, the primary distinctions between inventory and monitoring are the repeated collection of observations and the design requirements that allow for repeated collection of data to meet monitoring objectives. Objectives for monitoring may include understanding change over time, past trends, future trajectories, or early detection of unexpected change (threshold monitoring), which cannot be accomplished with a single data collection effort.

> Vegetation *inventory* is the process of applying an objective set of repeatable sampling methods to quantify the amount, composition, and condition of vegetation within specified limits of statistical precision (Helms 1998).

Vegetation *monitoring* is the collection and analysis of repeated observations or measurements to evaluate changes in vegetation condition and progress toward meeting a resource or management objective (SRM 1989, USDA Forest Service 2009a).

Geographic Area of Interest is the geographic extent that is to be studied.

Population is the area or aggregation of objects from which the sample is to be drawn (c.f. Bechtold and Patterson [2005], Cochran [1977]). In vegetation sampling, this population is usually equivalent to the area of interest, however, the population may be larger to ensure that all of the area of interest is included, such as when sampling a mosaic of forest and nonforest areas.

Inventory Levels and Associated Protocols

Existing vegetation inventories address agency **business requirements** and management questions at the four levels of analysis: (1) national, (2) broad, (3) mid, and (4) base (section 1, table 1-1). No "one size fits all" inventory **dataset** meets analysis needs at all levels. An inventory must be designed to include **attributes** that address specific management or policy questions and must be designed as a statistically valid sample for the population within the geographic area of interest. These requirements provide a dataset from which estimates and associated measures of reliability can be derived for the chosen attributes. Errors in decisionmaking can arise when one makes inferences from data extrapolated beyond the sampled population. The following information describes the four levels of analysis:

1. *National-level inventories* provide information about the status and trends of vegetation resources for national and international reporting and analysis. The FIA program (see http://www.fia.fs.fed.us/) gathers and supplies information on vegetation attributes related to the status and trends of the forest resource for the country on an annual basis[3] (e.g., National Report on Sustainable Forests, State of the Nation's Ecosystems, Resources Planning Act Assessment reports). Thus, this section does not describe how to use or design a national-level inventory. The FIA protocol is described in more detail in section 4.3.2.
2. *Broad-level inventories* generally provide information for ecological province, Forest Service region, or multiunit analysis. For example, broad-level inventories are used for region-wide coarse-filter monitoring to assess changes in **ecosystem** diversity and sustainability over time, assessment of cumulative effects, and to set the management context for projects occurring on national forests (e.g., Southern and Northern Forest Futures Assessments, State Assessments for State and Private Forestry, State 5-year analytical reports, and State annual statistical reports). The FIA protocol is the only existing vegetation protocol appropriate for use at the broad level.
3. *Mid-level inventories* generally provide information for one to several National Forest System (NFS) administrative units, large landscapes such as bioregions, or 4th level hydrologic units. For example, mid-level inventories are used for assessing national forest and grassland and district-wide cumulative effects and for setting the management context for individual projects (e.g., Climate Change Scorecard reports, national forest FIA analytical reports). FIA and CSE are examples of protocols applicable for mid-level inventory; both may need modifications or additions to meet information needs.

[3]Despite its name, the Forest Inventory and Analysis (FIA) program is designed as a monitoring program, with permanent plots and a regular data collection schedule.

4. *Base-level inventories* generally provide information for project-level planning and decisionmaking. Base-level inventories represent the highest thematic detail and highest **spatial resolution** (i.e., smallest size of polygons) required for vegetation data in the Forest Service. Inventories at this level are used for silvicultural diagnosis and prescriptions, wildlife **habitat** analysis, range assessment and allotment analysis, management treatment implementation, and monitoring. These inventories are unlikely to be spatially extensive due to cost. CSE is an example of a protocol applicable at the base level.

Quality Assurance and Quality Control

A good inventory has a **quality assurance** (QA) program to ensure that the data are of known quality and are thoroughly documented. An effective program must include QA audits and **quality control** (QC) checks. A thorough QA and QC program ultimately will make the inventory defensible if the data are challenged (see also section 1.6.2). The following paragraphs define QA and QC.

Quality assurance. QA is a *process-based approach* for ensuring that the uncertainties inherent in inventory and monitoring data are made known and do not exceed acceptable magnitudes, within a stated level of confidence. QA encompasses the plans, specifications, and policies affecting the collection, processing, and reporting of data. The most cost-effective QA tool used to ensure the integrity of data is a comprehensive manual for data collection. A key concept of the QA component is an independent, objective review by a third party to assess the effectiveness of the internal QC program and the quality of the inventory. QA should also reduce or eliminate measurement error. In summary, a comprehensive QA review program provides the best available indication of the inventory's overall quality completeness, **accuracy**, precision, representativeness, and comparability of data gathered (USDA Forest Service 2010, U.S. EPA 1997).

Quality control. QC is the routine application of prescribed field or database procedures to reduce random and systematic errors and ensure that data are generated, analyzed, interpreted, synthesized, communicated, and used within known and acceptable performance limits. *Whereas QA is a process-based approach, QC is a product-based approach*. QC encompasses hiring, training, and certifying qualified field crews; using reliable equipment and supplies; and adhering to recommended operating procedures, standardized protocols, and controls on lists of values. Data editing and data collection inspections are integral components of QC (USDA Forest Service 2010, U.S. EPA 1997).

General Inventory Principles

These principles apply to the full process of vegetation inventory described in this section, from defining information needs to evaluating results. The following principles are emphasized throughout the section because of their importance for conducting inventory activities that will result in the desired information products.

Inventory purpose. An inventory should be question driven, designed to address specific needs with bounds on scope, time, and effort. When multiple needs exist, inventory planners should look for opportunities to integrate the inventory by addressing multiple questions and meeting multilevel, multiresource, or temporal needs (Morrison and

Marcot 1995, Schreuder et al. 1993a). Inventories that are designed to integrate multiple needs can achieve a high level of utility and generate products that are useful to a variety of stakeholders (Lund 1986; see section 4.2.1, Identify Information Needs).

If the questions require remeasurement for monitoring changes through time, then the design must ensure that plot or polygon locations and all attributes of interest can be monumented, located, and remeasured over time. At the broad to mid level, remeasurement can be targeted to those plots affected by natural or human-caused events that alter the vegetation so that an updated existing condition can be assessed and changes due to an event can be determined. At the base level, all plots within a stand can be remeasured after disturbance to assess the effects of the disturbance.

Inventory design and implementation. Inventories that are designed based on sampling theory (i.e., design-based or probabilistic inventories) can be used to calculate estimates of population parameters for attributes of interest. Inventory designs define how sample units will be selected (e.g., random or systematic selection across the area of interest), how measurements will be taken within each sample unit (e.g., plot shape and size), and the required sample size (i.e., the number of sample units [plots] that will be sampled within the population). Because it is impractical to collect information on all **trees** within a stand or across a watershed, a design-based inventory can be used to identify a subset of the entire population(s) of interest to provide inferences about the entire population(s). The goal of a design-based inventory is to generate unbiased information about the population(s), including estimates and indices of confidence such as sampling errors and confidence intervals that inform the user about the quality of the estimates. Estimates from a design-based inventory are useful to managers who wish to make informed, defensible management decisions. If sample units (plots) are placed in a subjective manner (i.e., purposively), then the quality of the estimates generated from the inventory is unknown (see section 4.3.3, Determine Sampling Scheme).

Inventory Adaptation. To make inventory work truly adaptive, a feedback loop needs to be in place to allow the program to evolve. An adaptive inventory program involves regular and systematic reviews of each part of the inventory effort: statistical design, attributes collected and collection methods, data storage, analysis methods, and information products and reports. Like adaptive land management, adaptive inventory allows for improvements in methods, incorporation of new technologies, and correction of errors or false assumptions.

4.1.4 Applications and Use

The purpose of vegetation inventory is to characterize the status of vegetation resources. This characterization might include information about amount, size, and composition of vegetation and also about **site** characteristics, such as soil and geographic attributes.

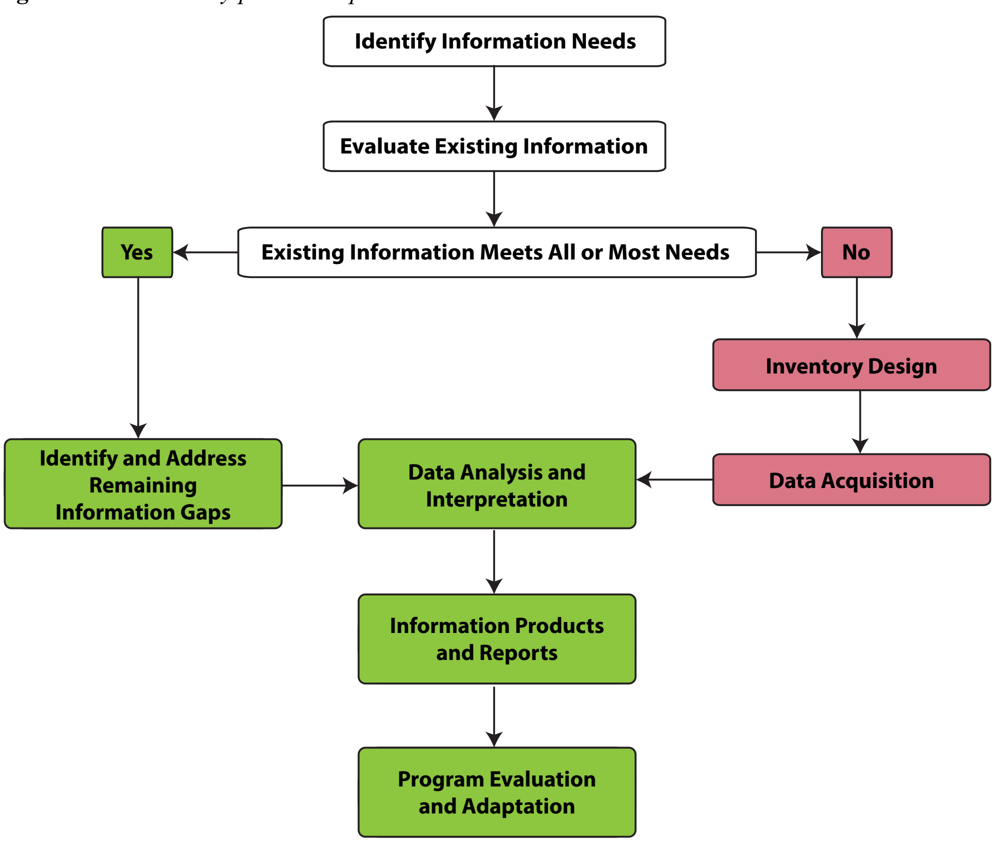
Many agency **business needs** can be met using vegetation inventory data, including the following:

1. Assessing resource conditions, determining capability and suitability of areas, and evaluating forest and rangeland health.
2. Characterizing the effect of natural disturbances or management activities on species, including threatened and endangered species and rare plant communities.
3. Describing land management desired conditions, objectives, and management opportunities.
4. Assessing risks related to invasive species, fire, insects, and disease.
5. Assessing the accuracy of maps, **remote sensing** applications, and spatial models used to inform agency decisions.

4.2 Information Needs and Existing Information

This section provides an overview of how to frame information needs, evaluate if existing inventory data and associated analysis tools exist to meet those information needs, and determine information gaps. These steps are necessary in the inventory process (figure 4-2) to determine if a new inventory will need to be initiated.

Figure 4-2.—*Inventory process steps.*



4.2.1 Identify Information Needs

The success of any inventory or analysis effort relies on clearly stating information needs, including the management or research questions that need to be answered, the stakeholders that need to be involved, and the attributes that can be used to answer the questions. This process may be best performed as a structured exercise by an interdisciplinary team. This type of approach can provide an understanding of multiple resource issues and the best use of information, achieving some cost effectiveness.

Management or Research Questions

Specific management or research questions should be developed and reflected in the objectives of an inventory effort. They will become the basis for data collection, compilation, and analysis. While developing questions, consider how they might be answered with attributes commonly collected in existing vegetation inventories. Question development will often be an iterative process as different attributes and information sources are considered. The following examples illustrate common existing vegetation questions:

- What is the current vegetation composition across my geographic area of interest? How does this composition compare with what historically occurred in this area? How do current conditions compare with desired conditions?
- How resilient to insects, diseases, herbivory or fire is this vegetation composition?
- What are the differences in vegetation conditions across land management areas, ownerships, ecoregions, or climatic zones?
- Where do noxious and invasive species occur? How is the extent of these species changing over time? What is the effect on native vegetation?

Issues and Stakeholders

Stakeholders are the groups and individuals who will benefit from the inventory data. Stakeholders may include all resource specialists involved in NEPA or National Forest Management Act (NFMA) planning and analysis, public interest groups, tribal representatives, resource managers, and research scientists, among others. Forest Service decisionmakers are key stakeholders, and their information needs often drive inventory planning and analysis. What type of information is important to all parties involved? What issues will the inventory address? Information needs should be carefully documented and each one considered in light of all the varied expressions of stakeholder interests.

Level of Risk and Needed Precision

The issues surrounding a decision or the level of risk associated with a management decision will influence the level of detail and precision required for an inventory. Decisions based on inventory information are simply based on statistical estimates with an associated confidence interval. Understanding the risk of the actual values being different from the estimates and the effect on the resource decision is an important part of identifying the precision requirements. Legal mandates or the decisionmaker's determination of risk and needed precision often determine what data to collect and keep current. Depending on the number of plots installed within an area and the variability of the attribute of interest, an inventory may or may not meet the precision needed to determine the stated criteria.

For example, existing data may indicate that critical habitat for a threatened or endangered wildlife population is directly above the minimum threshold before management action is required. The confidence interval is large and includes the threshold, however. Although the data may be sufficient in a court of law, the responsible official may decide that it is prudent in interacting with partners and public interest groups to collect more information and improve the precision of the estimates. In a similar way, the Forest Service at the national, regional, or national forest and grassland level may have requirements or policies that require additional information.

Geographic Area of Interest

No single inventory dataset meets analysis needs at all geographic levels. Rather, the inventory design must provide a valid sample for the identified geographic area of interest to allow estimates and associated measures of reliability to be derived for vegetation attributes.

For each question posed, determine the geographic level that you intend for it to address. More than one level of inventory data may be needed to address all questions posed. Do the questions require information from across the entire forest or similar administrative unit, or can information be focused on specified treatment areas or vegetation types? Can the area be subdivided into spatial subdivisions such as watersheds, ranger districts, or management areas to facilitate a more efficient inventory?

At the broad and mid levels, vegetation inventory plots should be spatially distributed across the entire geographic area of interest. At the base level, polygons of interest should be identified and inventoried individually. At the base level, the inventory data are collected only within those polygons, focusing resources where information is needed to support decisions.

Inventory Attributes

After questions have been developed, determine what attributes will answer the questions sufficiently. Many attributes in existing vegetation inventories describe vegetation composition and structure. Physical or biological attributes of the site may also be available (e.g., slope, ground cover). As an example, questions about forested vegetation condition might be answered by classifying the inventory data into dominance type, tree size class, and tree **canopy cover** class using classification algorithms applied to raw inventory data. If, for example, an assessment of habitat, such as “old growth” is needed, determine what inventory attributes are used to define and assess old growth. In the Northern Region (Forest Service Region 1), old growth is based on **habitat type** group (a **potential natural vegetation** [PNV] classification applied to each plot); old growth forest type (a dominance type algorithm applied to all trees with a 9-inch (22.9-centimeter) **diameter at breast height** [DBH] and larger); and the number of trees above a specified diameter that are a specified age or older. If these attributes are available in the inventory data or can be derived from the data, then old growth can be classified without additional inventory.

4.2.2 Evaluate Existing Information

After identifying information needs, take time to locate and review available inventory data to see if it will meet some or all of the information needs.

What Inventory Data Are Available?

For inventory data to be useful, it must be readily available using existing analysis and reporting tools. Inventory data on paper field forms that have not been converted to an electronic format or are in a format for which analysis tools have not been developed will probably not meet your needs. Electronic inventory data are readily available to the NFS in several applications. Table 4-1 provides a summary of Forest Service supported inventories and a guide to their suitability for developing information products to meet the business needs at various business-requirement levels described in section 4.1.3 and displayed in table 1-1.

Forest Inventory and Analysis. FIA provides a design-based inventory appropriate for national- and broad-level planning and analysis. Unbiased estimates and confidence intervals with a precision level adequate for management decisions can be derived for large geographic areas such as national forests (or multiple forest zones), landscapes, and ecological sections. The FIA sampling frame uniformly covers all lands, regardless of ownership or **land cover**. Therefore, forested vegetation within wilderness areas, roadless areas, and actively managed lands has the same probability of being sampled (Bechtold and Patterson 2005). FIA plots are remeasured on a 10-year cycle in the West and a 7-year cycle in the East (many eastern States have reduced the cycle length to 5 years), providing a temporally and spatially reliable dataset for monitoring changes in vegetation over time.

FIA collects data on lands that are considered to represent a forested[4] condition. Some NFS regions have worked with FIA to expand existing protocols to collect data on all vegetation types, not just those portions that meet FIA's definition of forested. This collection is currently being done in the Northern, Intermountain, Pacific Southwest, and Pacific Northwest Regions (Forest Service

Table 4-1.—*Summary of the suitability of national existing vegetation inventory protocols for developing information products to meet business needs at various levels.*

Protocol	National level (*millions of square miles)	Broad level (*20+ million acres)	Middle level (*50,000+ acres)	Base level (*< 50,000 acres)
Forest Inventory and Analysis http://fia.fs.fed.us/	**Protocol appropriate** at the national level.	**Protocol appropriate** at the broad level.	**Protocol useful for attributes; intensify number of sample units for use at the middle level.**	**Protocol not appropriate** at the base level.
Common Stand Exam http://www.fs.fed.us/nrm/index.shtml/products/fsveg/index.shtml	**Protocol not appropriate** at the national level.	**Protocol not appropriate** at the broad level.	**Protocol useful for attributes with appropriate sample design.**	**Protocol appropriate** at the base level.
Vegetation Sampling Field Guides for Rangeland Inventory and Monitoring http://fsweb.wo.fs.fed.us/rge/inventory/index.shtml	**Protocol not appropriate** at the national level.	**Protocol not appropriate** at the broad level.	Protocol appropriate at middle level **with appropriate sample design.**	Protocol appropriate at base level **with appropriate sample design.**

*Refers to map extent—see table 1-1.
Green = protocol appropriate.
Yellow = protocol appropriate with appropriate sample design.
Turquoise = protocol appropriate with intensified sampling and appropriate sample design.
Red = protocol not suitable appropriate.

[4] "…land has at least 10 percent canopy cover of live tally tree species of any size or has had at least 10 percent canopy cover of live tally species in the past, based on the presence of stumps, snags, or other evidence. Additionally, the condition is not subject to nonforest use(s) that prevent normal tree regeneration and succession, such as regular mowing, intensive grazing, or recreation activities" (USDA Forest Service 2012b:46).

Regions 1, 4, 5, and 6, respectively). These protocols, which allow for data collection on nonforested lands, are considered "core optional," available for any FIA region to use as long as resources are available for data collection.

FIA data are stored in the Natural Resource Manager (NRM) Field Sampled Vegetation (FSVeg) application, and all analysis tools and reports available in NRM FSVeg are available for FIA data. In the future, the Design and Analysis Toolkit for Inventory and Monitoring (DATIM), nationally supported inventory design and analysis tools, will be available to analyze FIA data to meet the information needs of NFS regions (see appendix F). The Northern and Pacific Southwest Regions (Regions 1 and 5) currently have their own analysis tools that use FIA data. FIA also has analysis tools available through its Web site at http://www.fia.fs.fed.us/tools-data/default.asp.

Common Stand Exam. CSE establishes nationally consistent protocols for acquiring terrestrial forested vegetation information necessary to meet site-specific information needs. These protocols have been used for forested vegetation inventory to describe vegetation composition, **structure**, and productivity in an ecological framework. The objective of CSE data is to help develop site-specific resource estimates to assess vegetation and site attributes at varying levels of data intensities and measurement **resolutions**. CSE is very flexible. Based on information needs, specific protocols and sample designs can be used to collect inventory data in an efficient manner. In addition, CSE has protocols that allow for remeasuring plots to monitor changes over time. The flexibility of the CSE protocols and existing supporting software applications facilitates the collection and analysis of a multitude of attributes to answer changing ecological questions.

CSE data are stored in the NRM FSVeg application. NRM's Field Sampled Vegetation Spatial (FSVeg Spatial) application tracks the spatial location of stand polygons and the associated plot locations that have inventory data stored in NRM FSVeg.

Vegetation Sampling Field Guides for Rangeland Inventory and Monitoring. The Rangeland Management and Vegetation Ecology programs maintain a suite of vegetation sampling protocols for nonforested vegetation. These protocols include the ocular macroplot, line intercept, cover frequency, nested rooted frequency, Robel pole, density, paced transect, macroplot, riparian greenline, riparian cross-section, and riparian woody regeneration field guides. These field guides provide sampling methods that, if applied to a statistically valid sampling design for the geographic area of interest, can contribute to a vegetation inventory.

The NRM Rangeland Inventory and Monitoring application and the NRM Geospatial Interface support Vegetation Sampling Field Guides for Rangeland Inventory and Monitoring.

Do Existing Data Cover the Geographic Area of Interest?

Look for existing data that cover the area of interest. As stated previously, FIA data are available for use at the national and broad levels and NRM FSVeg stores data at the stand level; mid-level datasets may or may not be available. In Regions 5, 6, and 9, some national forests have worked with FIA to increase the number of plots that are collected within their administrative boundaries. In Regions 1, 4, and 9, CSE protocols have been developed to be consistent with FIA protocols so that NFS oversees data acquisition and can integrate it with the existing FIA data. Check with the regional inventory specialist, forest and range management staffs, and regional ecologist to become familiar with the inventories that are available for the area of interest.

Do the Data Represent Current Conditions?

All inventory datasets have a shelf life. Vegetation is dynamic and naturally changes over time as a result of succession and from a variety of disturbance processes that affect the rate of change.

Review the date(s) of inventory and the disturbances that have happened within the geographic area of interest since data acquisition. Much disturbance information is available spatially, including harvest activities and prescribed fires (available in NRM Forest Activity Tracking System), burned area and burn severity (available in Monitoring Trends in Burn Severity), and insect, disease, and weather disturbance (available in Forest Health Protection Aerial Detection Surveys). These activities can be displayed by using the NRM Geospatial Interface. After all disturbances have been spatially depicted with the date of disturbance, the **layers** can be compared with plot locations, intensified **grid** locations, and stand polygons to compare measurement dates with disturbance dates. A field visit may be required to determine the magnitude of change.

Was It a Design-Based Inventory?

If the information needs indicate a reliable estimate of current conditions, then the estimate must be derived from a probabilistic sample. FIA provides a design-based sample for forested vegetation. Check with the CSE and NRM FSVeg **data steward** on your unit or region to ensure that the stand exams for the geographic area of interest had random placement of plots or a systematic placement with a random start. Review the plot locations within the polygon in NRM FSVeg Spatial to ensure that plots were collected throughout the stand. Although NRM FSVeg Spatial facilitates the combining of the two stands and merging their exams, performing this step usually invalidates the exam as a probabilistic sample of the combined polygon.

Were All Necessary Attributes Measured?

Thoroughly review the field manual and database guide to ensure that the necessary attributes were measured as expected. For CSE data, review the field protocols used, the sample design, and the stand folder to ensure the attributes were collected appropriately. For example, in some regions, CSE crews collect data across a subset of the entire population of trees, such as tallying trees only if they are above a minimum diameter. These CSE data would not be appropriate to use for assessing fire behavior metrics, such as a torching index, because no information was collected on small trees, which greatly influence the movement of fire from the ground to tree crowns.

If the needed attributes are not available, are surrogates available that can be used, or can the information be determined from other sources? For example, suppose that slope was not collected on the plot but fairly precise plot locations are known. Slope can be assigned to each plot by integrating **digital elevation model**, or **DEM**, information with the plot locations. In a similar way, if dominance type was not collected on the plot, then dominance type can be assigned by running the inventory data through a dominance type algorithm.

Do Enough Plots Exist Within the Area of Interest To Meet Precision Requirements?

Precision requirements for estimates are difficult to determine, but one common criterion is the level of risk the decisionmaker is willing to assume. For example, consider a decisionmaker who must feel comfortable that conditions depicted in the data would meet the land management plan guideline for a minimum of 0.5 snags per acre. If analysis of FIA data suggests there are 0.75 snags per acre, with the lower bound of the 95-percent confidence interval at 0.65, then the decisionmaker can be assured that the land management plan guideline will be met.

This example uses a 95-percent confidence interval; however, the level of precision should be commensurate with the variance of the population and the level of risk the decisionmaker is willing to assume. A 95-percent confidence interval may not always be necessary, given the variation of **natural vegetation**. It is common to use a 90-, 80-, or even 66-percent confidence interval. Increasing the sample size may be one way to achieve the desired level of precision. This approach is further discussed in section 4.3.5.

Could Information Needs Be Met in Other Ways?

If information needs do not appear to be met by existing inventory datasets, revisit the management or research questions. Could the questions be made less specific, for example, by grouping species or increasing geographic area of analysis (thus increasing the sample size if using FIA plots)?

Look for information beyond traditional inventory datasets to answer the management or research questions. Are reports, remote sensing products, maps, or published literature available that can meet at least a portion of the information needs? For example, if the question relates to the area by dominance type, then potential sources of information include statistically valid forest inventories; local, regional, or national **dominance** group maps derived from satellite data; or photo-interpreted maps. Previous studies on the area may provide some or all of the needed information.

It may be necessary to iteratively reconsider the objectives and questions posed by the stakeholders to pare down the list of attributes, generalize the questions, or consider larger or smaller geographic areas of interest. The target precision for estimates may also be reconsidered. The challenge often is that the data do not answer the question or address a decision directly or completely, but the cost of collecting desired information cannot be justified.

If possible, avoid using inventory datasets that do not adequately meet information needs simply because they are available. Always keep two things in mind: (1) If the information needs dictate using a reliable estimate of current conditions, then the estimate must be derived from a current probabilistic sample; and (2) the combination of disparate inventories does not create a probabilistic inventory across the area of interest.

4.2.3 Identify and Address Remaining Information Gaps

Given the criteria for evaluating existing inventory data, do data gaps exist? If so, are the gaps large enough that additional information is needed to meet the criteria? Is enough funding and time available to gather the additional information needed across the appropriate geographic area? Consider the following types of information gaps:

- **Spatial gaps**. The existing data do not cover the entire area of interest.
- **Temporal gaps**. The existing data are not current enough due to changing conditions.
- **Precision gaps**. The existing sample size is too small to achieve the precision required for the current analysis.

- **Attribute gaps**. The attribute(s) needed to answer the question was not measured in previous studies or was measured without sufficient detail (e.g., classes instead of continuous measurements).

Do Additional Data Need To Be Collected?

If existing inventory data are available and are sufficient to meet identified information needs, then inventory questions can be answered by skipping to section 4.6, Methods: Data Analysis and Interpretation.

If the existing data do not answer the questions fully, assess the need to collect additional data to fill the information gaps. Vegetation inventories must balance the cost of the inventory with the quality and quantity of previously collected data.

If data are not available to answer inventory questions, then section 4.3, Methods: Inventory Design, and section 4.4, Methods: Data Acquisition, provide the background necessary to begin a new vegetation inventory.

4.3 Methods: Inventory Design

The inventory design, including sample design and data collection protocols for specific attributes, largely determines the extent to which inventory data can be used for multiple purposes (e.g., analysis across large versus small land areas, answering management questions and hypothesis tests). A statistically valid inventory, designed as a probabilistic sample, can provide the user with data that can be integrated with mapping processes and is robust during adjudication.

4.3.1 Determine and Define Inventory Attributes

Review the questions posed when determining information needs to continue the iterative process of defining questions and inventory attributes (section 4.2.1). Inventory specialists and analysts should work together while framing inventory questions to reduce the risk of inconsistency between data collected and data needed for analysis. The Design Tool for Inventory and Monitoring (DTIM) provides a list of questions that may prove helpful in question development (see appendix F) and identification of the attributes needed to answer the questions. Avoid the temptation to generate large wish lists of attributes that could be expensive, marginally valuable, or logistically unobtainable. Design inventories to generate a core set of attributes that address as many stakeholder interests as is practical. Document objectives that require specific timing or need remeasurement over time. Many vegetation inventory objectives overlap and may be addressed with a multipurpose, integrated inventory. For example, a single inventory might address habitat conditions for wildlife species, attributes of watershed condition, and fuel conditions within these areas.

After you determine the attributes of interest, you then determine the population that will be sampled. At times, such as when timber is being cruised for a timber sale, trees above a certain diameter (i.e., trees that meet specific merchantability specifications) are the population. Therefore, you only sample large trees. In other cases, you may also need to assess wildlife habitat (based on live and dead trees, understory vegetation, down logs, etc.) and fuel loadings and estimate the area by habitat class. In this case, the population is the same as the geographic area of interest, within which the observation units are trees, understory vegetation, and down-woody material. A further look at just understory vegetation and its contribution to wildlife habitat is an example of a subpopulation. Subpopulation may be covered by **life form** (grass, **forbs**, **shrubs**) or by the presence of a certain shrub species.

Determine how attributes will be collected and how they will be used in data analyses and reporting. Attributes must be well defined and measurable, with collection methods that can be repeated by different observers over time and space. Some attributes may need to be measured in the field; others can be estimated by using remote sensing interpretation or calculated based on other collected data. When data are to be used in modeling, ensure all required input variables will be available (e.g., soil type, landform, and aspect) either from field data collection or by intersecting the plot locations with spatial layers.

It is important to collect the most basic or elemental level of data of vegetation attributes. To the extent possible, collect continuous rather than categorical data (e.g., measure tree diameter in tenths of inches rather than assign size classes), or measure the attributes that make up stand characteristics rather than characterizing the stand in the field (e.g., measure tree, snag, and down log diameter rather than classify the plot as old growth). Physical measurements are typically more repeatable than ocular estimates. Collected once, detailed information from a wide variety of vegetation attributes can be used in many ways for different analyses.

4.3.2 Select Protocols

After the attributes have been determined, protocols for measurement methods must be identified. Nationally accepted corporate protocols, associated inventory data, data storage, and analysis tools are available in the NRM corporate data system (http://www.fsweb.nrm.fs.fed.us/products) and from FIA. (Note: FIA data are also stored within NRM FSVeg database.) Existing protocols ideally contain the attributes of interest. These protocols have field guides that provide detailed information on how measurements are made to ensure repeatability by various field technicians and measurement tolerances that can be achieved in the field for each attribute. Furthermore, corporate software is available for (1) collecting data on portable data recorders (PDRs), (2) checking data for errors before loading into the corporate database, and (3) using data in analysis tools.

The advantages of using corporate protocols and tools are numerous. Inventories and associated analyses completed by using tested and reliable national or regional systems are scientifically sound, thoroughly documented, and defensible in court; they have training materials, QA and QC standards and procedures, existing databases, and analytical tools already reviewed and available for use. Developing new protocols and different comprehensive inventory systems for a district, forest, grassland, or region will require a huge investment of time and resources and probably is not sustainable given diminishing budgets.

In a similar way, using existing work force or contract work force for data collection according to existing protocols can enhance efficiency. The availability of crews outside of the work unit may help determine which protocol to select. For example, in Regions 5, 6, 8, and 9, the NFS regional FIA coordinator has worked with the appropriate FIA regional contact to pay FIA to collect all the data, load it into the FIA database (the National Information Management System, or NIMS), and either have FIA produce reports or have the data migrated into NRM FSVeg so the region can produce reports (see section 4.4.1).

Table 4-1 provides information about corporate protocols available to NFS and the associated geographic level over which the protocols are generally used. Table 4-2 provides information about the various protocols and associated analysis tools. The following sections of 4.3 will further help determine which protocols to use for data collection and, ultimately, for data warehousing and analysis.

Forest Inventory and Analysis. FIA has core attributes and associated field procedures that are consistent and uniform across all FIA units. The standards, codes, methods, and definitions are documented in Phase 2 Measurement Field Guide, Version 6.0 (http://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2013/Core%20FIA%20P2%20field%20guide_6-0_6_27_2013.pdf). These core attributes are the framework for regional FIA programs in the Northern, Southern, Interior West, and Pacific Northwest FIA regions. In addition, the field guide defines *core-optional attributes*. Core-optional attributes may or may not be collected by an FIA region but, if the attribute is collected, the procedures defined in the manual are specifically followed. Some FIA regions collect a subset of the core-optional attributes throughout their region, while some attributes are collected only within a State or on lands that are administered by certain agencies (such as nonforest information collected on all plots within the NFS Region 1). In addition, FIA regions may measure attributes called "regional add-ons." A specific FIA region defines these attributes. Regional add-ons are documented in each FIA region's field protocols, which comprise all core attributes plus core-optional attributes and regional add-ons that are collected within the FIA region. The national and regional guides are available at http://www.fia.fs.fed.us/library/field-guides-methods-pro.

Table 4-2.—*Summary of national existing vegetation inventory protocols and associated databases in which data are available.*

Inventory data	Database		Analysis tools*	
	Core	Core optional	Core	Core optional
FIA	FIADB, NRM FSVeg	NRM FSVeg. Depending upon the attribute, may or may not be available in FIADB	FIA online tools, NRM FSVeg reports and utilities, Regional tools available for R1 and R5, DATIM	NRM FSVeg reports and utilities, DATIM, Most data not available in FIADB for analysis
Common stand exam	NRM FSVeg		Analysis tools and utilities available through NRM applications including NRM FSVeg, NRM FSVeg Spatial, and Geospatial Interface. Additional analysis tools are available for each NFS Region.	
Vegetation sampling field guides for rangeland inventory and monitoring	NRM Rangeland Inventory and Monitoring, NRM Inventory and Mapping		NRM Geospatial Interface. Additional analysis tools are available such as Microsoft Office Excel and Access and ESRI ArcMap applications and extensions	

*Available analysis tools depend on which database is used for warehousing.

Core attributes, in general, are tree and site measurements. Core-optional attributes are additional tree measurements and measurements of understory vegetation, down-woody material, and protocols for collecting core attributes on nonforested areas. Regional add-ons are attributes or measurements that are specific to a certain region, such as habitat type in the Interior West FIA region and the hectare plot for large trees in a portion of the Pacific Northwest region.

Common Stand Exam. CSE provides various protocols for collecting site, tree, vegetation, down-woody material, and surface cover. The examination level indicates the scope and range of the information collected for tree, vegetation, down-woody material, and surface cover. Scope is the breadth of information collected and range is the precision of information collected. Every exam has minimum criteria that are required to be collected; additional attributes are required, depending on exam intensity. The criteria used to sample the various attributes are documented on the Sample Design Form. The inventory planner has quite a bit of flexibility in choosing what attributes will be collected and the sample design for collecting the data. For documentation on the protocols available, how to access the data in NRM FSVeg, and analysis tools available, see the CSE and NRM FSVeg User's Guide available at http://www.fsweb.nris.fs.fed.us/products/FSVeg/documentation.shtml. All NFS stand exam data are collected by using CSE protocols. NRM FSVeg has recently introduced inventory and monitoring protocols, which are an addition to the existing stand exam protocols. These protocols allow for collecting monumentation information on each plot and also azimuth and distance of each tree from plot center to allow for remeasurement over time.

Vegetation Sampling Field Guides for Rangeland Inventory and Monitoring. The Rangeland Management and Vegetation Ecology programs maintain a suite of vegetation sampling protocols for nonforested vegetation. These protocols include the ocular macroplot, line intercept, cover frequency, nested rooted frequency, Robel pole, density, paced transect, macroplot, riparian greenline, riparian cross-section, and riparian woody regeneration field guides. These field guides provide sampling methods that, if applied to a statistically valid sampling design for the geographic area of interest, can contribute to a vegetation inventory. The NRM Rangeland Inventory and Monitoring application and the NRM Geospatial Interface support Vegetation Sampling Field Guides for Rangeland Inventory and Monitoring.

Use existing protocols, databases, and analysis tools if available. If the area of interest is mid level or larger, it may be beneficial to use existing FIA data and add plots, either using FIA methods or modifying CSE protocols to mimic FIA. Each of these strategies will be further explored throughout the rest of section 4.3.

At times, existing protocols may not meet specific inventory requirements or it is desired to use new inventory protocols. If that is the case, then consider whether the differences in methodology and information collected are worth the effort. Determining data collection methods, data warehousing, and how to tie the attributes to existing data make this strategy very time consuming and expensive to develop and maintain over time.

Based on your geographic area of interest, start thinking about which protocols may best suit your needs. Further operational needs will be discussed throughout this section. When choosing FIA protocols, you must work with the NFS regional FIA coordinator, who will work with the FIA region that oversees the geographic area of interest. When choosing CSE protocols, work with the NFS regional inventory specialist and NRM FSVeg data steward. When choosing the range vegetation protocols, work with the regional vegetation ecologist or range specialist, the regional inventory specialist, and NRM Rangeland Inventory and Monitoring data steward.

4.3.3 Determine Sampling Scheme

A key decision when choosing a sampling design is how to select a representative sample of the population of interest. When budgets are extremely low, some inventories resort to purposive sampling, in which the inventory planner selects plots that appear to be typical for the conditions of interest, such as forest types. This approach cannot be statistically defended during adjudication. No measures of the reliability of the estimates can be formed, thus they are not defensible. To be a statistically defensible sample, every unit (e.g., acre, tree) within the population of interest must have a positive and known probability of selection. No statistically defensible inference may be made for collecting sample units having zero probabilities of selection (i.e., the unsampled portion of the target population). An example of a violation of this rule is moving plots away from population boundaries. Some common approaches to sampling are random samples (either randomly placing a grid on the population or taking a random sample of **points** across the population) or **stratified random samples** (in which plots are randomly placed within each stratum).

It generally is impossible to combine multiple inventories with different designs and objectives into a single set of data that meets the assumptions needed to qualify as a statistical sample. For example, a stand exam is a statistically valid sample across the polygon in which it was collected. In general, however, stands that are sampled are purposively selected for operational reasons. Therefore, multiple stand exams cannot be combined to derive estimates and associated confidence intervals for an analysis area unless all the stands within in the area have stand exam data that is representative of current condition. Without collecting a statistically valid inventory within the analysis area (geographic area of interest) the quality of the estimates (the bias and precision) is unknown. Unless the stands within an analysis area are randomly selected, they should not be combined. Furthermore, it is never appropriate to combine stand exams (or subsets thereof) from neighboring polygons to falsely represent an exam for a newly delineated polygon.

The optimal inventory sample design depends on identification of the population of interest. After the population of interest (i.e., the full set of all possible sample units) is known, a design-based, probabilistic sample can be designed and a small portion of the population can be randomly selected for sampling, with a known probability of selection. The population could be a stand, all stands within an analysis area, a national forest or grassland, or the entire landscape in which the forest or grassland sits. The population forms the first reporting unit—the unit for which estimates based on the sample are produced. The size and complexity of the population (e.g., variability of species, age and size classes, down-woody material) will influence the design of the inventory; a large homogenous population requires a different sampling intensity than a smaller or more heterogeneous population.

A fundamental rule in sampling theory, on which design-based inventories are based, is that every sample unit must have a known and positive probability of selection. Using a probabilistic design, it is possible to calculate, for example, per acre estimates of vegetation attributes for populations of interest and to understand how reliable those estimates are. Probabilistic (random) sampling of a population generates unbiased information about the population, including means and error estimates of the attributes of interest. By using a probabilistic sampling design, you can measure attributes of selected individuals of a population and infer results to the entire population. In contrast, if the location of a sample unit (i.e., the plots that make up an inventory) is selected based on the judgment of the observer (or inventory planner), then the selection is said to be purposive (nonprobabilistic) and is not random. Nonrandom sampling does not meet the underlying statistical assumptions of statistical sampling and, therefore, the reliability of the estimates is unknown; it simply provides information about the vegetation at the plot location or across the summarized plot locations.

Two common approaches are used to locate plots within the geographic area of interest: (1) equal probability based or (2) stratified random.

Equal Probability-Based Design Options

The most flexible approach is an equal probability-based design option, in which all sampling units (plots) within the geographic area of interest have the same probability of selection and, therefore, the same weight in analysis. The estimation of means, totals, and their variances follows standard statistical formulas and is readily available in corporate tools and analysis tools available within Microsoft (MS) Excel. At the broad level, the FIA grid of plots is an example of an equal probability based sampling scheme. Plots within a stand polygon are an example at the base level.

The most familiar placement of sampling units is **simple random sampling** (Gregoire and Valentine 2008). Plot locations are randomly chosen within the geographic area of interest until the desired number of samples is chosen. Through random chance alone, however, the spatial distribution of plot locations may lead to a nonspatially balanced set of plots. At the broad to mid levels, this spatial distribution can lead to unbalanced sample sizes when subdividing the plots by various attributes—that is, some forest types might be sampled a little more or less intensively than expected from their respective prevalence. At the stand level, randomly placed plots may not result in plots across the entire stand.

A common alternative is to use **systematic sampling** (Cochran 1977), in which a grid is randomly placed over the study area. Each point on the grid represents the same number of acres within the geographic area of interest and ensures a spatially balanced sample across the population (assuming that the population does not have any pattern that matches the grid). This method is commonly used for locating plots within a stand. FIA uses a hexagonal grid (Bechtold and Patterson 2005) and goes one step further by randomly locating the plot in each cell.

It can be challenging to find a grid size that results in exactly the desired sample size, but computer applications are available that assist with this challenge. Although systematic sampling generally improves the precision of the estimates, simple random sampling variance estimators are often used to analyze the data, which generally overestimates the true variance (i.e., using simple random sampling variance estimators is a conservative and risk-adverse approach).

Because of the development of sophisticated computer programs, methods are used to ensure that plots are located in a spatially balanced manner. In general, this approach produces plots that have the same underlying statistical assumptions of random sampling.

Stratified Design Options

At the mid to broad levels, one drawback to a random sample across a large geographic area is that common types have large sample sizes and rare types have few or no samples. A solution to this problem is **stratified random sampling**. Stratified random sampling (Cochran 1977) is an approach that develops strata based on grouping similar entities, therefore reducing uncertainty in estimates for key attributes of interest within the strata and subsequently reducing the sample size to meet the precision requirements. To be worth the effort and risk, stratification requires information about each sample unit (e.g., area, **pixel**, stand, and polygon) in the population to identify homogeneous strata (groupings of similar pixels or stands or polygons) for the key attributes of interest. This sample design focuses on minimizing the variability within strata and maximizing the variability among strata. If interest is in the individual stratum estimates (e.g., all ponderosa pine stands), then maximizing the variability between strata is less important.

With stratified sampling, sample sizes are specified in advance by stratum to maximize efficiency. A stratified random sample relies on specific, predefined geographic areas, which can each have the same (proportional allocation) or different sampling intensities. Different intensities result in different plot weights across the various strata. Although these stratified sampling approaches can be successful, problems can develop over time if the strata boundaries change. If strata that are used to allocate the sample change over time, then the selection probabilities can also change over time, greatly complicating analysis (Schreuder et al. 1993b). An example is choosing a sampling scheme based on existing vegetation condition (e.g., dominance type, size class, and canopy cover). Because vegetation is dynamic and disturbance processes can change membership in these classes very quickly, a sampling strategy developed based on vegetation maps of these attributes may quickly become obsolete. To avoid this problem, choose permanent strata boundaries like watersheds or ecoregions, use proportional allocation of samples to strata, or use a systematic or random sample and apply poststratification.

If the goal of an inventory is to generate acceptably precise estimates of levels of rare attributes, then a uniform intensification of an existing sample might not be the most efficient strategy. A design that is optimized to inventory rare vegetation might be a better approach. For example, in the intermountain west, woody draws are rare, linear features that are relatively permanent. Intensification of the FIA grid may not sample this vegetation sufficiently. It may be more efficient to set up a sample design that specifically targets and samples these features, such as using a much finer grid in the rare stratum.

After the strata are identified and the total desired sample size is determined, the sample must be allocated to the individual strata. Five common approaches are used:

1. Allocate equal sample sizes to each stratum. Although this approach is not efficient for estimating totals across strata, it treats the strata means equally and is sometimes used to provide data for modeling purposes.
2. Use proportional allocation, in which the total sample size is allocated according to the size (weight) of each stratum. This approach results in an equal probability sample both within and across strata and is generally recommended for monitoring over time. This is less risky than alternative approaches.
3. Use Neyman allocation, in which samples are allocated proportionately to the product of the stratum weights and the stratum standard deviation for the key attribute of interest (Cochran 1977). This approach results in the most precise estimates of the population totals.
4. Use optimal allocation, in which both stratum sample costs and variability are considered, resulting in the most cost-effective allocation. When sampling unit costs are identical across strata, then optimal allocation is equivalent to Neyman allocation. Disadvantages of Neyman or optimal allocation are that they are optimal for a single attribute and that the selection probabilities become complicated if stratum areas change over time (Schreuder et al. 1993b).

5. Select your sample units with unequal probabilities. This approach is the most complicated approach and is vulnerable to bias, perhaps considerable bias, if analyzed with an inappropriate estimation algorithm. Unbiased estimates require a statistical estimator that properly accounts for the unequal selection probabilities. Furthermore, the exact selection probability must be known to apply the appropriate estimator, and this requires sufficient documentation, database management, and dependable expertise now and in the future.

Double sampling for stratification (Cochran 1977) is an alternative for when stratum sizes cannot be known with certainty but can be estimated by sampling. For example, for decades FIA stratified a grid of points on aerial photography to estimate stratum weights (Bickford 1952). Sample allocation and estimation of the totals are the same as for stratified random sampling. Samples are chosen as a subsampling of the points. The variance estimator, however, includes a component to account for the fact that the stratum weights are estimated from a sample. With the increased availability of satellite imagery and automated classification software, the use of double sampling for stratification is diminishing for broad-level and mid-level inventories but still may be relevant for base-level inventories with features that are much easier to classify by photo interpreters, such as in range or for special status species.

Complex inventory designs can improve efficiency, but analysis of the data often requires assistance. It is very likely that complex designs and simple statistical estimators do not share the same assumptions; therefore, standard NRM and off-the-shelf analysis tools may not be sufficient. Using inappropriate estimators causes unintentional bias in statistical estimates, and that bias is nearly always large enough to misdirect data-driven decision-making processes. When implementing complex designs, inclusion of a qualified expert in sample-survey methodology and analysis greatly reduces the risk of inappropriate design, implementation, and analysis. The National Inventory and Monitoring Applications Center (NIMAC; see http://www.nrs.fs.fed.us/nimac/) develops leading edge forest ecosystem monitoring methods and tools to help organizations monitor forests and grasslands, and NIMAC can provide advice within limits of their resources. Other sources of help are statisticians, researchers with expertise in sample design, or university faculty with quantitative backgrounds.

Considerations for Sampling Polygons

Selecting polygons to sample instead of points poses additional considerations to produce statistically efficient estimators. A number of choices of how to draw a scientifically credible sample exist. You should consider the distribution of the primary attributes across the breadth of polygon sizes. If little or no relationship exists between magnitude of the attribute(s) of interest and polygon size, a **simple random sample** of polygons, although simple to execute, will not be a very efficient design. In general, the larger the polygon, the larger the attribute(s) of interest will be within the polygon. This information is not taken into account in a simple random sample of polygons.

If the areas of all polygons within your population are known, such as the area of every stand, a more efficient design will be to select polygons in proportion to their areas. This approach is easily accomplished by creating a list of the cumulative area. For example, if you have three polygons that are 5, 20, and 100 acres (2, 8.1, and 40.5 hectares) in size, a cumulative list would be 5, 25, and 125. Now draw a random number between 1 and 125. If the number is one, two, three, four, or five, then the 5-acre (2-hectare) polygon will be sampled. If the random number is from 26 through (and including) 125, then the large 100-acre (40-5 hectare) polygon is sampled. The large polygon is 20 times more likely to be sampled as the 5-acre (2-hectare) polygon; hence, this approach is an example of probability proportion to size sampling (Cochran 1977, Stehman and Overton 1994). This approach is a special form of unequal selection probabilities because large polygons have a higher probability of being selected for sampling than small polygons.

The analyst must use a statistical estimation algorithm that is appropriately designed for unequal selection probabilities. Otherwise, the estimates will be unintentionally biased, and the bias can be large. A similar mistake can occur if a simple random sample of polygons is selected. An estimator that assumes a simple random sample of polygons will weight large polygons the same as small polygons, which would make the simple random sampling estimator biased when used to estimate total area by forest conditions and applied to a sample so chosen. If the inference metric is number of polygons, not the area covered by a set of polygons, then the estimator for simple random sampling is unbiased. The point is that complex sampling designs require appropriate expertise on the ID team; otherwise, estimates can be unintentionally biased, and the bias can be large enough to distort informed decisions.

4.3.4 Determine Sampling Units

The sampling design requires a mechanism that objectively determines how to select and measure attributes of interest within each sample unit. Sampling involves collecting information about the population of interest from a subset of the total population so that you can make inferences about the entire population based on this sample. The subset of data is collected at predetermined points. At each point, measurements are taken on your population of interest. Think about the population of interest as a union of the subpopulations of interest, which may be trees, understory vegetation, and down-woody material. The way that the subpopulations are selected and the attributes of interest are measured is the sample unit. The basic concept is to characterize the point by observing the area surrounding it. This surrounding area is called the support region (Stehman and Czaplewski 1998).

Sampling Unit Options

Many options for sampling the various subpopulations of interest are available, including fixed radius plots, variable radius plots, and point intercept and line intercept methods. In the field, a plot ultimately may use multiple sampling unit methods. For the methods described in the following paragraphs, all distances are **horizontal** rather than slope distances.

Fixed area plot sampling samples all items (trees, cover and presence of nontree vegetation, down logs, etc.) that are inside a fixed area. It is most common to have the fixed area be a circle with fixed radius. Rectangles of a predetermined length and width, referred to as belt transects or strip plots, can also be used. This method is commonly used for collecting data on small trees. It is also used extensively, although on a much larger plot, to collect information on large trees. Fixed radius plots are commonly used if the plots will be remeasured over time.

Variable radius plot sampling (Gregoire and Valentine 2008, Schreuder et al. 2004) records all objects (usually trees) that appear larger than a specified angle defined by an angle gauge that the field crew holds at arm's length from a fixed point or defined by an optical device viewed from plot center. The tree is usually assessed at breast height (4.5 feet or 1.37 meters above the ground), particularly if the interest is in basal area. Trees are selected proportional to their cross-sectional area at the sighted point (which is approximately the diameter). Because the trees are selected proportional to the square of diameter, a simple count of those selected multiplied by a known constant, directly related to the specified angle, gives an estimate of the total basal area in the forest. This method is applicable beyond the traditional uses for volume estimation. Any attribute of interest that is related to the basal area of the tree can be efficiently sampled with this method. Variable radius sampling is an efficient tree selection method to use if you are interested in deriving volume, basal area, or old growth estimates. An example of a nontraditional application is to sample rare fungi where the probability of a tree being a host is related to the size of the tree, the larger the tree, the greater chance of the tree being a host. Variable radius plots generally are not used for tree selection if plots are going to be remeasured over time because of the increased measurement and estimation complexities.

Sampling with lines (transects) and points or **vertical** lines extending from the line or the vertical plane is a common way to select and sample many attributes that are not related to selecting trees. The two methods discussed here are suitable for use with plots that will be remeasured over time because the beginning and end of the transect can be monumented.

The *point-intercept* method uses a transect of fixed length and a set of sample points at fixed distances along the transect. At each point, the attribute found beneath the point on the ground is sampled. Percent cover of the ground surface, by specified cover categories, can be calculated by dividing by the total number of plots collected.

A common extension turns the points into vertical lines. This approach is generally used to sample the vegetation above the ground that is intersected. Oftentimes the presence of grasses, forbs, shrubs, and associated attributes are collected; cover by life form and cover by species can then be calculated. In general, this method is not used for shrubs that are expected to grow higher than 3 feet (1 meter) because the vertical line can be difficult to project higher vertically.

The *line-intercept* method uses a transect of fixed length and samples all items that intersect a plane that extend vertically from the transect. The rangeland and vegetation ecology national programs maintain a protocol for line-intercept sampling to measure species abundance based on canopy or **foliar cover**. This method is also commonly used to collect down-woody material using the protocol for Brown's Transects (Brown 1974, Brown et al. 1981) and information about shrubs and trees.

For down-woody material, the number of pieces is counted within specified diameter classes. For pieces larger than the minimum diameter (e.g., 3 inches [7.6 centimeters]) at point of intersection, additional information about the soundness of the log is recorded. This information is then used to calculate tons per acre of fuel loading. If large-end diameter and length of log is added to the down-log measurements, pieces per acre and volume per acre, by diameter class, of down logs can also be calculated. This approach makes for an efficient method when fuel loadings are needed to understand potential fire behavior and the prevalence of large logs is needed for wildlife habitat characterization.

Tree and shrub canopy cover, cover by species, and cover by life form by height class can also be measured by using the line intercept method. For example, when measuring tree canopy cover, the length of the transect that is covered by the vertical projection of the canopy of trees is recorded. The percent canopy cover is simply the sum of lengths divided by the length of the transect. If accurate tree canopy cover estimates are needed, this method should be used.

Determining the Size of Each Sampling Unit

The inventory planner must understand the different effects various sampling techniques have on statistical estimates for the attribute(s) of interest. In the general case, the sample design used in the field is a combination of various sampling protocols colocated at a shared plot center.

The larger the area observed, the more variability is captured within the plot, thereby reducing the variability between plots. If the plot is too large or the transect too long for the support region it is sampling, however, too much time will be spent collecting data that ends up being redundant. Presampling to determine optimum plot size, selecting basal area factor (BAF) for the prism, or determining transect length can save crews a lot of time in the field. When setting up monitoring plots that will be revisited over time, take time presampling to determine plot sizes and transects lengths; these presampling determinations will influence how quickly changes can be detected over time. The following paragraphs provide several examples.

Small trees. Quite often in forest inventory, small trees less than a certain diameter are collected on a fixed radius circular plot. The size of the plot is based on the prevalence of small-trees in the area of interest. For example, if all trees less than 3 inches (7.6 centimeters) DBH are being tallied on a fixed radius plot, a plot that is too small (e.g., 1/1,000 acre [.4/404.7 hectares]) may select very few small trees therefore not providing enough plots with samples to derive meaningful estimates about regeneration. Very large plots could take an exorbitant amount of field time measuring too many small trees.

Snags. When using variable radius sampling, generally choose a BAF factor that yields about five to seven trees. If you are trying to derive sound estimates of large snags, however, which are rarer features, a different BAF may need to be selected for sampling dead trees than live ones.

Fuels. Another example is the lengths for Brown's transects. In general, the population of down-woody material is subdivided into three mutually exclusive diameter classes (at the point of intersection with the transect) and three different transect lengths are used. The shortest length is used for the smallest diameter class and the longest length for the largest diameter class.

For stand exams, rules of thumb, or standards, are used for choosing a BAF factor for large trees and an appropriate fixed radius plot size for small trees that work well for the local vegetation.

When evaluating multiple attributes, the design for each colocated subplot size can be altered so that the precision requirements for the key attributes of interest can be achieved without oversampling one while undersampling another. After the sampling unit is determined, it needs to go into the inventory plan, be well documented in the field protocols, and stay consistent for all the plots within the inventory.

FIA has a national sampling method that is used on all their plots (figure 4-3). CSE and the rangeland program offer a more extensive selection of sampling units that can be chosen to meet your information needs.

Plot Design

Because all FIA regions collect data in a consistent manner, the sample design and associated protocols are consistent and remain the same over time and across all units. When using CSE or NRM Rangeland Inventory and Monitoring protocols, many more options are available for the final sample design, which include all the methods listed in the sampling units section of this guide.

If plots are spread out across a large geographic area and travel time between plots is long (such as in the case of FIA plots), a cluster of subplots may be collected at each point. For example, the FIA plot is composed of four, 1/24-acre (0.4/9.7-hectare) subplots within a 1-acre (0.4-hectare) cluster plot (figure 4-3). Subplots are defined by the size (length or area and shape), number of subplots per plot, and their (fixed) spatial arrangement. As the size, number of subplots, or the distance between subplots increases, the variance of the resulting estimates decreases, but the cost of sampling increases, so the inventory planner must evaluate these tradeoffs (Scott 1993). Large distances between subplots spread out mean that clusters are less likely to fall within a single stratum, thus complicating stratified estimation. Cluster plots require appropriate statistical estimation algorithms to produce unbiased estimates of population attributes and precision (e.g., variances), thus increasing risk of unintentional methodological mistakes.

The plot design optimization approach used by Scott (1993) was used to develop the FIA plot design, which is an example of multiple colocated subplot sizes, with different numbers of subplots, spatially distributed around a center point. Although a plot with multiple subplots is often referred to as a cluster, cluster-sampling estimators (Cochran 1977) do not necessarily apply if the subplots are in fixed locations rather than random samples within the cluster area (primary sampling unit).

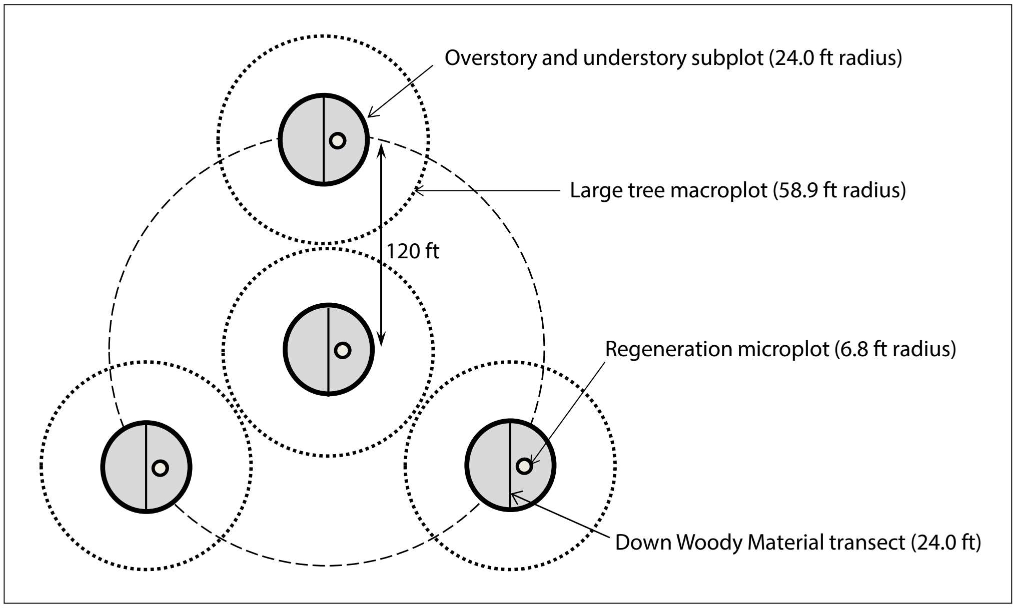
For population estimates, many small plots, in general, are more efficient; however, if the sample elements, such as the tree information collected on the plot, are used to classify the tree data into an existing vegetation classification, then larger plots may yield more accurate classifications. For example, a list of sampled trees from a very small plot in a mature stand might be dominated by seedlings, which might cause a quantitative classification algorithm to misclassify the mature stand as a seedling stand because, by chance, no large trees were sampled on the small plot (Williams et al. 2001). Larger fixed-radius plots may be more appropriate if modeling relationships between ground observations and satellite imagery (depending on the pixel sizes), or if characterizing larger trees.

If intensification requires several times as many plots, then a single plot at each point may be a better strategy than a cluster of subplots. Some regions, when increasing the number of "FIA-like" plots have reduced the number of subplots and sample more plots per day. For example, Regions 1 and 4 collect only one subplot when they intensify the grid. If the base FIA plots are integrated with the intensified grid data, then the number of FIA subplots must also be reduced to match the number of subplots on the intensified plots at the time of analysis.

In a similar way, for stand exams and for other inventories when the density of plots is high enough that multiple plots can be visited within a day, a single subplot at each sample point is used.

All FIA regions collect data consistently, which ensures the sample design and associated protocols are consistent and remain the same over time and across all units. When using CSE or Rangeland Inventory and Monitoring protocols that are available from NRM, many more options are available for the final sample design.

Figure 4-3.—*Example of a FIA plot design showing different subplot types, sizes, and spatial arrangements.*



Sampling at Boundaries

Sampling at population and other boundaries requires special attention. As plot size or the number of subplots within a cluster plot increases, so does the probability that the plot will cross multiple boundaries, such as forest/nonforest, different forest types, or structure classes. If inventory data are used to estimate the area in each of these classes, then the value at plot center, the proportion of subplot centers, or the field mapped portion of the plot can be used to estimate the proportion of the population area in each class. FIA has chosen to use this third option that maps the condition boundaries within each subplot to estimate the condition proportion within each plot (Bechtold and Scott 2005). All three methods can produce unbiased estimates of area by class. Estimates of other plot attributes, however, such as tree volume, by these area classes differ by method (Birdsey 1995). For example, the plot center may be in a recently planted stand, but the plot includes some of an adjoining mature stand. Therefore, the estimates of volume by stand structure class will include large volume for the regeneration class. This problem is reduced by using subplot centers to assign land use to the trees on the subplot. The problem is eliminated by using FIA's condition mapping method, however, it is challenging due to the difficulty of drawing boundaries between indistinct areas.

Various methods can be applied when inventory plots cross-population boundaries. FIA uses the approach in the previous section and then adjusts for all portions of plots that are outside the population (or denied access or were too hazardous to measure; Scott et al. 2005). Another approach is to use the mirage or mirror reflection method (Gregoire 1982) that adjusts for the reduced probability of sampling trees near the edge by mirroring sample points near the boundary so that trees can be selected again from the point outside. This approach results in an unbiased correction. It can also work for trees in square corners. If you know the tree coordinates and the boundary location, you can perform the calculations regarding which trees get double weight without having to go outside the stand. This method works well for a plot with no subplots. In the case with multiple subplots, an alternative is to use the walk-through method (Ducey et al. 2004), which is an analog to the mirage method. Some other approaches can lead to biased results, such as moving the plot into the population or condition (underrepresents edge conditions) or ignoring edge (underestimates the population totals). The magnitude of potential problems increases as the perimeter to interior area also increases. Areas that are highly fragmented by ownership patterns or by strata boundaries have a higher degree of edge issues as compared with contiguous areas that are relatively compact.

Determine How To Deal With Missing Data and Sample Locations

For mid- and broad-level inventories, the number of field sample locations is often less than originally planned. Hazardous access routes, hazardous plots, denial of access to plot locations, or unknown reasons for lack of data can all decrease the number of sample sites. Options for data collection in these situations range from simply accepting a lower number of sampling locations to replacing the missing locations with new ones. Replacement techniques are not without controversy and most depend on assumptions. Theoretically, the location that you cannot visit represents a proportion of the landscape where you have no information. The following paragraphs describe four common approaches, with their strengths and weaknesses.

1. Do not replace the plot. Report the population proportion (and its variance) for which you have no information. This option does not rely on any assumptions and is the most appropriate method if you have absolutely no information on the missing plot location. Although this approach is very defensible from a theoretical perspective, many people find this option unsatisfactory, especially if their goal is to estimate a quantity of the entire population.

2. Assume that the missing plot has characteristics of any random spot on the landscape and that other plots in your sample represent it. Simply adjust the number of plots in your sample to account for only those that have been visited and calculate the mean and variance as usual. Because the underlying assumption is that the nonsampled location is similar to other sampled locations, the estimate of the mean and variance of the population will be unbiased. Of course, if your assumption is false, say for plots that are hazardous to access that may have atypical vegetation, then your estimates for the population will be biased.

3. Create categories, or bins, using ancillary information, and assign sampled locations to those bins. Then, determine which of those bins the missing plot belongs to and randomly draw a plot to represent the missing plot location. This method is called *single* ***imputation*** and slightly underestimates the variance. Large surveys such as the United States and Canadian Census use sophisticated variations of this method (Rancourt 2001). The advantages are that you will have a complete dataset as originally designed. The disadvantage is the considerable setup effort necessary to create these bins and to select the replacement data, which may be prohibitive for small projects.

4. Replace the plot with another one in the same general vicinity. The concept behind this strategy is that locations relatively close to the intended location share similar vegetation. Some of the spatially balanced techniques in the previous section can easily be adapted to have a spare plot available for the field crew. The advantages are that you have a full dataset and it is easy to implement. This method will produce unbiased estimates if the reason for the missing data is not related to the size, composition, and structure of the vegetation that is at the missing plot location.

With the exception of the first technique, all these techniques depend on some information at the missing plot location. They substitute data from other locations for the missing plot. When using these techniques, think about the causes for the missing data. If it is purely a random event, then the methods described in the last three items will produce approximately unbiased estimates. The biggest danger would be in situations in which hazardous conditions exist and substituting plot data from easily accessible locations may bias the results. Similarly, if access is denied to an area for a reason that is related to the management of that location substituting plot data from an area with different management may bias the results.

4.3.5 Determine the Number of Plots To Meet Precision Needs

If you are evaluating an existing inventory, you can determine if the number of plots sampled meets your precision needs for the attributes of interest. It is difficult to create or inherit an inventory in which every single attribute meets the desired precision. The inventory planner, working with resource specialists, may need to determine those attributes that are most important and should be considered when determining the number of plots. The target precision for estimates may be reconsidered to control both the cost and the size of the sample. If the objectives or precision of the results cannot be met within the time and cost constraints, then other alternatives to the inventory must be investigated. It might be better to have no inventory than a cheap inventory that has little value.

Determining the number of plots needed within the geographic area of inference depends on how variable the attribute(s) of interest are. As discussed in 4.3.3, delineating various strata within a watershed or having thematically accurate stand delineation at the stand level reduces the number of plots needed to derive reliable estimates. The number of plots needed in a sample depends on how precise of an estimate is needed. Although funding is typically the primary limiting factor, precision constraints or targets should be set to ensure that sampling can produce estimates with sufficient precision to allow for natural resource management decisions to be made. Precision requirements typically are stated in terms of the confidence intervals for the estimates (sometimes expressed as sampling error) and in terms of the confidence level (e.g., 95 percent).

Estimated totals from individual reporting units are summed for estimates for the population as a whole. Because precision is influenced more by sample size than by the area of reporting unit (Czaplewski 2003), creating more subdivisions of the population will generally require more sampling units (i.e., plots) to achieve a given precision level for each subdivision.

Precision requirements are difficult to determine, but one common criterion is how risk averse the decisionmaker is (section 4.2.2). For example, if a confidence interval is plus or minus 10 percent of the estimate with a confidence level of 95 percent, then if a large number of similarly designed inventories were implemented, 95 percent of the confidence intervals generated would contain the true value; thus we would not capture the true value 1 out of 20 times. Given that statement, does the decisionmaker feel comfortable implementing a management activity?

For example, a wildlife species requires at least 2 snags at 9 inches (22.9 centimeters) DBH or larger per acre to meet habitat needs. Management originally funded collecting 20 plots within the watershed of interest. Analyzing the data showed that 25 plots were needed, however, to have the lower bound of the 90-percent confidence interval greater than 2 snags at 9 inches (22.9 centimeters) and larger per acre. Is collecting more information justified? The inventory planners must work with managers and stakeholders to weigh the options for balancing the precision desired (to avoid negative consequences) with the associated inventory costs. The decisionmaker and data analysts should be involved in determining the targeted precision for the results and how they will be calculated.

The simple random sample size formula is—

$$n = \left(\frac{t\,CV}{E}\right)^2$$

where t is the level of confidence, *CV* is the coefficient of variation, and *E* = error. In general the coefficient of variation (standard deviation divided by the mean) is available from presampling an area or using data from a stand or area that has similar characteristics for the attribute of interest. For an indepth discussion about how to calculate sample size, see chapter 2 of the Natural Resource Information System (NRIS) FSVeg/CSE User Guide (USDA Forest Service 2012a).

A number of reporting tools are available to help calculate the coefficient of variation, including FIA analysis tools (http://www.fia.fs.fed.us/tools-data/default.asp) and National NRM FSVeg Reports for CSE data. The DATIM (see appendix F) can help with determining the needed sample size given the variability of the underlying FIA data. Some NFS regions have additional tools or designated inventory and monitoring experts to assist with design. For example, Region 1 has the Intensified Inventory Sample Size Calculator (Berglund and Leach 2006), which is an MS Excel spreadsheet that uses the variability observed in an existing dataset to investigate the result of various intensification strategies on confidence intervals around attribute estimates. It is designed as an iterative tool to investigate a range of confidence levels, given various resolutions of plot density (i.e., sample sizes), to help choose a meaningful number of plots to install within the geographic area of interest. The tradeoffs between precision and cost can be evaluated by iteratively altering the constraints to identify the optimal design. Region 1 also has an MS Excel macro to help determine the number of plots needed for stand exams, see http://www.fsweb.r1.fs.fed.us/forest/inv/cse_exams/sampling.shtml. In some cases, it may become clear that some questions cannot be answered with available funds, and one can avoid the risk of promising the stakeholders something that cannot be delivered.

Distribution of Plot Locations

In addition to the common requirements of statistical independence and unbiasedness (Cochran 1977), interpretability of an estimate and its variance are also predicated on the distribution of the inventory plots across the geographic area of interest (Lister and Scott 2009). As discussed in section 4.3.3, distribution of plots in a random manner may not lead to a spatially balanced sample. If the goal of the sample is to characterize an area of interest, an approach that forces the samples to be spatially balanced might be appropriate (Lister and Scott 2009). Appendix G describes different methods to spatially distribute sample locations while avoiding violation of the assumptions of sampling theory and includes FIA's use of systematic tessellation (Olea 1984, Olsen et al. 1999, Reams et al. 2005, Shiver and Borders 1996).

Two Arc Map extensions developed by Region 1 are available to help place plots within a geographic area of interest (see table 4-3 and appendix G for details).

The Region 1 Intensification Plot Locator (RIPL) software program (Zeiler et al. 2010) is used for determining plot locations within a geographic area of interest, while buffering the FIA plots already located within the area. The program outputs plot locations while keeping the base-FIA grid locations confidential. The national forest provides a map of the intensification area and chooses

Table 4-3.—*Locating plots within a geographic area of interest.*

Geographic extent	Application	Documentation	Overview
Broad- to mid-level	R1 FIA Grid Intensification Plot Location Program	http://fsweb.r1.fs.fed.us/forest/inv/r1_tools/ripl_overview.pdf	The R1 Grid Intensification Plot Location Program (RIPL) places plots in a spatially balance fashion across a geographic area of interest while buffering the base FIA plots and any previously placed intensified grid plots. Since this program uses the confidential FIA plot locations, it must be run by the NFS FIA Inventory Coordinator or other RO employee that has the appropriate confidentiality agreement in place with FIA. This application is an ArcMap extension which runs on the user's computer.
Mid- to base-level	R1 Plot Locator Software	http://fsweb.r1.fs.fed.us/forest/inv/cse_exams/Region_One_Plot_Locator_Tool_Instructions.pdf	This ArcMap extension places plots randomly or on a grid within a polygon of interest. It can be run on the user's C: drive or can be used on Citrix. This application can be run on stand polygons that are delineated in NRM FSVeg Spatial.

the resolution of the intensification by specifying the number of plots to install. RIPL software is an Esri ArcMap extension designed to intensify within an area defined by a **geographic information system** (GIS) **layer** so as to provide a spatially balanced random sample within the geographic area. This process is accomplished by generating intensified points around the existing FIA grid and other preexisting intensified plot locations (if applicable) in the areas where new points will fall. Points are randomly placed and are constrained by minimum separation distances to existing grid points and the boundary of the project area. The search heuristic used maximizes the separation of point distributions while maintaining spatial balance and randomness. Because this application uses the confidential FIA locations, the NFS regional FIA coordinator must be consulted. A generalization of this application will be available within the DATIM suite of tools (see appendix F).

The Region 1 Plot Locator (ROPL) software determines plot locations within a polygon of interest to users' specifications (Kies et al. 2014). This application is an ArcMap extension that runs through Citrix or on a personal computer. ROPL will place the user-specified number of points randomly or balanced spatially. This application is generally used to derive sample locations within a NRM FSVeg Spatial polygon. The polygon needs to be spatially accurate because the exam will provide information about the vegetation within the delineated polygon. Similar vegetation is grouped in a stand, which reduces variability so that fewer plots need to be installed while achieving the desired confidence level for the exam. Users should take time to edit a stand polygon using the NRM FSVeg Spatial interface to more accurately portray stand boundaries before locating plots with ROPL.

Adding Plots to Areas That Have Not Been Sampled

When evaluating existing inventory datasets for mid- and broad-level information needs, spatial gaps may occur when the existing inventory does not cover the entire area of interest. For example, FIA covers the whole United States, but vegetation data are measured only on those areas that meet FIA's definition of forest land. The lack of vegetation information on grassland, shrubland, and woodland has been identified as a significant information gap by NFS. To address this gap on NFS lands, Regions 1, 4, 5, and 6 have worked with their associated FIA region to have vegetation measurements collected on nonforest land using the same protocols as on forested plots (see section 4.3.2). This data collection has been implemented in various ways. The method that provides the most seamless data delivery is to have FIA collect the data. Because the nonforest data are not part of FIA's core data collection, it is not available through FIA's Web-based analysis tools. Therefore, analysis of the data would need to be done by an FIA analyst when data are migrated into NRM FSVeg (easily done at the request of the NFS FIA regional coordinator).

For existing local inventories that do not cover the entire population of interest, the existing inventory can be extended into the rest of the population if reliable data collection protocols, software, databases to warehouse the inventory data, and analysis tools are available. If all these are available, then only the marginal costs of the additional plots would be incurred.

Reducing Remeasurement Cycle (Temporal Intensification)

Temporal gaps occur when existing data do not represent current vegetation condition due to natural **succession** or disturbance. If plots are being remeasured over time and the time period between remeasurements is too long to capture important changes of your population, then a shorter remeasurement cycle or a mid-cycle remeasurement may be needed.

For example, large fire events have occurred over vast areas of the West. Within certain mountain ranges, most FIA plots may have burned since the inventory date. If a national forest or grassland wants to quickly assess the changes to vegetation due to these large fire events, remeasurement of the burned plots provides a probabilistic set of inventory plots to quantitatively assess the effects. This type of data collection can be accomplished in a couple of ways: either by conducting a mid-cycle update or a full remeasurement. Furthermore, the data can be collected by either NFS or FIA. For FIA plots, the NFS regional FIA coordinator needs to work with the appropriate FIA contact to explore the feasibility of revisiting the FIA plots off cycle or sooner than what is generally planned. FIA plots are remeasured on a 10-year cycle for those plots administered by the Pacific Northwest FIA and Interior West FIA and on a 5- to 7-year cycle for those plots administered by the Northern and Southern FIA.

4.3.6 Add Additional Attributes

If the information needs assessment indicates that additional attributes of interest are not being collected, then consider if they can be added to current protocols.

If the inventory planner is interested in adding additional protocols to those that are already collected by FIA, he or she will need to work with the FIA regional program manager. Because FIA maintains consistent protocols, data collection software, and data warehousing for all FIA regions, the feasibility may be low and the cost may be high for adding additional attributes. FIA would consider if the additional attribute(s) would meet only local needs versus regional or national needs, how much time it would take to collect, if collecting the data would impact existing vegetation condition on the plot (i.e., destructive sampling), if the protocols would be objective, and if the measurement could be collected consistently by different field staff. Depending on these factors and others, FIA will determine if the attribute can be collected, how much it will cost to collect the information, and how soon the data collection will start. Proposed modifications to the existing FIA system go through a rigorous review process for data acquisition, data management, and data analysis before being added to the field protocols. This process can take at least a year and sometimes several years to initiate.

It may be easier to acquire an adjunct agreement with FIA and oversee the data collection for the additional attribute(s). To implement this strategy, send a person with the FIA crews to collect the attribute(s) of interest or send crews to the plots at a later time. Although the efficiencies of having an FIA crew collect the data are lost, this strategy may get the data collected much faster. The inventory plan needs to include documentation of the strategy, including how the data associated with the new attribute(s) would be made electronic, checked to ensure the values are within expected ranges, tied to the appropriate FIA plot, and ultimately tied to the analysis being done with the FIA data. The regional FIA coordinator will need to work with the FIA regional program manager to develop an adjunct agreement. Various forms will need to be completed, and FIA ultimately has authority for whether the adjunct agreement will be approved. The respective Forest Service Research Station director will need to approve all adjunct agreements. Having an adjunct agreement signed and in place can take more than a year.

If this need is mid-level and the inventory and monitoring capabilities of CSE are being used, it may be easy to add an additional attribute and CSE may have the attribute available. If protocols for the attribute are not currently available, CSE has user codes that can be collected at the setting, plot, tree, and vegetation composition levels. These fields are available in Exams software in which any type of data can be entered. This solution may be very simple because the new attribute is automatically tied to the rest of the inventory data and stored with the data in NRM FSVeg. Clear protocols would need to be written and included with the field guide and crews would need to be trained in data collection. For example, in Region 1, horizontal cover is needed when assessing lynx foraging habitat. In some cases, national forests collect horizontal cover according to specified protocols on supplemental data collection sheets. The average horizontal cover is calculated and entered into the plot-level user code.

4.3.7 Assess Time, Cost, and Priority Constraints

Timeframe

The time period for which results are needed is important to inventory design. Is it urgent to get information on a current condition, or to pose this question: Can the project staff afford to add time and cost in data collection and analysis to improve the results or to address more than one need? Planned or unplanned, new information needs may require comparison of past and current conditions. If long-term trends for three or more remeasurements are anticipated, then the commitment to the design and costs for remeasurement will be a large factor in the initial design decisions. Remeasurement may be designed into an inventory when monitoring is an objective, or it may be done at undetermined intervals so as to evaluate the effects of disturbance.

If change estimates will be needed, consider the timeframe and required attributes for each remeasurement. Consistent use of standard and well-documented protocols and the use of permanent plots for data collection are important for extending the use and value of the data to these new needs. Spatial attributes (e.g., compass and distance to known locations, map coordinates, center point **global positioning system** (GPS) coordinates, plot data point mapping, etc.), should be supported, as location data often are the most valuable plot attributes for **spatial data** analysis. In most cases, sample plots should be permanently marked if needed for revisits and remeasurement, but exceptions do exist. Permanent plots require investments in monumentation, which can add substantially to the initial costs of the inventory. Monumentation should not attract casual attention to the inventory plots (see section 0 of Version 6.0 of the *FIA National Core Field Guide* for monumentation procedures [USDA Forest Service 2012b]).

Time and Cost Constraints

Evaluate cost constraints before proceeding in the design of any inventory. Time, expertise, and funding are limited. Thus, affordability determines most inventory designs. Appropriate multifunding of projects could spread the cost and meet financial needs that otherwise might be impractical. For example, when information needs exist and funds are available, one might collect length of down logs and large-end diameters to assess wildlife denning opportunities in addition to collecting standard down-woody material by size class to assess fuel loadings.

The costs of inventory are primarily associated with field data collection, but data management and analysis usually take about one-third of the budget. The inventory planner should consider the following: equipment, training, supervision and QC of data collection, data warehousing, and data compilation. The planner should have some notion of the kinds of expertise that will be required so that qualified personnel or contractors can be hired to perform the work.

Final Considerations and Commitments To Proceed

When large investments in inventories are anticipated, it is important to document the decision to move forward and begin to make investments in designing the inventory. Special consideration should be given to technological and organizational commitments needed to maintain value in inventory work. Changing technologies and the long-term capacities of the agency may have significant influence in the value of collected data. Consider existing and expected data management policies and procedures and evaluate the capacity for and commitment to information management and remeasurement.

4.4 Methods: Data Acquisition

Inventory and monitoring programs, whether intended to address local or landscape-level questions, are costly endeavors that require extensive planning for data acquisition, warehousing, interpretation, reporting, and **evaluation**. Planning is critical to ensure that information needs will be met within a timely manner after the data are collected. After the protocols for data collection have been selected and plot locations have been determined (section 4.3), the logistics of the field inventory can be addressed. Before the data are collected, determine who will oversee the inventory, who will collect the data, what equipment will be needed, what the safety needs are, and what training is needed. The selected protocols will determine, to a certain extent, how the data will be collected, cleaned, loaded, and made ready for analysis. Many of these protocols are provided for when using mature corporate systems, such as CSE and FIA.

4.4.1 Prepare for Field Data Collection

After the protocols have been selected (see section 4.3), thoroughly review the existing field guides to determine if any additional attributes should be collected. Determine how these attributes will be recorded in the field. Will they go on paper forms while the other data are collected by using PDRs? Where will these additional attributes be stored? It is preferred that additional attributes are stored in the same database as the rest of the inventory.

Determine Who Will Collect the Data

In general, Forest Service force account crews, including forest or grassland, regional, zone, FIA field crews, and contract crews can collect data. These options vary in cost and in the degree of involvement by agency staff. A key consideration in selecting an option for data collection is QA and QC associated with data stewardship (see sections 1.6.1 and 1.7). The following paragraphs describe the different data collection crews.

Force account crews. Force account crews are hired and supervised by the forest, district, or zone within a Forest Service unit. These crews are generally hired for a field season. The national forest or grassland is responsible for all training required by the agency, region, and forest or grassland. All field gear, vehicles, data recorders, etc. need to be provided by the unit. At a minimum, use a crew boss who is proficient at implementing protocols and measuring vegetation attributes in the field. Force account crews, in general, are less costly than other data collection options, but keep in mind the added costs of vehicles, equipment, training, and extensive oversight. If forests or grasslands do not regularly hire vegetation data collection crews, other options may ensure higher quality data.

Regions 1, 4, and 9 have modified CSE protocols to mimic FIA protocols. This modification enables NFS staffs to use force account crews or contractors to collect the data using Exams software. This method is generally easier to contract, because of NFS staff's familiarity with Exams software and methods for cleaning and loading the data. If the NFS region and forest or grassland oversee the inventory project, it is easier to meet tight timelines and to add additional protocols (as long as they are available in CSE). Unless methods have already been determined (such as in Region 1), however, the NFS region will need to create the methods to tie FIA plots with the intensified grid data collected by using CSE protocols before analysis.

Contractors. Many national forests and grasslands use contractors to collect vegetation information. Units put together a contract package for bid that specifies the number of plots that will be collected, where they are located, tolerances for GPS locations of plots, and the protocols that will be used, including measurement tolerances. Various contractors provide resumes of previous experience, references, and cost estimates for the work. Contractors are variable in cost and data quality. Their ability to successfully complete a contract involving field data collection is highly correlated with how much experience they have with the protocols and associated data collection software. Contractors have defaulted, primarily when they have not fully read the contract before bidding on it. The Federal Acquisition Regulation allows for a more expensive contractor to be chosen if the Government believes it is a better overall value because data quality will be higher and the contractor will require less oversight. Contractors, in general, cost more than force account crews, but they bring all vehicles and equipment (unless specified in their technical proposal). Units will need a contracting officer's representative (COR) who is well versed in the protocols and vegetation data collection to inspect the plots before payment.

Regional cadre. Some regions have a cadre of highly trained individuals available for tasks such as timber cruising, timber sale marking, and vegetation data collection. Region 1 has such a group, called the timber strike team. If the regional office or multiple forests hire and supervise these crews, the hiring, training, and supervision of the crews are much more efficient. In addition, most team members are hired for multiple years and have extensive knowledge in national protocols, such as CSE, and vegetation measurements. Forests work with the regional cadre to schedule their field needs during the winter and spring before field season. Although these crews, in general, are more expensive than a force account crew, they come with vehicles, most equipment, and extensive knowledge, and they will require less training and oversight.

FIA crews. If FIA protocols are selected, then FIA crews may be available to collect the field data. National forests and grasslands should work with their region's FIA Coordinator and the appropriate representative from FIA to determine cost and timing, if this approach is an option. FIA field crews come with extensive field experience, are well versed in the protocols, and have all necessary equipment, but they are probably not versed in the use of the Exams computer program and other software tools the NFS uses to conduct inventories. FIA crews are probably the most expensive option. Furthermore, timing of the data delivery and format of the data should be explicitly discussed to ensure that FIA can meet the unit's information timelines.

In Regions 5, 6, 8, and 9, the NFS regional FIA coordinator has worked with the appropriate FIA regional contact to pay FIA to collect all the intensified data, load it into the FIA database (NIMS), and either have FIA produce reports or have the data migrated into NRM FSVeg so the region can produce reports. If this scenario is chosen, the inventory plan should have thorough documentation of what FIA will be doing for NFS with specific timeframes, including when the data will be available in NIMS or NRM FSVeg and, if agreed upon, when the analysis will be completed. With this scenario, the FIA region can provide an accurate cost estimate for the NFS region.

It is difficult to definitively say which data collection option is cheapest, because cost depends on a unit's specific circumstances. The following bullet points describe some cost inputs to consider:

- The unit is not responsible for any mandatory training (first aid, defensive driving, etc.) with regional cadres, FIA, or contractors.
- Forest Service employees tend to be easier to work with than contractors when a consistent, recurring data-quality problem exists.
- Forest Service employees have access to agency assets, such as backcountry cabins, bunkhouses, and unit radio networks.
- If the unit already covers fixed vehicle costs, using the vehicles may not be an additional cost.

Plan Fieldwork

The inventory planner must ensure that the timing of the fieldwork matches with the crews' availability and the seasonal patterns of the vegetation attributes of interest. Before crews perform fieldwork, the following information must be prepared.

Prepare stand/plot packets. Units will need to work with associated FIA regions if FIA will be collecting the data to determine what the unit needs to provide. If NFS crews are used, the unit will provide electronic coordinates; National Agriculture Imagery Program, or NAIP, imagery; a unit secondary base map; motor vehicle use map; and quad maps for each plot. Plot packets may also include determination of travel routes, accessibility, potential gate closures, travel restrictions, and administrative use documentation. If data collection will be contracted, the unit generally provides only electronic coordinates and the associated plot number. The additional specifics of accessibility and restrictions will be discussed at the prework meeting with contractors.

Prepare contract package. If data collection will be put up for bid, work with the contracting officer (CO) at least 6 months in advance of your intended start date. Specify the field manual, with all tolerances, before advertising the request for bids. It is important that the CO understands the protocols that will be used and that the contract accurately reflects the specifications to ensure bid prices reflect the work required and minimize the likelihood of contract default.

Secure Equipment

Equipment needs will be determined based on protocols selected, plot monumentation needs, and standard equipment needed for the field. Appendix H provides a general list of equipment that can be used as a starting point. In general, contractors and regional cadres will provide their own GPS and measurement equipment, while the unit provides the needed nails, tags, and stakes. Force account crews will need to have all equipment provided by the unit. If using FIA crews, negotiations should clearly define what equipment the unit is responsible for.

Review the field protocols to determine if crews will need to collect sample material such as soils, vegetation (particularly voucher specimens and unknown species), or insects. If needed, collection bags must be provided to the crews, appropriate storage locations must be provided, and specific protocols for labeling samples must be in place so that material can be tracked and related back to the site from which it was taken. Some samples, like soils, may require refrigeration or immediate analysis.

It is recommended that as much field data as possible be collected electronically using PDRs. Most national data collection protocols available for NFS, such as FIA and CSE, have data entry software. Web sites for these software packages are listed in table 4-1. One advantage of using mobile devices is that they minimize data collection errors, such as missed fields or the entry of invalid codes, by having real-time edit checks built into the software, allowing for errors to be corrected in the field. For example, tree species that are not found in the geographic area where data are being collected cannot accidentally be recorded, or a very large height cannot be recorded for a small-diameter tree without a warning being issued. Other benefits include eliminating the need to electronically enter the data from paper forms, ultimately saving time, eliminating transcription errors, and making the data ready for analysis much sooner. Mobile devices have advanced in their technology and durability. Rugged and waterproof types with the capability of downloading aerial photography and topographic maps are currently available. Mobile devices can also serve as temporary storage devices for data. Use of this temporary storage may be a consideration in situations when weeklong work tours in remote areas prevent daily uploading to a centralized database. The storage capacity and accommodation for expansion varies by model, but a user-accessible memory card slot has become standard in many newer models.

If data collection software is being used, then the inventory planner or field crew boss needs to have some knowledge of the software, or have made appropriate accommodations to answer questions as they come up during the season. If Exams software is being used for collecting CSE data, then the default template file should be created, which selects which attributes are being recorded in the field, identifies which trees are growth sample trees, sets defaults, and lists valid values for categorical fields. Furthermore, someone with technical expertise must be available to answer questions about the model of PDR used. Ensure that the data collection software is compatible with the model of PDR that is being planned for use in the field. For more information about using the Exams software, see chapter 4 of the NRIS FSVeg/CSE User's Guide (USDA Forest Service 2012a).

Any plot collected by NFS needs GPS locations. Review the specifications of field protocols to determine the type of GPS unit needed. Make sure that the datum and coordinate system used are specified in the field protocols and that all GPS units used by field crews are set accordingly.

Develop a Safety Plan

A detailed safety plan and a job hazard analysis (JHA) that identifies potential hazards and mitigation measures should be developed (see appendix K for an example of JHAs for inventory fieldwork). Crew check-out and check-in procedures should be thoroughly documented. Review the suggested equipment list in appendix H to make sure all safety equipment has been secured.

Field Training

Training needs are to be assessed for everyone involved with the inventory project, including the inventory coordinator, field crews, and COR. Consider the training needs described in the following paragraphs.

Inventory coordinator. Does the inventory coordinator understand the protocols, associated field guide, data collection software, process of cleaning and loading of the data, database storage, and analysis tools available? An inventory coordinator must have fairly extensive knowledge of the system to oversee the entire project. NRM FSVeg and CSE training are offered through NRM. In addition, staff are available to answer questions. Each region should have an NRM FSVeg data steward who can help make sure that the inventory runs smoothly if CSE protocols will be used and NRM FSVeg will warehouse the data. If FIA protocols will be used, the inventory planner will need to work closely with the regional office and FIA regional contact to ensure that he or she has the knowledge necessary to oversee data collection and work with the electronic data.

Field crews or COR. Crews must understand the field procedures that will be used, how various vegetation measurements are performed, and how to use all of the equipment. Even experienced crews refine their skills with each training session. Specific training on the field procedures that will be used helps ensure that data are collected consistently within and between crews. Training also provides an opportunity to raise questions and to provide feedback to the inventory planner. It is highly recommended that all field data collectors receive standardized training and meet certification requirements before collecting data.

4.4.2 Collect Data

Although the primary responsibility for data collection lies with the field crew, the inventory planner or COR must oversee QA/QC procedures. Protocols and field guides contain specifics for data collection; here we present recommendations for field data checks.

Perform Field Data Measurement Checks

Soon after data collection starts, a subset of the electronic data collected should be cleaned and loaded into the database, follow specified protocols to ensure that no additional problems exist with the field data procedures that were not identified until the loading process occurred. To maintain data integrity, it is imperative to detect errors in the data collection process early and address them.

Routine and consistent inspections must be performed throughout the data collection process to identify and mitigate further errors and to ensure contract specifications are met before payment. The crew must correct the errors detected in the field to minimize the amount of office editing. Attempting to fix errors in the office rather than on site could result in entering erroneous information, thereby jeopardizing the integrity and legal defensibility of the data.

The Data Quality Act, Section 515 of the Treasury and General Government Appropriations Act of 2001, directs the Office of Management and Budget to issue Governmentwide guidelines to ensure the information disseminated meets certain quality standards. These basic standards are quality, objectivity, utility, and integrity. To meet these standards for contracted work, the FIA and CSE protocols have tolerances assigned to each data collection attribute. These tolerances are acceptable data measurement ranges for comparison with QA/QC inspection results and are intended to ensure the data are collected within contract specifications. Cold checks (defined in the following section) are the primary method for inspecting contracted work, although hot checks are performed as well. A minimum of 10 percent of contracted plots should be inspected.

The goal of checking field data measurements is to ensure that all resource inventory data are scientifically sound, of known quality, and thoroughly documented. Measurement quality objectives (MQOs) are established as standards to define data quality. Part of the MQO is the allowable range of measurement or classification error, termed the tolerance. Data item tolerance limits are indicated for every attribute within the field protocol manual. Inspections are required for contractors, but should be considered a standard component of data collection for force account crews as well. Everyone collecting data should be subject to periodic onsite inspections to ensure that the fieldwork is being performed with required accuracy and precision. Field checking is also conducted for the following reasons:

- To check the performance of each individual crew member.
- To minimize measurement errors.
- To obtain uniform and consistent interpretation and application of field instructions among all field crews.
- To reveal inadequacies in the manual and at training.
- To assess and document the quality (accuracy, precision, completeness) of field data.

A portion of all field plots (e.g., 10 percent) should be blind or cold checked for QA. The national forest or grassland should provide all QA/QC documentation to the regional office as required. The regional office will monitor these audits to ensure strict **data standards** are maintained. QA/QC inspections are described in the following paragraphs.

Hot checks. This type of inspection provides immediate feedback to the field crew regarding protocol interpretation and if attributes are measured within stated tolerances. A hot check inspection should be performed soon after the start of data collection, preferably within the first few weeks. The inspector (usually the COR or a crew boss) is present while the field crew is collecting data and immediately discusses any measurement errors or misinterpretation of the protocols. This interaction serves as part of the training process and provides an opportunity to correct how crews are to measure data before it is a problem inherent to the dataset.

Cold checks. This type of inspection must be conducted throughout the field season with multiple checks completed for each crew. A cold check inspection evaluates the crew's work compared with the inspector's. The inspection is performed after the field crew has completed data collection, and the inspector has the completed plot data in hand as checks are being performed. Inspections can be based on the whole or subset of the plot.

Blind checks. This type of inspection is done on plots that are randomly selected from the entire population of sampled plots and must be measured by a second crew. Blind checks are performed to ensure that tolerances stated within a field guide can be obtained. Blind check plots can be measured at any time during the field season, but are generally planned to be within a 2-week window of the first crew to avoid the confounding effects of seasonal changes on the plots. The protocol is a complete remeasurement of the plot with access to only the first crew's location data. This procedure compares first crew's plot data with an independent, blind measurement of the same plot to evaluate the relative uncertainty associated with FIA field-collected data. The second crew ideally does not know that the plot they are evaluating was recently measured. In general, blind checks are not a needed part of an inventory unless the tolerances for collecting a specific attribute are unknown (i.e., it has not yet been determined how accurately the attribute can be measured in the field). Most protocols used by NFS have been in place for many years with known tolerances for measurement. If a measurement tolerance is not known, check to see if FIA has any information. They have been performing blind checks for many years to ensure that the tolerances in the field guide can be met.

4.5 Methods: Process and Compile Data

The electronic data from the field should be stored in a location that is automatically backed up and retained for permanent record. If data are not already electronic, they need to be made electronic using the appropriate software. For example, CSE data use Exams software and FIA data use the Mobile Integrated Data Acquisition System (MIDAS).

4.5.1 Clean and Load Field Data

Data collection is expensive. Therefore, a commensurate amount of effort in developing the methods for obtaining data of high quality should be applied to the data checking process. The data checking component can take a considerable amount of time, and if not performed can compromise the statistical analysis. If sufficient resources are not available to assure sufficiently accurate, scientifically sound, and legally defensible data that inform decisions now and into the future, perhaps the inventory should not be done.

Data should be run through software applications that check the data for errors after being converted to an electronic format but before loading to a corporate database. The interval between the completion of data collection and the availability of the final database will vary due to the QA checks performed. For CSE data, it generally can take a month for the data to become available. Data collected by FIA for NFS use may take 6 months or longer before it is available for use.

FIA data go through analytical QA checks and through the data checks described in section 4.4. The analytical QA ensures all core tables have been populated, all plots are accounted for, and some of the variable logic checks have been completed. In addition, summary level estimates are used to provide initial, broad-based QA checks. These checks look for system wide errors such as data loading errors, errors with computed variables, and stratification errors. These checks compare current summary estimates with previous summaries using a select set of core tables and tables of differences. Further checks are completed to look for **outliers**, missing data, off patterns in the measurements, and how the groupings of current measurements compare with previous measurements. Other QA reviews can include GIS populated values (e.g., elevations, congressional districts, and ecological units). The final steps in the QA process are reconciling comments from external reviews and performing one last QA check to ensure all data were loaded correctly.

Exams PC Pre-load Check Utility

For CSE data, before the data are loaded into NRM FSVeg using DBLoad (see chapter 5 of the NRIS FSVeg/CSE User's Guide [USDA Forest Service 2012a]), database loader performs additional checks (http://www.fsweb.nris.fs.fed.us/products/FSVeg/documentation.shtml). The Pre-Load Check utility processes each setting in the current file to look for trees that do not fall within the sample design and associated selection criteria and species of management interest, tree species, or understory vegetation species that are not found in the species list for the unit (TAXA list). It also verifies that all capable growth area entries are acceptable.

The database loader performs the checks through a combination of database constraints and coded logic. The major steps involved are (1) rechecking for species not specified within (TAXA) lists for the region and national forest or grassland, (2) validating the existing and potential vegetation codes, (3) checking tree damage codes, (4) translating data into standard loading format, and (5) checking for an identical stand in the database. The user must correct any errors the database loader detects before loading into the NRM FSVeg database is possible.

The clean data files should be backed up and stored in the project folder on the network drive to fulfill any future need to revert or refer back to the original raw or clean data files. In addition, data collection sheets and sketch maps should be stored in specified folders. If electronic photos were taken, the images should be loaded to the network drive, labeled with project name and plot identification number, and digitally archived.

National Information Management System Audits

FIA developed the NIMS for managing and storing field-sampled data. The NIMS audit system uses a combination of database constraints and logic coded into packages and triggers to check data. Most of these edit checks exist both in the portable MIDAS application used to collect data and the NIMS-Compilation System (CS) database application used to store and compile the data. NIMS-CS has additional edit checks. Many of the edit checks in the MIDAS application are applied automatically during data entry, although some edit checks permit overrides to account for data anomalies. Edit checks are reapplied during office review in the MIDAS application. After the data have been moved to NIMS-CS, the edit check system becomes more user driven. The edit checks can be run multiple times, including and excluding certain checks, allowing for the data editor to verify changes made to the data before and after compilation. After the data have successfully passed edit checks and compilation, they are flagged as clean and ready for analysis.

Load Data to Corporate Databases

After the error checking on the data has been completed, it is ready to load into the corporate database. For CSE, DBLoad, accessed through the PC Exams interface, loads the data into NRM FSVeg. As the data are loaded, additional edit checks are automatically performed that could reveal some inconsistencies or duplication of data. Therefore, it is possible that additional editing may be needed to get the data loaded into the database. At base level, the Forest Service standard is the NRM FSVeg module, which accommodates stand exams or the NRM Rangeland Inventory and Monitoring application.

Storing Plot Locations

Storage of the acquired plot locations depends on the protocols selected for field data collection. For CSE data, the latitude and longitude fields in Exams software automatically populate when the GPS and data recorder are communicating via Bluetooth, or a cable, or the PDR and GPS are integrated within the unit. MIDAS also stores the plot locations for FIA plots as the data are collected in the field. After these data are loaded into corporate databases, where they are ultimately stored depends on the database. After the locations are in the specified database, the theoretical locations should be compared with the acquired locations to make sure that they are within tolerance. Storage of the spatial locations should meet documented data dictionary standards that are adhered to over the life of plot remeasurement so that the acquired plot locations, over time, can be easily accessed and tied to the appropriate measurement record. If security of the plot locations is required, such as with FIA, then specific protocols for storage and use of locations are specified in agreements between NFS and FIA.

Consider the following provisions:

- Know that the intended coordinates, sometimes called the theoretical coordinates, are the coordinates given to the field crew to navigate to the plot.
- Collect actual GPS coordinates with a GPS unit that is set correctly for your geographic area each time the plot is visited. GPS have been getting more accurate as time passes, so each new measurement should yield more accurate locations. At some point in the future, as technology stabilizes, returns may diminish by continuing to collect coordinates; this situation will have to be evaluated on a case by case basis by comparing what GPS units were used on the last measurement with what will be available and within budget in the future.
- Record the model of the GPS unit and keep the specifications for that model on file, preferably electronically. The accuracies of the instruments are constantly improving, so this information may help with future assessment of the spatial data collected.
- Store coordinates that are offset from the intended location as well as the distance and azimuth to the plot center. The plot center may not be accessible, or a reading may not be possible. Recording the coordinates with offset will enable the next crew to relocate the plot. Also, calculate where the plot center should be using the offset information and store this information for use in analysis. Protocols for how this information is collected and stored in the field should be clearly presented in the field manual.
- Know that GIS boundaries, GPS coordinates, and humans inherently introduce some errors, and distinguishing these components from one another is often not possible. Without evidence to the contrary, the field crew GPS coordinates should be considered the best source of information. If errors are present, they usually are most apparent at boundaries of ownership or distinct and abrupt vegetation changes such as a clear cut. Consider creating a field and label it “apparent coordinates.” The apparent coordinate will move the plot into the correct area for GIS analysis. Only use apparent coordinates if evidence

strongly indicates that the field crew's coordinates are correct. Never change the field GIS coordinates. Use of apparent coordinates is optional but should be consistent within an analytical area, and is generally used only for analysis.

- Know that, in a long-term monitoring program, the following coordinates are conceivable:
    1. Theoretical.
    2. Up to three sets of field plots.
    3. Offset.
    4. Apparent, which may depend on various spatial data layers.

Because the end user is usually interested in only the best coordinates, it is recommended to create one more set for GIS analysis derived from the coordinates listed in the previous section and have a column that will code the data source for that set. Every time new data are added to the database, this information clearly will need to be updated. To reduce confusion, consider making this field-acquired set of coordinates available to the user.

Not all GPS units provide the same level of quality. If the GPS information will be used to link ground data with remote sensing imagery, GPS accuracy can be very important. For instance, high-resolution remote sensing imagery, including hyperspectral and airborne LIDAR (Light Detection and Ranging), requires a high level of GPS accuracy for many applications (Schreuder et al. 1993b). Consider the following three grades of GPS units (Andersen et al. 2009):

1. Recreational-grade GPS units are low cost ($100 to $500), sufficient to relocate plots, and provide accuracies of 6.6 to 23 feet (2 to 7 meters) in good, clear-sky conditions with good satellite visibility but are less accurate (greater than 65.6 feet [20 meters] error) under typical forest conditions.
2. Resource-grade GPS units have a moderate cost ($2,000 to $12,000), provide accuracies of 0.8 inches to 3.3 feet (2 centimeters to 1 meter) but do not consistently provide positions with submeter error under dense forest canopy.
3. Survey-grade GPS units are expensive ($12,000 to $75,000) and provide consistent submeter accuracy across a wide variety of forest conditions.

In summary, the expected use of the coordinate data must be considered—for linking individual trees with high-resolution imagery, submeter accuracy is important. For linking them with coarse-resolution data, accuracies in the 32.8-feet (10-meter) range (those available with many recreation grade GPS systems) can be acceptable. It is possible to acquire better accuracies for any GPS unit using external antennas and bipods or tripods.

4.5.2 Compile Data

Calculated Attributes

After the dataset has been reviewed and detected errors have been addressed, calculations may be performed on the raw inventory data. Standard forestry metrics, such as basal area, quadratic mean diameter, volume, or biomass, may be calculated from the plot-measured data as a step in data processing and compilation. More complex calculations may be carried out after data loading and may require species and bioregional specific equations. For example, one can apply classification algorithms to the inventory data; these classification attributes can then be added to the dataset (this process is called tabular inventory compilation). Another example of a complex calculation is the use of linear or mixed effects models to estimate trees heights in the event no tree heights were measured or only a subsample of heights were measured. A well-designed data repository can accommodate the calculated attributes and have **metadata** associated with the attribute, fully describing how that attribute was computed and providing relevant published references.

Spatial Attributes

Like calculated attributes, spatial attributes are added based on the inventory data. These map-based values are determined by intersecting the plot coordinates with maps of interest, such as ecomap class or hydrologic unit code, and storing the results along with the inventory data. Depending on the accuracy needed, it may be necessary to check those plots near polygon boundaries more carefully.

Stratum and Population Information

The analytical tool (see section 4.6.1) will need some information (metadata) on the population area and, if used, the strata sizes. This information depends on the sampling design used, but often includes the population name and its total area, the names and sizes (area or proportion) of each stratum and perhaps the sample size of each stratum. The data must also include a means of linking population, stratification and plot data to one another.

Dealing With Remeasurement Data: Reconciliation

Data reconciliation is the comparison of the same **data element** at two points in time. For existing vegetation inventory, it is the comparison of selected attributes (data) between two measurements on monumented plots. Reconciliation is performed after the data have been cleaned and loaded for each measurement event. Only reconcile data that have a strong correlation between the two measurements, such as slope and aspect at the plot and subplot level or tree-level attributes such as live/dead, species, DBH, and height. Reconciling data that may change significantly between the two sampling events, such as understory vegetation species or down-woody material, should not be attempted unless it makes sense and has been thought through. See appendix I for detailed guidelines on detecting and reconciling errors.

4.6 Methods: Data Analysis and Interpretation

A fundamental part of the inventory planning process is to consider the specific questions to be addressed and development of information products needed to serve as a foundation for addressing those questions by agency decisionmakers. The primary role of data analysts is to develop information from data and to provide information products in a form that provides managers with improved knowledge of how systems react to different management options. This knowledge then informs their decisionmaking using “the best available science,” as required by the NFMA, NEPA, and Endangered Species Act, and using information on the “error sources affecting data quality,” as required by the Data Quality Act.

The purpose of data analysis and interpretation is to develop information products that serve the needs of those sponsoring the current inventory or to address questions that may emerge over time (section 4.2.1). Analysts also look for patterns, concerns, and anomalies in the results, such as forests not regenerating themselves, low growth to removals rates, and shifting species composition, to help understand the resource status and trends. In some instances, the initial analysis and interpretation of data may help managers identify management issues or questions that they could not see because the root cause or situation was masked by the complexity of the ecological system. In other cases, the understanding of the relationship between attributes or indicators selected to address a particular management question may change as a result of new information or changed conditions. As a result, data analysis and interpretation should always be conducted with the end in mind, should recognize the fluidity of management's needs over time to ensure management needs are being met with resulting information products, and should evaluate and verify that these needs have not changed (see section 4.8).

The following key factors are involved in developing information products that influence data analysis and interpretation methods.

- *Data quality*. Providing decisionmakers with concise information regarding the quality of the data used to serve as a basis for decisionmaking. The Data Quality Act does not specify data standards; it establishes a requirement for documenting data quality. This documentation usually takes the form of metadata and should include accuracy information on the statistical estimates and inferences used in the analysis and interpretation process.
- *Presentation*. Providing decisionmakers with information products that enable them to apply the results of the inventory to meet their needs. Summary displays resulting from analysis and interpretation must convey the results of the analysis and interpretation in a form that can be incorporated into supporting documentation. Describing the source of inventory data, including the QA/QC aspects of the program, is an important component of information products provided to decisionmakers.

The following subsections address data analysis for computing statistical estimates of forest or other vegetation resources (volume, carbon, forage, etc.) or for performing change analyses between two or more inventory cycles to assess resource trends.

Key Statistical Concepts

Correct statistical estimators must be used for the selected sampling design (section 4.3). Otherwise, the estimates will be unintentionally biased, and the bias can be large and undetected, even with flawless field data. For example, if the sampling design uses prestratification with different sampling intensities among strata, but estimates are made with the simple random sampling estimator, then field data from intensely sampled strata will be weighted too heavily versus plots from lightly sampled strata, due to their unequal stratum selection probabilities. In this example, the plots clearly have different weights.

It is common to think in terms of the contribution of a single plot to the overall estimation—the plot weight or expansion factor. The plot weight is typically expressed as the number of acres represented by a plot in the estimate. For simple random samples, it is the area of the population divided by the number of plots (sample size). For stratified samples, it is the stratum area divided by the number of plots in the stratum. This calculation is true for both prestratification and poststratification. For FIA analysis tools, the plot weight is stored in the database with the plot data. For stand exam data, the acres of the stand are stored in FSVeg Spatial while the associated stand exam data are stored in FSVeg. For inventory data, such as FIA and intensified grid data, that is stored in FSVeg, the plot weights are stored in tables that are not generally in FSVeg but are uniquely tied to the data.

Storing the plot weights with the data can make simple estimates easy, however, it can lead to at least two problems. First, this approach to estimating the means or totals does not directly lend itself to the uncertainty estimates—more detail is needed to compute variances. Second, the plot weights are often affected by the particular analysis. If the poststratification is changed, the weights change. If plots that are not accessed are removed from the analysis, the weights change. If the population is subdivided into subpopulations, the weights change. Although the analyst can perform estimates by using database or spreadsheet tools, it is often best to use resource inventory software to compute the estimates and their uncertainty.

4.6.1 Creating Estimates by Using Existing Tools

Software to estimate current vegetation conditions and trends and the uncertainty of the estimate has been available for decades. For example, FIA developed the EVALIDator Web-based analytical tool and EVALIDatorPC, which uses Microsoft Access to combine both the data and the analytical tool. These tools enable users to take a snapshot of the data, which can be useful to long-term analyses and uses such as land management planning. Both of these tools (and others) are available at http://www.fia.fs.fed.us/tools-data/default.asp. The Analytical Tool for Inventory and Monitoring (ATIM) was developed as part of DATIM (see appendix F) for NFS to provide the functionality of EVALIDator plus enhancements to meet the needs of NFS. ATIM can use FIA data, NFS additions to FIA data, and similar vegetation data collected by NFS as long as it is a statistically valid sample. The associated Spatial Intersection Tool (SIT) works with ATIM to select the subpopulation of interest (study area) and optionally use map attributes to summarize the inventory estimates.

Although the FIA data are the single most complete forest inventory data for the United States, not all of the data that FIA has collected are available on line. The data collected each year is typically available 6 months into the next year. Some NFS regions have enhanced the inventory by having FIA collect data on nonforest areas, added attributes, or intensified the inventory by adding plots (section 4.3.5). Although these data are available internally, not all are available for use by the tools. Contact FIA for details (see http://www.fia.fs.fed.us/regional-offices/).

Each analytical tool produces the appropriate estimates and their associated uncertainty estimates, such as percent sampling error (sampling error expressed as a percentage of the estimate). The tools can produce one-, two- or three-way tables of estimates (and sampling errors) enabling the analyst to display the results for a variety of estimation domains and to help detect and understand patterns in the data. Filters can be applied to narrow the scope of the results to better address the specific monitoring questions.

Other data summary tools are available for corporate data. NRM FSVeg and NRM FSVeg Spatial are applications for analyzing vegetation data, typically at the stand level. The tools produce several standard reports and can produce aggregated stand estimates, but with limited uncertainty estimates. Summarizing the data in FSVeg can be used to derive additional attributes that are not readily available. For example, habitat classes can be assigned to the plot or stand using specific criteria applied to the inventory data. Summary data can be exported for further analysis. See http://www.fsweb.nris.fs.fed.us/products/FSVeg/index.shtml for information and go to https://www.iweb.fs.usda.gov/login/welcome.html to access the interface. FIA can also provide data through NRM FSVeg upon request.

Data can be translated from FSVeg into the Forest Vegetation Simulator (FVS) format through an application available in the FSVeg utilities. FVS is a stand- or plot-level growth and yield model that calculates many timber-related attributes, such as total cubic foot volume and merchantable cubic foot volume, and it summarizes the data by category or stands. In addition, FVS has the ability to create user-specified attributes using the COMPUTE function. For example, Region 1 has developed hazard ratings for insects and diseases such as mountain pine beetle and Douglas-fir beetle. This hazard rating enables users to classify current conditions and to understand how management actions and disturbance processes may affect the stand's or plot's susceptibility to these agents over time. Although means are generated by stand or plot for these computed attributes, FVS provides information about model prediction errors and not sampling errors. FVS does not summarize across stands, but the "Suppose" interface to FVS has other tools (postprocessors) that can do so. FIA data can also be used in FVS and can be accessed from FIADB or NRM FSVeg. Furthermore, FVS output is easily analyzed within MS Excel to derive estimates and confidence intervals across multiple plots if the plots are a statistically valid sample. For more information about FVS, go to http://www.fs.fed.us/fmsc/fvs.

How To Check Estimates

Nationally and regionally supported analytical tools have been extensively tested to ensure that they produce the correct estimates. The tools still depend on clean data and metadata to provide correct estimates, however. Section 4.5.1 addresses cleaning individual data points. The analytical process provides the opportunity to evaluate the data in aggregate. Common problems that occur during the analytics process include (1) not including all the plots or stands expected in the analysis due to either not loading all the data or not selecting (or querying) all the data for the estimate, (2) applying the wrong filters when selecting data, and (3) providing inaccurate spatial (stratification) information for the plots. To identify these and other problems, the following examples are checks that can be performed on the tabular results:

- Ask: What is the sample size for the area of inference? Are all plots accounted for in the analysis?
- Ask: Do all the pieces add up to the total? Do area estimates match known sources, such as a table of area by land use over time?
- Chart the average volume or height per tree by diameter class to look for inconsistencies by diameter class and perhaps over time.
- Look for illogical combinations of data, such as table of area by Quadratic Mean Diameter class and Stand Age.
- Compare the area by stable classes (such as productivity class, slope class, or aspect) over time.
- Check for consistency with past reports. Net annual change times the number of years between inventories should be close to the difference between inventory estimates.

- Compare results from intensified inventories with those of the base inventory—the estimates should be similar and the sample error should be roughly reduced by the square root of the intensification factor. Thus, intensifying the sample by a factor of 4 should result in sampling errors that are roughly one-half of those for the base sample.

4.6.2 Spatial Poststratification

When trying to improve the precision of an existing spatially balanced inventory (or other form of equal probability sample), poststratification may be useful. Prestratification (or simply stratification) is a common tool for developing an efficient sampling design by identifying homogeneous strata and selecting plots accordingly. Poststratification, however, is used when the sample has already been determined with equal plot-selection probabilities. Poststratification normally requires a larger overall sample size. By identifying homogeneous strata after establishment of the sample, often through the use of mapped data, the variance of the overall estimate can be reduced. Each stratum will have a random sample size that is approximately proportionate to its area (Cochran 1977, Scott et al. 2005, Westfall et al. 2011). Each poststratified stratum generally should have at least 10 or more field plots (Westfall et al. 2011). Small strata may be collapsed into larger strata with similar expected conditions. Most gains in statistical precision (e.g., reduction in size of confidence intervals) are typically achieved with six or fewer poststrata, with additional strata offering little incremental improvements (Cochran 1977).

4.6.3 Using Spatial and Tabular Inventory Compilations

Spatial inventory compilation (figure 4-1) is the intersection of inventory data with information from map products. Spatial inventory compilation allows for using map information as classification (domain) variables, which allow for calculating inventory data summaries for each map class. In this process, the design-based inventory data (e.g., FIA data) are spatially intersected with map products in GIS. The analytical tools can use the resulting map classes for each plot to produce inventory data summaries that quantify various vegetation characteristics for each map class. For example, volume by species or snags per acre (from the inventory data) can be calculated for each dominance type (from the map data). Due to variations in map accuracy and the inherent variability and number of inventory plots within the **map units**, map-based estimates calculated in this way can have high variance. The ATIM and SIT within DATIM are designed to facilitate spatial inventory compilation.

Another example of spatial inventory compilation would be to analyze geographic areas and use the inventory plots to describe vegetation characteristics within those areas. For example, an analysis of snag density may be done inside and outside wilderness and roadless areas. This analysis helps in the understanding of the impact that timber harvesting and firewood cutting has on the density of snags in areas that permit dead-tree harvesting. To partition the plots into wilderness/roadless versus nonwilderness/roadless areas, the plots are intersected with a spatial coverage that has this information, and then analysis is performed. As another example, a unit in the midst of land management plan revision may choose to intersect FIA plots with geographic areas that divide the unit into management zones. The plots within each zone can then be analyzed to derive estimates (and confidence intervals) for topics such as wildlife habitat, insect and disease hazard, or acres that have regeneration of certain tree species.

Tabular inventory compilation (figure 4-1) is similar to spatial inventory compilation but does not use map information as the source of the classification (domain) variables. In tabular inventory compilation, inventory data, classified to the taxonomic units of the vegetation classification, are commonly used to estimate the composition of vegetation for the inventory area. Inventory data summaries that quantify various vegetation characteristics for each map class can be produced. The classification (domain) variables can also be attributes collected on the plots such as potential natural vegetation, or PNV, type.

4.6.4 Imputation of Inventories

Imputation is the process of estimating missing data (Schreuder et al. 1993a). This process is briefly discussed in appendix I in the context of reconciling remeasurement data. Although it is beyond the scope of this technical guide to discuss in detail the types of missing data and the various approaches to imputation, Schreuder et al. (1993a) present a good summary of the missing data analysis. A brief discussion of imputation to provide substitute values for **data validation** and reconciliation is included in appendix J. Within this technical guide, however, the production of nearest neighbor imputation-based data surfaces (hereafter, NN data surfaces; i.e., geospatial modeling of design-based inventory data) is presented because of its increasing use within natural resource science and management (see review by Eskelson et al. 2009). Production of NN data surfaces is intended to supplement, not replace, the mapping approaches presented in section 3 of this technical guide. This section presents an overview of the topic with a more detailed discussion in appendix J.

This technical guide describes and discusses vegetation inventory as the process of applying an objective set of sampling methods to quantify the amount, composition, and condition of vegetation within specified limits of statistical precision. The traditional inventory approaches described thus far provide a wide variety of desirable characteristics and address the intended uses of inventory data. They do not, however, provide the characteristics of these data explicitly connected to vegetation pattern delineations or **raster data** surfaces (see section 3.3.2 for a discussion of spatial modeling surfaces). For planning purposes, it would be convenient to be able to operate as if detailed inventory information were available for all modeling units in the planning area. Therefore, a methodology that uses designed-based inventory data is needed to populate vegetation delineations or raster data surfaces with detailed inventory data (i.e., plot-level tree list data).

As an alternative to historically common stand-based statistical approaches (e.g., regression estimates or stratum averages) to populating unsampled units with data, imputation can be used. Imputation involves estimating values for variables of interest (Y variables) by supplying measurements from one or more sampled units to unsampled units with similar characteristics in auxiliary (X) variable space (Ek et al. 1997, Eskelson et al. 2009, Hassani et al. 2004, LeMay and Temesgen 2005, McRoberts 2001, Moeur et al. 1995, Ohmann and Gregory 2002, Ohmann et al. 2012, Temesgen et al. 2002). Imputation of inventory data from sampled areas to similar unsampled areas produces datasets that function like wall-to-wall data for planning purposes. Many methods and variations of imputation exist, both univariate and multivariate. Eskelson et al. (2009) provide a good summary of common imputation approaches and summarize variable-space nearest neighbor methods compared with other estimation methods.

Nearest Neighbor data surfaces developed for forest polygon data (reviewed in LeMay and Temesgen 2005) involve choosing a substitute for stands without detailed information (target stands) from a pool of stands that have detailed tree and stand data (reference stands), based on stand-level (or plot-level) characteristics (X variables) that are available for every polygon (Ek et al. 1997, Hassani et al. 2004, Maltamo and Kangas 1998, Moeur 2000, Moeur and Stage 1995). In a similar way, NN data surfaces developed from raster data involve choosing a substitute for a raster cell (or regions of cells) without detailed information (target cells) from a pool of raster cells (or regions of cells) that have detailed tree data (reference cells), based on plot-level characteristics (X variables) that are available for every raster cell (Grossmann et al. 2009, Ohmann and Gregory 2002, Wilson et al. 2012).

4.6.5 Using Inventory Data in Vegetation Classification

As discussed in Existing Vegetation Classification, (section 2) the process of classifying vegetation types consists of a preliminary stage and an iterative stage (see section 2.1.5 for description). Inventory data can contribute to the classification process in both stages, when appropriate.

In the preliminary stage (section 2.2.2, Evaluate Available Vegetation Data), some inventory data may be used to inform development of the classification, while other inventory data may be useful to help stratify the area for reconnaissance or sampling.

Following the completion of a vegetation classification, inventory data, classified to the taxonomic units of the vegetation classification, are commonly used to compile an unbiased quantification of the composition of vegetation for the inventory area. This process, referred to as tabular inventory compilation, is useful for obtaining estimates of abundance and composition for a variety of uses. The classification ideally should be developed and tested before conducting inventory projects so that the types in the classification can be used to describe vegetation during the inventory process.

4.7 Methods: Information Products and Reports

Following analysis, the analyst or interdisciplinary, or ID, team generates tables depicting the results of the analysis to answer the management and research questions (section 4.2.1). Often, answering the questions leads to more questions to help understand the underlying drivers, leading to the creation of more displays or tables of estimates. After the questions can be answered with the data, the analyst creates information products and reports. These results, interpretations, and conclusions are then shared with resource specialists and decisionmakers, plus other interested parties in a variety of reports or data summaries.

4.7.1 Information Product and Report Design Principles

Although tables of statistical estimates may form the foundation of the analyses, the key findings should be identified and presented in a format(s) and information products useful to management's intended purposes for the inventory. Although large tables may have been used to answer the questions, they might best be put in an appendix and a simpler, compact table presenting the answer to the question should be included with text to explain the result and the interpretation. If the rows or columns in a table are map classes, then the results can be presented in the form of a map, which can be used in a variety of ways. Although it is tempting to map individual plot locations, FIA has a policy that prohibits displaying the actual coordinates due to concern for data integrity on all lands and by law on private land. The patterns presented by the plot values can be presented in other ways.

Figures such as bar and pie charts and scatter plots can be used to present the findings. Methods and tools for presenting the results in appealing and easily interpretable ways are becoming increasingly available. Bar charts can present both current and past values to show trends by class. Scatter plots can help show relationships between attributes or changes over time. Photographs of examples of resource conditions can also help tell the story. Before and after photographs can be a powerful way to show resource change.

4.7.2 Reporting Tools

Section 4.6.1 described a number of data summarization and report regeneration tools. Several of them have the ability to output the results in a variety of formats for incorporation into information products and reports. Some also have the capability to produce maps and figures. Because questions are often common across multiple national forests and grasslands and regions, most of the tools have standard table templates that promote consistency and make it easy to produce useful results. These standard reports can also be used as helpful templates that can be modified to meet specialized needs. For example, FIA produces many standard tables for each State, making it easy to compare the results from State to State and to summarize the results across a region and across the country.

4.7.3 Relationship Between Reports and Forest Service Business Needs at Various Levels

Information products and their design are related to the requirements addressed at different inventory and monitoring levels. As shown in table 1-1, inventory reports can be produced at a variety of levels, which include the following examples.

- *National level*. Annual and periodic reports to inform policymakers and the public, such as the National Report on Sustainable Forests, State of the Nation's Ecosystems, Resources Planning Act Assessment reports, and also contributions to international reports such as the Global Forest Resources Assessment.
- *Broad level*. Reports designed to inform States, NFS regions, partners, and the public in formulation of programs and priorities, such as the Southern and Northern Forest Futures Assessments, bioregional assessments, conservation strategies, State Assessments for State and Private Forestry, State 5-year analytical reports, and State annual statistical reports.
- *Mid level*. Reports to support planning and monitoring, such as watershed assessments, annual forest-level Climate Score Card reports, forest assessments, and forest-level FIA analytical reports.
- *Base level*. Summaries and information needed support vegetation management project design, planning, and monitoring, including fuel reduction treatments, timber harvest, noxious weed or forest pest treatments, or rangeland improvement/type conversions.

4.7.4 Information Quality, Uncertainty, and Decisionmaking

Data quality assurance and quality control are mandated by the Data Quality Act, USDA, and Forest Service policy (see section 1.6.1). Describing the source of inventory data and sources of errors (transparency), including the QA/QC aspects of the program, is important information for decisionmakers. In a similar way, using the correct estimators and disclosing the statistical accuracy of the estimates are important aspects of understanding uncertainty.

Decisionmakers should understand that the estimates are simply that—statistical estimates with an associated confidence interval. Decisions should be made understanding that the actual values may be different from the estimates—making a decision based on probabilities.

4.8 Evaluation and Adaptation

The process of evaluating and adapting inventory design, analysis, and presentation occurs in response to—

1. *Management relevancy*. Evaluation and adaptation revolve around the relevance of inventory design components to management needs. As a result, managers must be involved in the evaluation and adaptation of inventory design, analysis, and information to ensure they meet management needs.
2. *Program efficiency*. Improvements in the execution of data collection methods, analysis procedures, and development of information products and reports are focused on improvements in overall program efficiency.

The following sections describe evaluation and adaptation procedures related to ensuring continued management relevancy and improving program efficiency.

4.8.1 Management Relevancy

After completing the data QA process, the ultimate evaluation comes in the use of the data to support decisionmaking. A strong partnership or relationship with managers during the design and execution of the inventory program will strengthen the ability to make adjustments in the program and maintain the support of program sponsors. Consider the specific questions to be addressed and the specific analytical needs of the end user identified in the design phase (see section 4.2.1). Success in planning and conducting the inventory will be determined in reflecting back and asking several questions. “Were the business requirements and objectives for the inventory achieved?” “Are the results accurate and reliable?” “Have new issues or concerns emerged as a result of changed conditions or improved understanding or knowledge developed as a result of analyzing the inventory data?”

Inventory programs must evolve as questions change. Before another round of sampling, evaluate any changes to management’s information needs. Have the objectives changed, or have objectives been dropped or added?

Use caution when making improvements, as they can have at least two negative impacts. First, changes in data collected, measurement protocols, or estimation methods affect the ability to detect and quantify change over time. Second, making changes to the system may introduce errors or result in unintended consequences (dependencies within the system).

To mitigate these problems, develop a change-management process in which proposed changes are reviewed by a team of stakeholders with expertise in sampling design and estimation, field methods, information management, data analysis, and management. The team will help ensure that changes do not create additional problems and that estimates of change over time can be maintained (sometimes by applying old and new methods for a time). They may even determine that the improvement is not sufficient to justify the additional cost and consequences.

4.8.2 Program Efficiency

Program efficiencies can result from a combination of (1) change in technologies used to support planning, design, and collection of data and (2) the use of after-action reviews to identify efficiencies and improvements in various practices.

Technological Improvements

Although the use of GIS, GPS, field data recorders, and laser-measuring devices have been incorporated into inventory design, planning and data collection, other technologies may also affect program efficiency.

Inventory and monitoring applications development, particularly the use of remote sensing, has contributed significantly to program efficiencies over the years. Remote sensing increases operational efficiency by providing information that enables one to field sample only some of the plots. It also improves precision of estimates, primarily through stratification, and supports small area estimation. Remote sensing adds information not available from field measurements (e.g., vegetation pattern metrics plots) and provides opportunity for more timely revisits for information like land cover and land use change.

For example, within the FIA program, remote sensing was recognized as early as 1946 with the first use of aerial photography. The shift from statewide line transects to photo-based nested plots cut the number of plots required to one-third of the original total, while adding even more accuracy to permit publishing statistics for individual counties (Morgan 1960). Later, the use of photo interpretation in the Forest Survey program (now FIA) facilitated a new sampling design (two-phase sampling or double sampling with stratification). This design introduced by Bickford (1952) presented the concept of stereoscopically classifying a grid of points on an aerial photo. The points were stratified into a set of classifications, such as forest, nonforest, etc. This concept is the heart of the current FIA design and forest inventories worldwide. Within the current FIA program, emphasis has increased on remote sensing and other **geospatial data** and analyses. In the uncertain fiscal environments faced by land management agencies, remote sensing data provide opportunities to develop information in a more cost effective manner (Nelson et al. 2007).

In a similar way, remote sensing plays a pivotal role for NFS inventory and monitoring activities. From the 1940s through the present, aerial photography and imagery has been the basis for most stand delineations and subsequent stand exam programs. Individual stand-level exams and compartment inventories have used aerial photo delineation and interpretation to establish photo interpretation strata for statistical inference (Stage and Alley 1972). The Forest Service currently uses aerial imagery to photo sample, estimate, and continuously model tree canopy cover for the National Land Cover Database tree canopy cover layer (Coulston et al. 2012). Technological advances have also been made in geospatial delivery of inventory data (Nelson et al. 2007, Wilson et al. 2012).

After-Action Reviews

The end of an inventory or field season is a good time to reflect on lessons learned using an after-action review. Bringing the inventory team together to discuss fieldwork logistics, emerging technology, and suggestions for future efforts provides the opportunity to identify and capture suggestions directly from individuals involved in the most expensive part of any inventory process.

In a similar way, structured interactions with management can be helpful in improving the efficiency of the program. If objectives were not met, what would change in another round of sampling? If precision requirements were not met, perhaps the sampling intensity could be modified or sample design altered. If cost constraints were not met, look for opportunities to improve precision and field efficiencies.

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6.0 Glossary

For some terms, one or more definitions are given, and often more than one is in common usage.

abiotic. Pertaining to the nonliving parts of an ecosystem, such as soil particles, bedrock, air, and water (Helms 1998 as cited in FGDC 2008).

absolute composition. List of the absolute amounts of each plant species present in a given area or stand, expressed as percent cover (Jennings et al. 2003).

abundance. The total number of individuals of a taxon or taxa in an area, volume, population or community; often measured as cover in plants (Lincoln et al. 1998 as cited in FGDC 2008).

accuracy. The closeness of results of observations, computations or estimates to the true values or the values accepted as being true (FGDC 1998).

accuracy assessment. In mapping, the process by which the accuracy or correctness of an image (or map) is evaluated.

accuracy assessment site. In mapping, the site identified on a satellite image (or map) and on a reference dataset for the purposes of an accuracy assessment of the image or map (Lachowski et al. 1996).

alliance. A vegetation classification unit containing one or more associations, with a defined by a characteristic range of species composition, habitat conditions, physiognomy, and diagnostic species, typically at least one of which is found in the upper most or dominant stratum of the vegetation (Jennings et al. 2006 as cited in FGDC 2008).

association. A vegetation classification unit 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).

association table. Summary of species data by plot for a given association. Association tables are essential to determine plot membership in a type and are used for comparison of individual plots to other plots in a type. They may include information on environmental characteristics (e.g., slope, aspect, or elevation). See also **synthesis table**.

attribute. A defined characteristic of an entity type (e.g., composition; FGDC 1998).

attribute gaps. The attribute(s) needed to answer the question was not measured in previous studies or was measured without sufficient detail (e.g., classes instead of continuous measurements).

business needs. Ongoing tasks related to a particular business or project and the information and other support contributing to the completion of these tasks.

business requirements. "A business need identified as necessary for successful achievement of business goals/objectives, (including strategic, tactical, legal, or operational objectives). Business requirements may be represented in a variety of contexts and are most often defined in response to establishing requirements for processes, compliance to business direction, and to identification of information technology functionality requirements" (USDA Forest Service 2009a: 18).

canopy cover. The percentage of ground covered by the vertical projection of the outermost perimeter of the natural spread of foliage of plants. Small openings in the canopy are included (SRM 1989 and USDA NRCS 1997, as cited in FGDC 2008). Contrast with **foliar cover**.

character species. A species that shows a distinct maximum concentration (quantitatively and by presence), in a well-definable vegetation type, sometimes recognized at local, regional, and general geographic scales. Character species may also be viewed as very strong differential species (Bruelheide 2000 as cited in FGDC 2008, Mueller-Dombois and Ellenberg 1974: 93).

class. A group of individuals or other units similar in selected properties and distinguished from all other classes of the same population by differences in these properties (Buol et al. 1973).

classification. (1) The process of grouping similar entities into named types or classes based on shared characteristics. (2) The grouping of similar types (in this case, vegetation) according to criteria (in this case, physiognomic and floristic) (FGDC 2008).

classification methodology standards. Procedures to follow to implement a data classification standard. Procedures describe how data are analyzed to produce a classification (FGDC 1996).

classification scheme or system. A set of target classes or a legend that serves as the basis of a classification or map (Lachowski et al. 1996).

community. (1) A group of organisms living together and linked together by their effects on one another and their responses to the environment they share (Whittaker 1975 as cited in FGDC 2008). (2) Any group of organisms interacting among themselves (Daubenmire 1978). (3) A general term for an assemblage of plants living together and interacting among themselves in a specific location; no particular ecological status is implied.

community composition. The kinds, absolute amounts, or relative proportions of plant species present in a given area or stand. It can be described qualitatively or quantitatively. The latter may use absolute amounts or relative proportions of the plant taxa present. Typically expressed as percent cover for each plant taxon (Jennings et al. 2003).

community type. An aggregation of all plant communities with similar structure and floristic composition. A unit of vegetation in a classification with no particular successional status implied. See also **vegetation type**.

composition. (1) The amount or proportion of the plant species on a given area (adapted from SRM 1989). (2) A list of the species that comprise a community or any other ecological unit (Lincoln et al. 1998).

constancy. The percentage of plots in a given data set that a taxon occurs in (Jennings et al. 2006 as cited in FGDC 2008). If a particular community has 10 plots and a taxon is found in 8 of the 10, the constancy of that taxon is 80 percent.

constant species. “species that are present in a high percentage of the plots that define a type, often defined as those species with at least 60 percent constancy” (Mueller-Dombois and Ellenberg 1974, as cited in FGDC 2008: 57).

coordinates. In mapping, pairs of numbers that express horizontal distances along orthogonal axes; alternatively, triplets of numbers measuring horizontal and vertical distances (FGDC 1998).

cover from above (CFA). The percentage of ground covered by a vertical projection of the outermost perimeter of the natural spread of foliage of plants visible from above. Any portion of a taxon, growth form, layer, or size class that is overtopped by taller vegetation is excluded from cover from above. Small openings in the canopy are included as cover. Contrast with **canopy cover** and **foliar cover**.

cover type. A vegetation type defined on the basis of the plant species forming a plurality of composition and abundance (Eyre 1980 as cited in FGDC 2008). The Society of American Foresters (SAF) forest cover types (Eyre 1980) and the Society for Range Management (SRM) rangeland cover types (Shiflet 1994) are examples of cover types.

cultural vegetation. Vegetation with a distinctive structure, composition, and development determined by regular human activity (cultural vegetation sensu stricto of Küchler as cited in FGDC 2008). Cultural vegetation has typically been planted or treated, and has relatively distinctive physiognomic, floristic, or site features when compared with natural vegetation (FGDC 2008). Contrast with **natural/seminatural vegetation**.

data classification standard. Provides groups or categories of data that serve an application (e.g., wetland and soil classifications; FGDC 1996). In other words, a data classification standard specifies and defines a set of categories that must be used or crosswalked to by Federal agencies. The physiognomic levels of the National Vegetation Classification Standard are a data classification standard.

data element. A logically primitive item of data (FGDC 1998).

data reconciliation. The comparison of the same data element at two points in time and the process used to reconcile any observed differences.

dataset. A collection of related data (FGDC 1998). See also **geospatial data**.

data standards. Describe objects, features, or items that are collected, automated, or affected by activities or functions of agencies. Data standards are semantic definitions that are structured in a model (FGDC 1996).

data steward. A person designated to manage large datasets and ensure their updating and quality.

data validation. Evaluating the completeness, correctness, and conformance of specific data and evaluating these data to determine the data quality. The evaluation for completeness, correctness, and conformance is sometimes called verification (U.S. EPA 2002) and begins with the software to collect the data in the field.

diagnostic species. Any species or group of species whose relative constancy or abundance differentiates one vegetation type from another (Jennings et al. 2006 as cited in FGDC 2008). It can include character, differential, constant, indicator or dominant species. Some authors restrict the term to include only character, differential, and constant species (Westhoff and van der Maarel 1973 as cited in FGDC 2008).

diameter at breast height (DBH). The mean diameter at 4.5 feet or 1.37 meters above the ground (Helms 1998).

differential species. A plant species that is distinctly more widespread or successful in one of a pair of plant communities than in the other, although it may be still more successful in other communities not under discussion (Curtis 1959 and Bruelheide 2000 as cited in FGDC 2008).

digital elevation model (DEM). Digital data file containing an array of elevation information over a portion of the Earth's surface (USDA Forest Service 1999).

digital image or imagery. A two-dimensional (2-D) array of regularly spaced picture elements (pixels) constituting a picture (FGDC 1998).

digital orthophoto quad (DOQ). Digital representation of an aerial photo with ground features located in their actual ("true") positions (USDA Forest Service 1999).

division. The fourth level in the National Vegetation Classification (NVC) natural vegetation hierarchy, in which each vegetation unit is defined by a group of plant communities in a given continental or other broad geographic area exhibiting a common set of dominant growth forms and many diagnostic plant taxa (including character taxa of the dominant growth forms) corresponding to broad climatic and environmental characteristics (Westhoff and van der Maarel 1973, Whittaker 1975 as cited in FGDC 2008).

dominance. The extent to which a given taxon or growth form has a strong influence in a community because of its size, abundance, or cover (Lincoln et al. 1998 as cited in FGDC 2008).

dominance type. A class of communities defined by the dominance of one or more species, which are usually the most important ones in the uppermost or dominant layer of the community, but sometimes of a lower layer of higher coverage (Gabriel and Talbot 1984 as cited in FGDC 2008).

dominant species. The species with the highest percent of cover, usually in the uppermost dominant layer (in other contexts dominant species can be defined in terms of biomass, density, height, coverage, etc.; Kimmins 1997 as cited in FGDC 2008).

double sampling for stratification. A sample design alternative for when stratum sizes cannot be known with certainty but can be estimated by sampling. Sample allocation and estimation of the totals are the same as for stratified random sampling. Samples are chosen as a subsampling of the points (Cochran 1977).

dwarf trees. Trees that are typically less than 39.4 feet (12 meters) tall at maturity due to genetic and environmental constraints (e.g., pinyons and junipers; FGDC 2008).

dynamic sampling. The collection and analysis of resource data to measure changes in the amounts, spatial distribution, or condition of resource types or parameters over time (adapted from Helms 1998).

ecosystem. (1) A complete interacting system of organisms and their environment (USDA Forest Service 1991). (2) A community of organisms and their physical environment interacting as an ecological unit: the entire biological and physical content of a biotope (Lincoln et al. 1998).

ecotone. The boundary or transitional zone between adjacent communities or biomes; tension zone (Lincoln et al. 1998).

electromagnetic spectrum. The range of energy transmitted through space in the form of electric or magnetic waves, extending from cosmic waves to radio waves. Included in this spectrum are visible and infrared regions that are particularly important for land remote sensing applications (Lachowski et al. 1996).

element. Parts of the sections or chapters in the Federal Geographic Data Committee (FGDC) Content Standards for Digital Geospatial Metadata (http://www.fs.fed.us/gac/metadata/glossary.html). They are numbered starting with the section number. A set of elements with subparts is called a compound element, for example, 2.1.1 (Data Quality Information, Attribute Accuracy, Attribute Accuracy Report). The FGDC standard contains 334 different elements, 119 of which exist only to contain other elements (FGDC 1998).

error matrix. A contingency table used as a starting point for a series of descriptive and analytical statistical techniques used for accuracy assessment of maps or other products. Error matrices score each observation (sample) according to the class it has been assigned to in the classified map and the actual ("true") class, as determined by reference data. Error matrixes are sometimes referred to as confusion or difference matrixes because reference data are not always absolutely accurate (Lachowski et al. 1996).

evaluation. An appraisal and study of social, economic, and ecological conditions and trends relevant to a unit. The analysis of monitoring data that produces information needed to answer specific monitoring questions. Evaluation may include comparing monitoring results with a predetermined guideline or expected norm that may lead to recommendations for changes in management, a land management plan, or monitoring plan. Evaluations provide an updated compilation of information for use in environmental analysis of future project and activity decisions (USDA Forest Service 2009a).

existing vegetation. Vegetation found at a given location at the time of observation (Jennings et al. 2006 as cited in FGDC 2008). Contrast with **potential natural vegetation**.

Federal Geographic Data Committee (FGDC). An interagency committee, organized in 1990 under the Office of Management and Budget Circular A-16, that promotes the coordinated use, sharing, and dissemination of geospatial data on a national basis. The FGDC is composed of representatives from 17 Cabinet-level and independent Federal agencies.

Federal Geographic Data Committee (FGDC) compliant metadata. To be compliant with the FGDC metadata standard, a metadata record must successfully pass through the FGDC metaparser. The metaparser is often run directly from the metadata creation tool, such as MetaLite, but can also be run separately. If the record is incomplete or improperly formatted, the metaparser flags the errors. In general terms, FGDC compliant metadata can be relatively simple or complex depending on the number of elements that are required. If the metadata exists for a required element, it should be entered (FGDC 2008).

fidelity. The degree to which a species is confined in a given vegetation unit. The fidelity of a species determines whether it can be considered a **differential** or **character** species, or just a companion (a species not particularly restricted to any vegetation type) or accidental species (a species not normally occurring in a particular vegetation type or habitat: Bruelheide 2000, Lincoln et al. 1998 as cited in FGDC 2008).

flora (adj. floral, floristic). (1) All the plant species that make up the vegetation of a given area (Allaby 1994). (2) The plant life of a given region, habitat, or geological stratum (Lincoln et al. 1998).

floristic classification. Classification of plant communities, emphasizing species composition. It may include considerations of species abundance, dominance, growth form, and so on. Floristic classification emphasize the plant species comprising the vegetation instead of life forms or structure. Floristic classifications are based on community composition and diagnostic species.

floristic composition. A list of plant species of a given area, habitat, or association (Lincoln et al. 1998).

foliar cover. The percentage of ground covered by the vertical projection of the aerial portion of plants. Small openings in the canopy and intraspecific overlap are excluded (SRM 1989 as cited in FGDC 2008).

forb. A nonaquatic, nongraminoid herb with relatively broad leaves and/or showy flowers. Includes both flowering and spore-bearing, nongraminoid herbs (FGDC 2008).

formation class. The first (highest) level in the National Vegetation Classification (NVC) natural vegetation hierarchy, in which each vegetation unit is defined by a characteristic combination of dominant growth forms adapted to a very basic set of moisture/temperature regimes (FGDC 2008).

geographic area of interest. The geographic extent that is to be studied.

geographic information system (GIS). The term frequently applied to geographically oriented computer technology. In its broadest sense, GIS is a system for capturing, storing, checking, manipulating, analyzing, and displaying data that are spatially referenced to the Earth (Lachowski et al. 1996).

geometric correction. An image processing technique that reorients the image data to compensate for the Earth's rotation and variations in satellite position and attitude (USDA Forest Service 1999).

geospatial data. Information that identifies the geographic location and characteristics of natural or constructed features and boundaries on the earth. This information may be derived from, among other things, remote sensing, mapping, and surveying technologies (FGDC 1998).

global positioning system (GPS). An array of space satellites and ground receivers that uses geometry to provide information about the precise latitude, longitude, and elevation of a particular point (Lachowski et al. 1996).

grid. (1) A set of grid cells forming a regular, or nearly regular, tessellation of a surface. (2) Set of points arrayed in a pattern that forms a regular, or nearly regular, tessellation of a surface. The tessellation is regular if formed by repeating the pattern of a regular polygon, such as a square, equilateral triangle, or regular hexagon. The tessellation is nearly regular if formed by repeating the pattern of an almost regular polygon, such as a rectangle, nonsquare parallelogram, or non-equilateral triangle (FGDC 1998).

group. The sixth level in the National Vegetation Classification (NVC) natural vegetation hierarchy, in which each vegetation unit is defined by a group of plant communities with a common set of growth forms and diagnostic species or taxa (including several character species of the dominant growth forms), preferentially sharing a similar set of regional edaphic, topographic, and disturbance factors (cf. Pignatti et al. 1994, Specht and Specht 2001 as cited in FGDC 2008).

growth form. The shape or appearance of a plant reflecting growing conditions and genetics. Growth form is usually consistent within a species, but may vary under extremes of environment (Mueller-Dombois and Ellenberg 1974 as cited in FGDC 2008). Growth forms determine the visible structure or physiognomy of plant communities (Whittaker 1975 as cited in FGDC 2008).

habitat. (1) The combination of environmental or site conditions and ecological processes influencing a plant community (Jennings et al. 2003). (2) A general term referring to the locality, site and particular type of local environment occupied by an organism or community (Lincoln et al. 1998 as cited in FGDC 2008).

habitat type. A collective term for all parts of the land surface supporting, or capable of supporting, a particular kind of climax plant association (Daubenmire 1978; Gabriel and Talbot 1984 as cited in FGDC 2008). See also **potential natural vegetation**.

herb. A vascular plant without perennial aboveground woody stems, with perennating buds borne at or below the ground surface (Whittaker 1975 as cited in FGDC 2008). Includes forbs (both flowering forbs and spore-bearing ferns), graminoids, and herbaceous vines (FGDC 2008).

horizontal. Tangent to the geoid or parallel to a plane that is tangent to the geoid (FGDC 1998).

image classification. The process of assigning the pixels of an image to discrete categories or classes (Lachowski et al. 1996).

image interpretation. (1) The systematic examination of image data; frequently involves other supporting materials, such as maps and field observations (Lillesand and Kiefer 1994). (2) Basis for delineation of map units is normally discontinuities in texture reflecting life form composition, stocking, tree crown size differences, and/or apparent tree height (Stage and Alley 1972).

image processing. A general term referring to manipulation of digital image data; includes image enhancement, image classification, and image preprocessing (or rectification) operations (Lachowski et al. 1996).

image segmentation. The process of dividing digital images into spatially cohesive units or regions. These regions represent discrete objects or areas in the image (Ryerd and Woodcock 1996).

imputation. The process of estimating missing data (Schreuder et al. 1993b). and the production of Nearest Neighbor imputation–based data surfaces (i.e., geospatial modeling of design-based inventory data; Grossmann et al. 2009, Wilson et al. 2012).

indicator species. (1) A species whose presence, abundance, or vigor is considered to indicate certain site conditions (Gabriel and Talbot 1984 as cited in FGDC 2008). (2) Species that are sensitive to an important environmental feature of a site such that their constancy or abundance reflect significant changes in environmental factors.

inventory. (1) To survey an area or entity for determination of such data as contents, condition, or value, for specific purposes such as planning, evaluation, or management. An inventory activity may include an information needs assessment; planning and scheduling; data collection, classification, mapping, data entry, storage and maintenance; product development; evaluation; and reporting phases (USDA Forest Service 2009a). (2) An objective set of sampling methods designed to quantify the spatial distribution, composition, and rates of change of resource parameters within specified limits of statistical precision and the listing (enumeration) of data from such a survey (following Helms 1998). Contrast with **monitoring**.

land cover. (1) The ecological state and physical appearance of the land surface (e.g., forest and grassland). Note that land may be changed by human intervention, natural disturbances, or plant succession (Helms 1998). (2) The observed (bio)physical cover of the Earth's surface (Di Gregorio and Jansen 1996 as cited in FGDC 2008).

layer (geographic information system [GIS]). A digital information storage unit; also known as theme. Different kinds of information (e.g., roads, boundaries, lakes, and vegetation) can be grouped and stored as separate digital layers or themes in a GIS (Lachowski et al. 1996).

layer (mapping). An integrated, areally distributed, set of spatial data usually representing entity instances within one theme, or having one common attribute or attribute value in an association of spatial objects. In the context of raster data, a layer is specifically a two-dimensional (2-D) array of scalar values associated with all of part of a grid or image (FGDC 1998).

layer (vegetation). (1) A structural component of a community consisting of plants of approximately the same height and growth form (e.g., tree overstory, tree regeneration; FGDC 2008). (2) The definition and measurement of these structural components in their vertical and height relationships to each other (e.g., tree subcanopy layer, shrub understory layer; adapted from ESA, Nature Conservancy, USGS, FGDC 1999).

life form. (1) The characteristic structural features and method of perennation of a plant species; the result of the interaction of all life processes, both genetic and environmental (Lincoln et al. 1998). Life form is related to growth form, physiognomy, and habit but also includes consideration of the type and position of renewal (perennating) buds that the other terms typically do not include. (2) Includes gross morphology (size, woodiness, etc.), leaf morphology, life span, and phonological (or life cycle) phenomena (Barbour et al. 1980). (3) Plant type defined by the characteristic structural features and method of perennation, generally as defined by Raunkiaer (1934; see Beard 1973 as cited in FGDC 2008).

map. (1) A spatial representation, usually graphic on a flat surface, of spatial phenomena (FGDC 1998). (2) A representation, usually on a plane surface, of a region of the Earth or heavens (Robinson et al. 1978).

map feature. An individual area or delineation on a map is a map feature. Specific map features are nonoverlapping and geographically unique, but will contain one or more thematic components (i.e., map unit) that may be repeated across multiple map features. Map feature is synonymous with the commonly used terms of polygon and region.

map keys. Define relationships between the taxonomic units or technical groups from vegetation classifications and the map units identified in the map unit design process. Map keys are developed as a part of the map unit design process and included in project metadata.

map levels. Define different intensities of field study, different degrees of detail in mapping, different levels of abstraction in defining and naming map units, and different map unit designs. Adjustment in these elements forms the basis for differentiating four levels of vegetation mapping: (1) national, (2) broad, (3) mid, and (4) base. The levels are intended to aid in identifying the operational procedures used to conduct vegetation mapping activities and also indicate general levels of the QC applied during mapping. These levels affect the kind and precision of subsequent interpretations and predictions (adapted from USDA Soil Conservation Service 1993).

map unit. A collection of features defined and named the same in terms of their vegetation characteristics (USDA Soil Conservation Service 1993). Each map unit differs in some respect from all others in a geographic extent. Map units are differentiated in map unit design and defined in a map unit description. Design of map units generalizes the taxonomic units present to the smallest set that (1) meets the objectives of the map, and (2) is feasible to delineate with available resources and technology.

map unit design. The process establishing the relationship between vegetation classifications and map products depicting them.

metadata. Information about data. The term describes the content, quality, condition, and other characteristics of a given dataset. Its purpose is to provide information about a dataset or some larger data holdings to data catalogues, clearinghouses, and users. Metadata are intended to provide a capability for organizing and maintaining an institution's investment in data and to provide information for applying and interpreting data received through a transfer from an external source (FGDC 2008).

minimum map feature. Smallest map feature delineated; requirements vary for different map levels. (Note: The term *minimum map feature*, as used in this technical guide, is analogous to the term *minimum mapping unit*, which is widely [although imprecisely] used in the mapping literature.)

modeling units. The elemental modeling entities for the mapping process. Modeling units can be polygons (manual delineations or regions of raster cells) or individual raster cells.

monitoring. (1) The collection and analysis of repeated observations or measurements to evaluate changes in condition and progress toward meeting a resource or management objective. A monitoring activity may include an information needs assessment; planning and scheduling; data collection, classification, mapping, data entry, storage, and maintenance; product development; evaluation; and reporting phases (USDA Forest Service 2009a). (2) The systematic collection, analysis, and interpretation of resource data to evaluate progress toward meeting management objectives (adapted from SRM 1989). Contrast with **inventory**.

multispectral. Sensors or images that record or display data from two or more bands of the electromagnetic spectrum (USDA Forest Service 1999).

natural/seminatural vegetation. Vegetation where ecological processes primarily determine species and site characteristics; that is, vegetation comprised of a largely spontaneously growing set of plant species that are shaped by both site and biotic processes (Küchler 1969, Westhoff and van der Maarel 1973 as cited in FGDC 2008). Contrast with **cultural vegetation**.

noise. In vegetation data analysis, nonmeaningful variation in species abundances that obscure patterns and relationships in the dataset. Sources of noise include chance distribution and establishment of seeds, local disturbances, microsite variation, outliers, and misidentification of species.

nonvascular. A plant or plant-like organism without specialized water or fluid conductive tissue (xylem and phloem). Includes mosses, liverworts, hornworts, lichens, and algae (FGDC 2008).

nonvegetated (mapping). A category used to classify lands with limited capacity to support life and typically having less than 1 percent vegetative cover. Vegetation, if present, is widely spaced. The typical components of the surface of barren land are sand, rock, exposed subsoil, or salt-affected soils. Subcategories include salt flats; sand dunes; mud flats; beaches; bare exposed rock; quarries, strip mines, gravel pits, and borrow pits; river wash; oil wasteland; mixed barren lands; and other barren land (adapted from NRI 2003 as cited in FGDC 2008). Exceptions include vegetation, which exhibits a distinct composition under very sparse conditions (e.g., sea rocket coastal shore vegetation, or amaranth coastal vegetation). These types rarely have greater than 1 percent cover (FGDC 2008).

nonvegetated (soil). Landscape usually associated with open water or human-modified land, such as heavy industrial commercial transportation facilities (adapted from USDA Soil Conservation Service 1993).

outlier. Refers to data or a sample that has low similarity to all other samples in the dataset.

overall accuracy. The number of samples where observed and mapped types agree divided by the total number of samples. The percentage of all samples where the observed and mapped types agree (Jensen 2004).

overstory tree diameter. The mean diameter at breast height (4.5 feet or 1.37 meters above the ground) for the trees forming the upper or uppermost canopy layer (Helms 1998).

patch. A relatively homogenous nonlinear area that differs from its surroundings (Forman 1995); can specifically describe forested patches, nonforest vegetation patches, rock/barren patches, or water patches.

pattern. Repeating coordinated species abundance and groups of samples with similar species composition.

physiognomic classification. A level in the classification hierarchy defined by the relative percent canopy cover of the tree, shrub, dwarf shrub, herb, and nonvascular life form in the uppermost strata during the peak of the growing season.

physiognomy. (1) The visible structure or outward appearance of a plant community as expressed by the dominant growth forms, such as their leaf appearance or deciduousness (Fosberg 1961, Jennings et al. 2006 as cited in FGDC 2008). (2) The overall size and shape of an organism. Descriptions such as “trees,” “shrubs,” and “herbs” are frequently used to characterize the general appearance of the vegetation of a region. Moreover, plant physiognomy can be broadly correlated with environmental conditions, so that regions of the world with similar climates tend to have a dominant vegetation of similar life forms. (3) The characteristic feature or appearance of a plant community or vegetation (Lincoln et al. 1998). (4) The overall appearance of a kind of vegetation (Barbour et al. 1980, Daubenmire 1968). (5) The expression of the life forms of the dominant plants and vegetation structure (Barbour et al. 1980, Mueller-Dombois and Ellenberg 1974).

pixel. Two-dimensional (2-D) picture element that is the smallest nondivisible element of a digital image (FGDC 1998). Contrast with **raster data**.

platform. In remote sensing, the physical object (e.g., balloon, rocket, or satellite) that carries the remote sensor. In computing use, may also refer to a type of technical system that is used for processing, displaying, querying, and storing information (e.g., a technology platform; Lachowski et al. 1996).

plot. (1) “A circumscribed sampling area for vegetation” (Lincoln et al. 1998: 235). (2) “Any two-dimensional (2-D) sample area of any size. This includes quadrats, rectangular plots, circular plots and belt transects (very long rectangular plots). Belt transects are often called strips or transects” (Mueller-Dombois and Ellenburg 1974:93). (3) In the context of vegetation classification, an area of defined size and shape that is intended for characterizing a homogenous occurrence of vegetation.

point. In reference to geospatial data, a zero-dimensional object that specifies geometric location. One coordinate pair or triplet specifies the location. Area point, entity point, and label point are special implementations of the general case (Brohman and Bryant 2005).

population. The area or aggregation of objects from which the sample is to be drawn (c.f. Bechtold and Patterson [2005], Cochran [1977]). In vegetation sampling, population is usually equivalent to the area of interest; however, the population may be larger to ensure that all of the area of interest is included, such as when sampling a mosaic of forest and nonforest areas.

potential natural vegetation (PNV). The vegetation that would become established if successional sequences were completed without interference by human or natural disturbance under the present climatic and edaphic conditions (Tüxen 1956 as cited in FGDC 2008). Concepts such as succession, site, and environmental factors are all part of PNV. Existing vegetation is simply what is growing at a location at the time of sampling. PNV classifications are based on existing vegetation, succession and environmental factors (e.g., climate, geology, soil) considered together. Although climax vegetation and PNV are sometimes used synonymously, common usage is for PNV to have a shorter time reference (e.g., decades to a few centuries) than that associated with climax vegetation (several centuries or more). Contrast with **existing vegetation**.

precision gap. The existing sample size is too small to achieve the precision required for the current analysis.

preferential sampling. Locating plots subjectively without preconceived bias (Mueller-Dombois and Ellenberg 1974).

probabilistic sample. A sample in which every sample unit has a known and positive probability of selection. Probabilistic (random) sampling of a population generates unbiased information about the population, including means and error estimates of the attributes of interest. By using a probabilistic sampling design, one can measure attributes of selected individuals of a population and infer results to the entire population.

process standards. Describe how to do something, procedures to follow, methodologies to apply, procedures to present information, or business rules to follow to implement standards (FGDC 1996).

project management. The discipline of planning, organizing, securing, and managing resources to achieve specific goals.

protocol. Repeatable instructions for inventory, monitoring, and assessment activities for such tasks as assessing information needs, and collecting, mapping, classifying, analyzing and evaluating, and applying information (USDA Forest Service 2009a).

quality assurance (QA). (1) The total integrated program for ensuring that the uncertainties inherent in inventory and monitoring data are known and do not exceed acceptable magnitudes, within a stated level of confidence. QA encompasses the plans, specifications, and policies affecting the collection, processing, and reporting of data. It is the system of activities designed to provide officials with independent assurance that quality control (QC) is being effectively implemented uniformly throughout the inventory and monitoring programs (USDA Forest Service 2009a). (2) A *process-based approach* for ensuring that the uncertainties inherent in inventory and monitoring data are made known and do not exceed acceptable magnitudes, within a stated level of confidence. QA encompasses the plans, specifications, and policies affecting the collection, processing, and reporting of data. The most cost-effective QA tool used to ensure the integrity of data is a comprehensive manual for data collection. A key concept of the QA component is an independent, objective review by a third party to assess the effectiveness of the internal QC program and the quality of the inventory. QA should also reduce or eliminate measurement error. In summary, a comprehensive QA review program provides the best available indication of the inventory's overall quality completeness, **accuracy**, precision, representativeness, and comparability of data gathered (USDA Forest Service 2010, U.S. EPA 1997).

quality control (QC). (1) The routine application of prescribed field and office procedures to reduce random and systematic errors and ensure that data are generated within known and acceptable performance limits. QC involves use of qualified personnel, reliable equipment and supplies, training of personnel, and strict adherence to servicewide standard operating procedures for tasks such as information needs assessments, establishment of standards and methods, data collection, data processing, classification, mapping, analysis, and dissemination (USDA Forest Service 2009a). (2) The routine application of prescribed field or database procedures to reduce random and systematic errors and ensure that data are generated, analyzed, interpreted, synthesized, communicated, and used within known and acceptable performance limits. *Whereas QA is a process-based approach, QC is a product-based approach*. QC encompasses hiring, training, and certifying qualified field crews; using reliable equipment and supplies; and adhering to recommended operating procedures, standardized protocols, and controls on lists of values. Data editing and data collection inspections are integral components of QC (USDA Forest Service 2010, U.S. EPA 1997).

quantitative inventory. The objective quantification of the amount, composition, condition, and/or productivity of resource types or parameters within specified levels of statistical precision (adapted from Helms 1998).

radiometric correction. In remote sensing, an image preprocessing technique that adjusts for influence from scene illumination, atmospheric conditions, viewing geometry, and instrument response characteristics (USDA Forest Service 1999).

raster data. Data organized in a grid of columns and rows. Raster data usually represent a planar graph or geographical area (Lachowski et al. 1996). Contrast with **pixel**.

reference data. (1) Ground truth data used in the image classification and accuracy assessment processes and/or for direct image interpretation. Ground truth data are assumed to be true information regarding surface features. In remote sensing projects, reference data serve two main purposes: (a) they establish a link between variation on the ground and in the image that is necessary for assigning image-modeling units (pixels or regions) to discrete land cover classes in the image classification process, and (b) they help assess the accuracy of a map. (2) Any secondary data that support the primary remote sensing data and thus may include the ancillary data used to classify the image (adapted from Lachowski et al. 1996).

reflectance. The total solar energy incident on a given feature minus the energy that is either absorbed or transmitted by the feature. Reflectance is dependent on the material type and condition and allows different features in a visual image to be distinguished (Lachowski et al. 1996).

relative composition. List of the proportions of each plant species relative to the total amount of all species present in a given area or stand (Jennings et al. 2003).

remote sensing. (1) The gathering of data regarding an object or phenomenon by a recording device (sensor) that is not in physical contact with the object or phenomenon under observation (Lachowski et al. 1996). (2) The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer 1994).

representative sampling. Systematic or random location of plots within strata. In vegetation classification rejection criteria may be necessary to avoid sampling obvious **ecotones**, which are of limited use for classifying vegetation. The gradsect technique or gradient directed sampling is one example of representative sampling (Austin and Heylingers 1991, as cited in Jennings et al. 2003).

resolution. The minimum difference between two independently measured or computed values that can be distinguished by the measurement or analytical method being considered or used (Brohman and Bryant 2005).

scale. (1) The relationship between a distance on a map and the corresponding distance on the Earth. For example, a scale of 1:24,000 means that 1 unit of measure on the map equals 24,000 of the same units on the earth's surface (Helms 1998). (2) In ecology, the level of spatial resolution perceived or considered (Helms 1998). (3) In general, the degree of resolution at which ecological processes, structures, and changes across space and time are observed and measured (Brohman and Bryant 2005).

sensor. A device that records electromagnetic radiation or other data about an object and presents it in a form suitable for obtaining information about the environment (Lachowski et al. 1996).

shrub. A woody plant that generally has several erect, spreading, or prostrate stems that give it a bushy appearance. For instances in which growth form cannot be determined, woody plants less than 16 feet (4.9 meters) in height at maturity shall be considered shrubs. Includes dwarf- shrubs, krummholz, and low or short woody vines (Box 1981 as cited in FGDC 2008).

simple random sample. A sample design in which plot locations are randomly chosen within the geographic area of interest until the desired number of samples is chosen (Gregoire and Valentine 2008).

site. An area delimited by fairly uniform climatic and soil conditions (similar to habitat).

spatial data. See geospatial data.

spatial gap. The existing data do not cover the entire area of interest.

spatial inventory compilation. The intersection of inventory data with map products. Spatial inventory compilation allows for the use of map information as classification (domain) variables; the inventory data are then summarized to quantify various vegetation characteristics for each map class.

spatial resolution. The measure of sharpness or fineness in spatial detail; determines the smallest object that can be resolved by a given sensor, or the area on the ground represented by each pixel. For digital imagery, spatial resolution corresponds to pixel size and may be understood as roughly analogous to grain in photographic images (Helms 1998).

species. In biological classification, the category below genus and above the level of subspecies and variety; the basic unit of biological classification (adapted from Lincoln et al. 1998).

stand. (1) A spatially continuous unit of vegetation with uniform composition, structure, and environmental conditions. This term is often used to indicate a particular example of a plant community (Jennings et al. 2006 as cited in FGDC 2008). (2) The basic unit of mapping and inventory (Graves 1913). (3) A community, particularly of trees, possessing sufficient uniformity regarding composition, age, spatial arrangement, or condition, to be distinguishable from adjacent communities, so forming a silvicultural or management entity (Ford-Robertson 1971). In the context of the protocol supported by this technical guide, the terms *patch* and *stand* may be synonymous, depending on the degree that management considerations are incorporated into stand delineations along with compositional and structural characteristics.

standard. Criteria for desirable or tolerable conditions, or a statement or demonstration representing conditions of a job done properly. Standards define how well something should be done, rather than what should be done (USDA Forest Service 2009a).

stratified random sample. A sample design that develops strata based on grouping similar entities, therefore reducing uncertainty in estimates for key attributes of interest within the strata and subsequently reducing the sample size to meet the precision requirements. This sample design focuses on minimizing the variability within strata and maximizing the variability between strata. (Cochran 1977).

stratum. In general, one of a series of layers, levels, or gradations in an ordered system. In the natural environment, the term is used in the sense of (1) a region of sea, atmosphere, or geology that is distinguished by natural or arbitrary limits, or (2) a structural component of a community consisting of plants of approximately the same height; e.g., tree, shrub, or herb strata (Jennings et al. 2006 as cited in FGDC 2008). (3) Strata in stratified random sampling (Cochran 1977) are used as a way to group similar entities therefore reducing variability of the key attributes of interest within the strata and subsequently reducing the sample size within each strata.

structure. (1) The spatial pattern of growth forms in a plant community, especially regarding their height, abundance, or coverage within the individual layers (Gabriel and Talbot 1984 as cited in FGDC 2008). (2) The spatial arrangement of the components of vegetation resulting from plant size and height, vertical stratification into layers, and horizontal spacing of plants (Lincoln et al. 1998, Mueller-Dombois and Ellenberg 1974 as cited in FGDC 2008).

succession. Partial or complete replacement of one community by another (Daubenmire 1978).

successive refinement. The basic working approach of community ecologists; involves repeated cycles of knowledge, questions, and observations (Gauch 1982, Pfister and Arno 1980).

supervised classification. A method of image classification that depends on the direct involvement of the analyst in the pattern recognition process. See also **unsupervised classification** (USDA Forest Service 1999).

synthesis table. Summary of mean and constancy by species and by types in a table with types across the top and species down the side. These tables are essential to compare between types. The data are summed by type in a synthesis table; association tables present data by plots or sample units.

systematic sample. A sample design in which a grid is randomly placed over the study area. Each point on the grid represents the same number of acres within the geographic area of inference and ensures a spatially balanced sample across the population (assuming that the population does not have any pattern that matches the grid; Cochran 1977).

tabular database. Data that describe things using characters and numbers formatted in columns and rows (Brohman and Bryant 2005).

tabular inventory compilation. A process used to compile an unbiased quantification of the composition of vegetation for the inventory area. After being compiled, inventory data summaries that quantify various vegetation characteristics for each map class can be produced.

taxonomic unit (taxon [s.], taxa [pl.]). The basic set of classes or types that comprise a classification. Taxonomic units can be developed for physiognomic classifications (e.g., tree dominated classes or shrub dominated classes), floristic classifications (e.g., dominance type classes or plant association classes), and they can be developed for structural classifications (e.g., canopy cover classes and/or tree size classes). Taxonomic units represent a conceptual description of ranges and/or modal conditions in vegetation characteristics. A taxonomic unit (or taxon) is a class developed through the scientific classification process, or a class that is part of a taxonomy (USDA Soil Conservation Service 1999).

temporal gap. The existing data are not current enough due to changing conditions.

terrain correction. An image processing technique that corrects for the distortion resulting from recording a three-dimensional view in two dimensions. Terrain correction is recommended if precise location is required, and if the study area has topographic relief differences greater than 500 feet (152.4 meters) (Lachowski et al. 1996).

theme. Group of data that represents a place or thing, such as soils, vegetation, or roads. A theme may be less concrete, such as population density, school districts, or administrative boundaries (Brohman and Bryant 2005).

theme (geographic information system). See layer.

tree. A woody plant that generally has a single main stem and a more or less definite crown. In instances where growth form cannot be determined, woody plants equal to or greater than 16 feet (4.9 meters) in height at maturity shall be considered trees (FGDC 2008). Includes dwarf trees (FGDC 2008) or treelets (Box 1981 as cited in FGDC 2008).

unsupervised classification. In mapping, a computer-automated method of spectral pattern recognition in which some parameters are specified by the user and used to uncover statistical patterns inherent in the image data (USDA Forest Service 1999). See also **supervised classification**.

vascular plant. A plant with specialized water or fluid conductive tissue (xylem and phloem; adapted from FGDC 2008). Includes seed plants, ferns, and fern allies.

vector data. Data that represent physical forms (elements) such as points, lines, and polygons. In terms of geographic information system (GIS), vectors typically represent a boundary between spatial objects (Lachowski et al. 1996).

vegetated. Areas having typically 1 percent or more of their surface area with live vegetation cover (FGDC 2008).

vegetation mapping. The process of delineating the geographic distribution, extent, and landscape patterns of vegetation types based on composition, physiognomy, and structure.

vegetation type. A named category of plant community or vegetation defined on the basis of shared floristic and/or physiognomic characteristics that distinguish it from other kinds of plant communities or vegetation (FGDC 2008). This term can refer to units in any level of the National Vegetation Classification (NVC) hierarchy (FGDC 2008).

vertical. At right angles to the horizontal; includes altitude and depth (FGDC 1998).

7.0 Abbreviations and Acronyms

ATIM	Analytical Tool for Inventory and Monitoring
BAER	Burned Area Emergency Response
BAF	basal area factor
BARC	Burned Area Reflectance Classification
CFA	cover from above
CIR	color infrared
CO	contracting officer
COR	contracting officer's representative
CS	Compilation System
CSE	Common Stand Exam
DATIM	Design and Analysis Toolkit for Inventory and Monitoring
DBH	diameter at breast height
DEM	digital elevation model
DOQ	digital orthophoto quad
DQA	Data Quality Act
DRC	diameter at root collar
ESA	Ecological Society of America
ESD	ecological site description
FACTS	Forest Service Activity Tracking System
FGDC	Federal Geographic Data Committee
FHM	Forest Health Monitoring
FIA	Forest Inventory and Analysis
FIADB	Forest Inventory and Analysis Database

FSH	Forest Service Handbook
FSM	Forest Service Manual
FSVeg	Field Sampled Vegetation
FSVeg Spatial	Field Sampled Vegetation Spatial
FVS	Forest Vegetation Simulator
GIS	geographic information system
GPS	global positioning system
InSAR	Interferometric Synthetic Aperture RADAR
IW	Interior West
JHA	job hazard analysis
LIDAR	Light Detection and Ranging
MIDAS	Mobile Integrated Data Acquisition System
MQO	measurement quality objective
MS	Microsoft
MTBS	Monitoring Trends in Burn Severity
NAIP	National Agriculture Imagery Program
NDVI	Normalized Difference Vegetation Index
NEPA	National Environmental Policy Act
NFMA	National Forest Management Act of 1976
NFS	National Forest System
NIMAC	National Inventory and Monitoring Applications Center
NIMS	National Information Management System
NLCD	National Land Cover Database
NRCS	Natural Resources Conservation Service
NRIS	Natural Resource Information System
NRM	Natural Resource Manager

NSDI	National Spatial Data Infrastructure
NVC	National Vegetation Classification
OCMA	ocular macroplot
OMB	Office of Management and Budget
PDR	portable data recorder
PNV	potential natural vegetation
PNW	Pacific Northwest Station
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PSW	Pacific Southwest Station
QA	quality assurance
QC	quality control
R&D	Research and Development
RAVG	Rapid Assessment of Vegetation Condition after Wildfire
RIPL	Region 1 Intensification Plot Locator
ROPL	Region 1 Plot Locator
RPA	Forest and Rangeland Resources Planning Act of 1974
RSAC	Remote Sensing Applications Center
S	shrub
S&PF	State and Private Forestry
SAF	Society of American Foresters
SIT	Spatial Intersection Tool
SL	low shrub
SM	medium shrub
SRM	Society for Range Management
ST	tall shrub
T	tree

TO	tree overstory
TOMC	main canopy
TOSB	subcanopy
TOSP	supercanopy
TR	tree regeneration
TRSA	sapling
TRSE	seedling
TEU	Terrestrial Ecological Unit
TEUI	Terrestrial Ecological Unit Inventory
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey