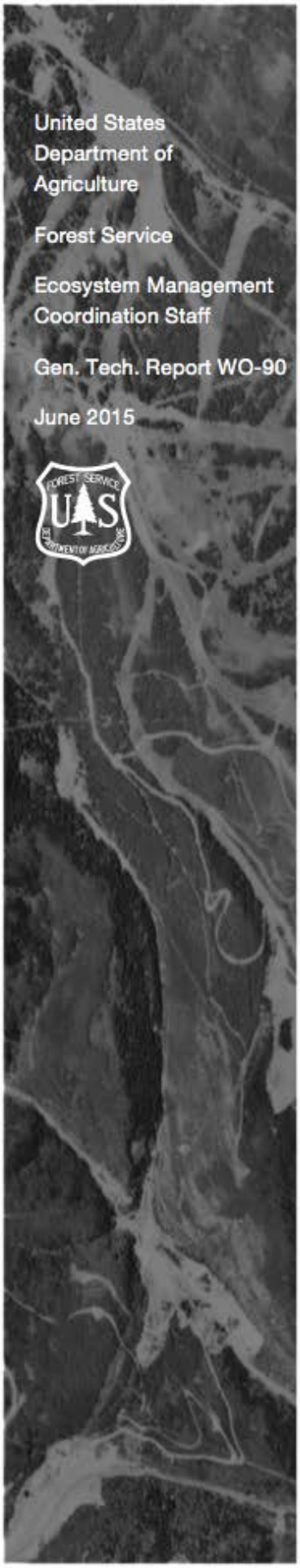

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Existing Vegetation Classification, Mapping, and Inventory Technical Guide Version 2.0

Appendixes

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Introduction

The *Existing Vegetation Classification, Mapping, and Inventory Technical Guide*, Version 2.0, (hereafter, the technical guide) provides 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 U.S. Department of Agriculture, Forest Service and its partners. The technical guide also includes geospatial and tabular database standards and guidelines that apply to existing vegetation data and information products.

The 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.

The purpose of appendixes A–K is to provide Forest Service personnel involved with existing vegetation classification, mapping, and inventory activities with additional details and examples about the guidance and methods described in the technical guide. These appendixes will be updated as new information becomes available (e.g., new vegetation types are added to the National Vegetation Classification [NVC] Standard, new remote sensing satellites are launched, or additional tools are developed and added to the Design and Analysis Toolkit for Inventory and Monitoring [DATIM]).

- Appendix A provides a variety of land cover definitions and describes Forest Service physiognomic units. The appendix should be used as a crosswalk to ensure compliance with the Federal Geographic Data Committee NVC Standard described in section 1.5.1 of the 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 provides a summary description of current active and passive remote sensing systems.
- Appendix D provides background information on the basics of image interpretation and presents an image interpretation workflow.
- Appendix E is list of regional tools for vegetation mapping, project examples, and protocols.
- Appendix F describes the DATIM project, which is a joint effort between the Forest Inventory Analysis (FIA) program and the National Forest System regional FIA coordinators to improve inventory and monitoring designs and data analyses by developing nationally consistent tools and by leveraging existing data.
- Appendix G focuses on methods to develop spatially balanced plot locations.
- Appendix H is a list of recommended field gear that is necessary to conduct an existing vegetation field inventory.
- Appendix I provides detailed guidelines on detecting and reconciling errors in existing inventory data.
- Appendix J provides a summary of the imputation of inventory data from sampled areas to populate unsampled units with data to create data surfaces for modeling.
- Appendix K is an example of job hazard analysis for inventory fieldwork.

Appendix A. Land Cover Definitions

Compiled by C. Kenneth Brewer and Monique L. Nelson

Both land cover classes and Forest Service physiognomic units are typically used in existing vegetation classification and mapping. Use of land cover classes ensures all land areas are classified and mapped, even if no vegetation exists on the site. The purpose of this appendix is to describe Forest Service physiognomic units (figure A-1). The appendix should be used as a crosswalk to ensure compliance with the Federal Geographic Data Committee National Vegetation Classification Standard described in section 1.5.1 of the *Existing Vegetation Classification, Mapping, and Inventory Technical Guide*, Version 2.0. The appendix also describes Anderson Land Cover classes, which include other land cover and land use classes besides existing vegetation, and National Land Cover Database classes. These three systems, which are widely used for vegetation and land cover classification and mapping, address Forest Service business needs.

Figure A-1.—*Key to Forest Service physiognomic units.*

1a	All vascular and nonvascular plants total < 1% canopy cover	**Non-Vegetated**
1b	All vascular and nonvascular plants total ≥ 1% canopy cover	2
	2a Vegetation structure and/or composition determined by regular human activity	3
	2b Vegetation comprised largely of a spontaneously growing set of plant species shaped by abiotic conditions and biotic processes	7
3a	Trees total ≥ 10% canopy cover	4
3b	Trees total < 10% canopy cover	6
	4a Stand dominated by planted, native tree species	**Forest & Woodland**
	4b Stand dominated by planted, non-native tree species	5
5a	Stand dominated by trees maintained by regular human activity	**Cultural Forest**
5b	Stand dominated by trees grown for agronomic purposes	**Agricultural Vegetation**
5c	Stand dominated by trees grown for ornamental purposes	**Developed Vegetation**
	6a Stand composed of planted crop, hay, or pasture species	**Agricultural Vegetation**
	6b Stand composed of planted ornamental species	**Developed Vegetation**
7a	All vascular and nonvascular plants total < 10% canopy cover	**Sparse Vegetation**
7b	All vascular and nonvascular plants total ≥ 10% canopy cover	8
	8a Terrestrial and emergent wetland plant species total < 1% canopy cover	9
	8b Terrestrial and emergent wetland plant species total ≥ 1% canopy cover	10
9a	Aquatic submerged and/or floating plant species total ≥ 10% canopy cover	**Aquatic Vegetation**
9b	Aquatic submerged and/or floating plant species total < 10% canopy cover	**Non-Vegetated (Water)**
	10a Trees total ≥ 10% canopy cover	11
	10b Trees total < 10% canopy cover	12
11a	Stand located above continuous forest line and tree species stunted (< 5m tall) by harsh alpine growing conditions	**Shrubland**
11b	Stand not above continuous forest line; trees not stunted due to cold	**Forest & Woodland**
	12a Shrubs total ≥ 10% canopy cover	**Shrubland**
	12b Shrubs total < 10% canopy cover	13
13a	Herbaceous vascular plants total ≥ 10% canopy cover	**Herbland**
13b	Herbaceous vascular plants total < 10% canopy cover	14
	14a Nonvascular plants total ≥ 10% canopy cover	**Nonvascular Vegetation**
	14b Nonvascular plants total < 10% canopy cover	**No Dominant Life Form**

This key applies only to existing vegetation, not potential or historical vegetation. Canopy cover as used in this key is cover from above as defined and discussed in Section 3 Mapping Existing Vegetation in the main technical guide text.

A.1 Forest Service Physiognomic Unit Definitions[1]

agricultural vegetation (AG). Areas that are dominated by vegetation grown for producing crops (food, nonwoody fiber, and ornamental horticulture), including land in any stage of annual crop production and land being regularly cultivated for the production of crops from perennial plants. Agricultural vegetation shows (1) rapid turnover in structure, typically at least annually, either through harvesting or planting, or by continual removal of aboveground structure (e.g., cutting, haying, or intensive grazing), or (2) strong linear (planted) features. The soil surface may be bare at various times of the year (FGDC 2008). Examples include row crops and closely sown crops; sod farms, hay, and silage crops; orchards (tree fruits and nuts, Christmas trees, nurseries of trees and shrubs), small fruits, and berries; vegetables and melons; unharvested crops; and idle cropland (can include land in cover and soil-improvement crops and cropland on which no crops were planted). When idle or fallow land becomes predominantly covered with nonmanipulated vegetation, then it is no longer agricultural vegetation.

aquatic vegetation (AQ). Areas where floating or submerged aquatic vegetation is the dominant vegetation layer, totaling at least 10 percent cover.
Note: Terrestrial and emergent plants must total less than 10 percent cover (Jennings et al. 2006).

cultural forest (CF). Cultivated or planted forest vegetation with a distinctive structure, composition, and development determined by regular human activity (Küchler 1969).

developed vegetation (DV). Areas predominantly covered by vegetation with highly manipulated growth forms (usually by mechanical pruning, mowing, clipping, etc.), but are not used for crop production (FGDC 2008). Examples include lawns, planted gardens, maintained utility rights-of-way, office parks, and cemeteries.

forest and woodland (FW). Tropical, temperate, and boreal forests, woodlands, and tree savannas characterized by tree life forms with at least 10 percent cover, where a tree is defined as a woody plant that, in general, has a single main stem and a more or less definite crown. For instances in which growth form cannot be determined, woody plants equal to or greater than 5 meters in height at maturity shall be considered trees (adapted from FGDC 2008). The definition of a tree also includes dwarf trees (Brohman and Bryant 2005) or “treelets” (Box 1981). Forest and woodlands include native forests as well as managed forests and some plantation forests, where human management is infrequent.
Note: The National Vegetation Classification (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.
Note: The 10 percent threshold for the Forest and Woodland physiognomic unit was selected to be consistent with the Forest Inventory and Analysis cover criteria within the definition of forest, the National Forest Management Act definition of forest, and the Food and Agriculture

[1] Definitions adapted from FGDC-STD-005-1998, FGDC-STD-005-2008 (Version 2), and Faber-Langendoen and others (2012) to meet Forest Service business needs.

Organization of the United Nations definitions of forests and forest change (FAO 1999, 2001). The Society of American Foresters Forest Cover Type definitions (Eyre 1980) use a 25 percent canopy cover threshold.

herbland (HB). Herbaceous vascular plants total greater than or equal to 10 percent canopy cover, where herbaceous vascular plants are defined as vascular plants without perennial aboveground woody stems, with perennating buds borne at or below the ground surface (FGDC 1997, Whittaker 1975). Includes forbs (both flowering forbs and spore-bearing ferns), graminoids, and herbaceous vines.
Note: Tree canopy cover or shrub canopy cover must be less than 10 percent.

no dominant life form (ND). Total vegetation cover, including nonvascular, constitutes greater than or equal to 10 percent cover, but with no single physiognomic class type equal to or exceeding 10 percent.
Note: This physiognomic unit ranges from 10 to 36 percent total vegetation cover comprising any combination from 9 percent nonvascular with 1 percent herb cover to 9 percent cover each of trees, shrubs, herbs, and nonvascular.

nonvascular vegetation (NV). Nonvascular plants total greater than or equal to 10 percent cover, where nonvascular plants are defined as plant or plant-like organisms without specialized water or fluid conductive tissue (xylem and phloem). Includes mosses, liverworts, hornworts, lichens, and algae (FGDC 2008). Growth is often concentrated on soil and rock surfaces (Jennings et al. 2006)

nonvegetated (NO). Cover of less than 1 percent vegetation during the peak of the growing season. 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 surface of barren land typically is 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 (Faber-Langendoen et al. 2012). Exceptions include vegetation that 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.

shrubland (SH). Shrubs total greater than or equal to 10 percent canopy cover, where a shrub is defined as a woody plant that, in general, has several erect, spreading, or prostrate stems, which give it a bushy appearance. For instances in which growth form cannot be determined, woody plants with less than 5 meters in height at maturity shall be considered shrubs. Shrubland also includes dwarf shrubs and low or short woody vines (adapted from FGDC 1997 and Box 1981).
Note: Tree canopy cover must be less than 10 percent.
Note: Some species may be shrubs or trees and height thresholds may vary depending on the ecological setting and range of the species.
Note: The National Vegetation Classification (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.

sparse vegetation (SV). Total vegetation cover, including nonvascular, constitutes less than 10 percent cover.

A.2 Anderson Land Cover Classification Descriptions

The Anderson Land Cover classifications (Anderson et al. 1976) are hierarchical, with Level 2 providing more detail of what types of land cover are included in Level 1. Forest Service physiognomic units correspond with Anderson Level 1 classifications (table A-1).

Level 1

Urban or Built-up Land comprises areas of intensive use with much of the land covered by structures. Included in this category are high-density developed areas, such as cities, commercial complexes, industrial areas, compact residential clusters, and strip areas along transportation corridors. Urban or Built-up Land is further classified into six subcategories.

Level 2

Residential Land uses range from high-density, multiunit structures located in urban centers to low-density, single-family homes located in areas on the periphery of suburban expansion, where houses are on lots greater than 1 acre. Rural residential and recreational subdivisions are also included in this category because this type of land is typically almost entirely committed to residential land use.

Commercial and Service Areas include urban central business districts, shopping centers, and commercial strips. These areas may also include some noncommercial uses too small to be identified separately. Institutional land uses, such as the various educational, religious, health, correctional, and military facilities, are also part of this category.

Industrial Areas range from light manufacturing facilities designed for assembly, finishing, processing, and packaging to heavy manufacturing facilities that use raw materials, such as iron ore, timber, or coal. These heavy manufacturing facilities can include mills, electrical power plants, tank farms, chemical plants. Stockpiles of raw materials and waste-product disposal areas are usually visible, along with transportation facilities capable of handling heavy materials.

Transportation, Communication, and Utility Land uses occur in some degree with all other urban or built-up land use categories. They will be included in each category unless they can be mapped separately from the land use in which they occur. For this reason, the statistical summary of these areas is only a portion of the total. Transportation classification typically includes highways, railways, parking lots, rail stations, rail yards, and airport facilities. Communication classifications include areas used for radio, radar, or television and phone towers. Utilities can include facilities and stations used in treating, processing, and transporting water, oil, gas, and electricity substations.

Mixed Urban or **Built-up Land** classification is used for a mixture of Level 2 categories in which individual uses cannot be separated. This use typically includes development

along transportation routes and in cities, towns, and other areas where separate land uses are mixed.

Other Urban or Built-up Land typically consists of uses such as golf courses and driving ranges, urban parks, cemeteries, waste dumps, water control structures, and ski resorts. It also includes land that is considered vacant or undeveloped within urban areas.

Level 1

Agricultural Land may be defined broadly as land used for producing food and fiber. Agricultural Land is further subdivided into three subcategories.

Level 2

Cropland and Pasture include cropland harvested, summer-fallow cropland on which failure occurs, cropland in soil improvement grass and legume areas, cropland used in pasture rotation with crops, and pastures on land more or less predominately used for the purpose of animal grazing.

Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas include orchards, groves, and vineyards that produce fruit and nut crops. Nurseries and horticultural areas include floricultural, seed-and-sod areas, greenhouses, and nurseries that provide seedlings for planting. Many of these areas may be included in other categories, such as cropland and pasture.

Confined Feeding Operations include large-scale, specialized livestock production enterprises, such as beef cattle feed lots, dairy operations with confined feeding, poultry farms, and hog feed lots.

Level 1

Forest Land contains a tree-crown aerial density (crown closure percentage) of 10 percent or more. These areas are stocked with trees capable of producing timber or other wood products, and they exert an influence on the climate or water regime. Forest Land is further subdivided into three subcategories.

Level 2

Deciduous Forest Land includes all forested areas having a predominance of trees that lose their leaves at the end of the frost-free season or at the beginning of a dry season. In most areas these forest lands include the hardwoods.

Evergreen Forest Land includes all forested areas where the trees are predominately those that remain green throughout the year. Both coniferous and broad-leaved evergreens are included in this category.

Mixed Forest Land includes all forested areas where both evergreen and deciduous trees are growing and neither is predominant. When more than one-third intermixture of either evergreen or deciduous species occurs in a specific area, it is classified as Mixed Forest Land.

Level 1

Water includes all areas that are persistently covered with water; provided these areas are at least one-eighth mile wide and if extended cover at least 40 acres. Water is further subdivided into three subcategories.

Level 2

Streams and Canals include rivers, creeks, canals, and other linear bodies of water. When the watercourse is interrupted by a control structure, the impounded area will be placed in the Reservoir category.

Lakes are nonflowing, naturally enclosed bodies of water, including regulated natural lakes, but excluding reservoirs. Islands that are too small to be delineated are included in the water area.

Reservoirs are artificial impoundments of water used for irrigation, flood control, municipal water supplies, recreation, hydroelectric power generation, and so forth. Dams, levees, other water-control structures, and the excavation of water-control structures and spillways are included in the Other Urban or Built-up Land category.

Level 1

Wetlands are areas where the water table is at, near, or above the land surface for a significant part of most years. Wetlands are usually associated with topographic lows, even in mountainous regions. The Wetlands classification is subdivided into one subcategory.

Level 2

Forested Wetlands are wetlands dominated by woody vegetation. They include flooded bottomland hardwoods, shrub swamps, and wooded swamps, including those around bogs.

Level 1

Barren Land is land with a limited ability to support life where less than one-third of the area has vegetation or other cover. In general, it is an area of thin soil or rock. Vegetation, if present, is thin, widespread, and scrubby. Barren Land is further subdivided into two subcategories.

Level 2

Strip Mines, Quarries, and Gravel Pits include mining activities that have significant surface cavities. Vegetation cover and overburden are removed to expose such deposits as coal, iron ore, limestone, and copper. Quarrying of building and decorative stone and recovery of sand and gravel deposits also result in large open surface pits and are included in this classification. Current mining activity is not always distinguishable, and inactive, unreclaimed, and active strip mines, quarries, borrow pits, and gravel pits are included in this category until other cover or use has been established.

Transitional Areas are categorized as areas in transition from one land use category to another. They are categorized when the data cannot be interpreted. These areas usually

include forests that are cleared for agricultural use, wetlands being drained for development, or when any type of land use ceases as areas become temporarily bare during construction for future uses.

Table A-1.—*Relationship between Anderson Level 1 and Forest Service physiognomic unit classifications.**

	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 Vegetatio		X							
Developed Vegetatio	X								
Non-vascular Vegetatio								X	
Aquatic Vegetatio						X		X	
Sparse Vegetatio	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.**

A.3 National Land Cover Database 2006 Classes

The National Land Cover Database (NLCD) 2006 is a 16-class land cover classification scheme that has been applied consistently across the conterminous United States at a spatial resolution of 30 meters (Fry et al. 2011). The classification system used by NLCD 2006 is modified from the Anderson (1976) system and is included in table A-2 as a general reference.

Table A-2.—*National Land Cover Database 2006 classification.*

Class\Value	Classification Description
Water	Areas of open water or permanent ice/snow cover.
11	Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.
12	Perennial Ice/Snow - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	Areas characterized by a high percentage (30% or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).
21	Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	Developed High Intensity -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no “green” vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the green vegetated categories; lichen cover may be extensive.
31	Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25% to 100% of the cover.
41	Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.
51	Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

Table A-2 (continued).—*National Land Cover Database 2006 classification.*

Class\Value	Classification Description
Water	Areas of open water or permanent ice/snow cover.
11	Open Water - areas of open water, generally with less than 25% cover of vegetation or soil.
12	Perennial Ice/Snow - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	Areas characterized by a high percentage (30% or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc.).
21	Developed, Open Space - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	Developed, Low Intensity - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	Developed, Medium Intensity – areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	Developed High Intensity -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no “green” vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the green vegetated categories; lichen cover may be extensive.
31	Barren Land (Rock/Sand/Clay) - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25% to 100% of the cover.
41	Deciduous Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	Evergreen Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	Mixed Forest - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.
51	Dwarf Scrub - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	Shrub/Scrub - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

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Appendix B. Map Assessment

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B.1. Overview

This appendix introduces methods for designing and implementing an accuracy assessment of existing vegetation map products produced in accordance with the guidance in section 3 of the *Existing Vegetation Classification, Mapping, and Inventory Technical Guide*, Version 2.0. This overview demonstrates four main points: (1) the links among inventory, classification, and mapping; (2) the purpose of the guidance provided; (3) key concepts related to accuracy assessment in the context of sample design, response design, and analysis protocol; and (4) applications and uses for existing vegetation map product accuracy assessments.

B.1.1 Conceptual Framework

As stated in section 1.4 of the technical guide, vegetation mapping is the process of delineating the geographic distribution, extent, and landscape patterns of vegetation types and structural characteristics. An accuracy assessment for vegetation map products produces statistical summaries or metrics, comparing the mapped classes with reference data or "truth." For accuracy assessment results to be interpreted correctly, statistical design principles should be used and detailed methods should be provided along with results.

B.1.2 Purpose

This appendix, Map Assessment, outlines a process to design and implement an accuracy assessment for map products developed following the protocol in section 3 of the technical guide. It also provides guidelines for processing and interpreting accuracy assessment data and results. The purpose of this appendix is to—

- Inform Forest Service employees about the importance of accuracy assessments for existing vegetation map products.
- Educate inventory users about the theory of accuracy assessment approaches.
- Illustrate how these approaches are implemented and how results are interpreted.

B.1.3 Key Concepts

Accuracy assessment is the process of characterizing the relationship between mapped feature labels and reference (true) map feature labels (Woodcock 1996). It involves statistical summaries or the calculation of metrics that compare mapped feature labels with reference feature labels. The accuracy assessment provides information about the quality or reliability of the map and can be used to determine the efficacy of the map regarding specific uses.

Accuracy assessments are essential parts of all remote sensing projects. During the project design process (see section 3.2 of the technical guide), accuracy metrics and requirements are used to 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. The concept of "accuracy" is predicated on the potential use of the map. For example, if a map is to be used for stand-level management, accuracy metrics applied to average, overstory tree-size classes might be useful for determining precommercial versus commercial thinning opportunities. If a vegetation map is used as input to a geospatial habitat suitability model, then

an accuracy assessment of the final habitat suitability map would help determine the value of the habitat map in support of land management decisions. It is thus critical that during the planning process, accuracy metrics relevant to the specific uses of the map are developed. An accuracy assessment characterizes the spatial data used in the decisionmaking processes.

Measuring Agreement/Accuracy Within a Mapped Area

Accuracy assessment depends on the collection of reference data. Reference data (commonly referred to as "ground truth") are composed of data that represent the map categories of interest at specific locations, and are assumed to be collected without error. The reference data can be obtained from ground visits, photo interpretation, video interpretation, or some combination of these methods. They generally co-occur and are coincident with the input data and map features used to create the map.

One important objective of an accuracy assessment is to quantify the level of agreement between mapped and observed attributes within an area. This assessment is performed for categorical maps by creating an error/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 shows the number of reference sites found in every combination of reference data category and map unit category. 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 presented in at least two ways:

1. An error matrix supports agreement as overall, producer's and consumer's/user's statistics as developed for the area from which results are tallied.

-or-

2. An error matrix supports agreement as marginal distributions comparing mapped and observed proportions as developed for the area from which results are tallied.

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 agree within the area. The first case is discussed in detail in the "error matrix" discussion section B.2.7 (Build the Error Matrix) and B.3.1 (Evaluating Producer's and Consumer's Accuracy; the second is discussed in detail under the comparing marginal distribution part of section B.3.1 (Evaluating Producer's and Consumer's Accuracy-KHAT/Kappa; discussion on Marginal Distributions; and method to develop KHAT statistic).

Scale of Agreement in an Accuracy Assessment

The interpretation of an accuracy assessment depends on its design. For example, if reference data are collected only near rivers, the accuracy assessment applies only to areas of unspecified size "near rivers," something that might not be very helpful when attempting to use the map to help manage vegetation communities away from rivers. Data that are distributed uniformly

across the landscape (e.g., Forest Inventory and Analysis [FIA] data) are thus helpful because they represent the full map extent.

In a mapping project, samples are typically collected for use as training data for the mapping process. Sometimes these samples are withheld and used to assess the accuracy of the map. It is important to ensure that data used for the accuracy assessment are collected using the principles of sampling theory. The probability of selecting each reference datum must be known and nonzero for accuracy results to be generated and reported in a way that enables users to interpret them through the lens of sampling theory. In contrast, a probability of selection is typically not placed on the collection of training data.

During the final mapping stages, modeling units (individual polygons) are usually aggregated to larger polygons, referred to as map features with a minimum mapping unit size (i.e., they are labeled and merged). This aggregation process may result in final map features that are more heterogeneous than envisioned during the map unit design process. Therefore, it is important to consider the relationship between available accuracy assessment data and final map features regarding homogeneity and map unit definition. It is important to maintain both spatial and definitional similarity between accuracy assessment data and map features.

FIA plots can be a viable source of accuracy assessment data if several assumptions are made: (1) they can be classified to correspond with map unit definitions; (2) the FIA plot, which consists of an array of four subplots, characterizes the map feature in which it sits; and (3) a sufficient number of FIA plots represent each of the map unit categories on the map. Furthermore, FIA has traditionally not collected vegetation data in portions of plots that do not meet FIA's definition of forest. One benefit of using FIA data for accuracy assessment, however, is that the cost savings associated with using existing data can be substantial, thus making it an attractive alternative to collecting new data for the sole purpose of accuracy assessment.

An accuracy assessment is typically done for the entire study area being mapped. When working with smaller subsets of the mapped area, the accuracy assessment for the larger map does not necessarily estimate the accuracy of a smaller geographic area. If smaller, unique areas, are being considered for use (e.g., a single ranger district within a forest) accommodations should be made to support an accuracy assessment in this area.

Accuracy Assessment Definitions

Some of the terms used most commonly when describing or performing an accuracy assessment are included here.

accuracy. The degree to which a measured quantity approaches the true value of what is being measured.

accuracy assessment. A process that quantitatively estimates the quality of a map for a specific use.

accuracy assessment site. A ground location where both the mapped and observed types are known.

chance agreement. The accuracy achieved when the observed and mapped marginal distributions, as derived from an error matrix, are assumed to be statistically independent (Jensen 2004).

commission error. Given all the samples that were mapped as a certain type, the percentage of those samples that were observed not to be of that same type. Commission error is calculated as 100 percent minus the user's accuracy (Campbell 2002).

consumer's/user's accuracy. The number of samples that are both mapped and observed to be of a particular type divided by the number of samples that are mapped as that same type. Given all samples that are mapped to be of a particular type, the percentage of those samples that are observed to be of that same type (Jensen 2004).

error matrix. A two-dimensional table of observed versus mapped samples. Each entry in the table accounts for one combination of mapped and observed types (Jensen 2004).

fuzzy logic. A type of reasoning designed to accommodate ambiguity. Using fuzzy sets in accuracy assessment permits explicit recognition of the possibility of ambiguity regarding appropriate map labels for some locations on a map/classification (Jensen 2004).

Kappa/KHAT statistic. A linear remapping of the overall accuracy to a scale in which a value of 0 indicates that the overall accuracy is equal to the chance agreement, and a value of 1 indicates that the overall accuracy is equal to 100 percent. Kappa is calculated as overall accuracy minus chance agreement divided by 100 percent minus the chance agreement (Jensen 2004). Some controversy is associated with the use of the Kappa statistic because it tends to take the observed categories' frequencies as known values. It is sometimes considered an overly conservative measure of agreement (Czaplewski 2003, Pontius and Millones 2011, Stehman 1997).

mapped marginal distribution. A listing of the error matrix row totals expressed as frequencies.

mapped type. The assignment of an attribute to a particular location on the ground as the result of a mapping process.

observed marginal distribution. A listing of the error matrix column totals expressed as frequencies.

observed type. The assignment of an attribute to a particular location on the ground as the result of direct observation either on the ground or from a higher source of truth.

omission error. Given all the samples that were observed to be of a certain type, the percentage of those samples that were not mapped as that same type. Omission error is calculated as 100 percent minus the producer's accuracy (Campbell 2002).

overall accuracy. The number of samples in which observed and mapped types agree divided by the total number of samples, or the percentage of all samples in which the observed and mapped types agree (Jensen 2004).

producer's accuracy. The number of samples that are both mapped and observed to be of a particular type divided by the number of samples that are observed to be of that same type. Given all samples that are observed to be of a particular type, the percentage of those samples that are mapped as that same type (Jensen 2004).

Overview of Accuracy Assessment Design Principles

The inventory design principles discussed in this section should be used to help ensure statistical validity and improve consistency when conducting an accuracy assessment. The principles described here are not exclusive of one another; rather, they are complementary and can each be applied to any inventory project.

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 addresses how and where the sites are located, while the response design describes the classification system. The analysis protocol determines the estimation procedures. For accuracy assessment data, the sample design should meet certain criteria to ensure that the assessment is statistically rigorous and scientifically valid. These criteria place restrictions on the collection of accuracy assessment data that do not apply to the collection of training data. Training data for generating a map may be collected according to a preferential (purposive) or representative sampling scheme, taking into account accessibility as well as distribution across the landscape. Accuracy assessment data are typically collected according to a sample design independent of the map being evaluated and evenly distributed across the landscape. For this reason, it is usually advisable to collect an alternate dataset to support an accuracy assessment.

Accuracy Assessment Sample Unit

The three types of accuracy assessment sample units are raster cells, polygons/map features, and fixed-area plots. It is not required that sample units for accuracy assessment correspond exactly with the spatial extent of the map features in the map product. The reference data, however, should be a generalization of the conditions within the map feature with which they are associated. Each type of sample unit has advantages and disadvantages outlined in Stehman and Czaplewski (1998). Because of locational accuracy issues, a cluster of pixels is often used as a surrogate for a polygonal map feature when map features are composed of pixels. Polygon sample units ideally correspond with individual map features. Reminder: If the map is updated, the accuracy assessment polygons may no longer correspond to the updated map polygons (section 3.4 of the technical guide). Fixed-area plots are independent of mapped polygons but

may include more than one map feature label within a plot (split conditions) that may make the plots undesirable for use as accuracy data.

Use of Forest Inventory and Analysis Data for Accuracy Assessments

FIA (http://www.fia.fs.fed.us/) is a nationwide census of forest resources using a systematic random sample design and three phases of sampling to provide information about status and trends of forest area, location, composition, and health. Bechtold and Patterson (2005) provide the details of the sample design, but it is essentially a nationwide array of 6,000-acre hexagons, each of which contains at least one permanent ground plot (section 4.3 of the technical guide). The advantage of using FIA data is that it represents an equal probability sample frame, and thus is well suited for accuracy assessment purposes. FIA collects sufficient plot data on tree structure and composition to address its business needs. FIA plots can be used for continuous or categorical data accuracy assessments for existing vegetation maps (Riemann et al. 2010). Using data that have already been collected using well-documented, standard protocols can significantly reduce costs of accuracy assessment sampling, but a number of issues should be considered.

1. The spacing of the plots dictates that the data are most useful for assessment of mapping efforts covering large areas, such as mid-, broad-, and national-level maps. Rare types may not be represented, and not all classes may have a sufficient number of samples to provide acceptable standard errors. A number of Forest Service regions have intensified their FIA sample grid, mitigating this issue to some extent (Milliken et al. 1998). In the event that rare types are of interest, a prestratified sampling design can be implemented, in which extra plots are put in map features thought to contain the rare type. Another option is to purposively collect reference data containing the rare type of interest, with known ground locations. This approach makes the assessment difficult to interpret because it is difficult to make inferences about the site as a whole, as opposed to just the areas that were chosen for assessment. In either method (prestratified from the map, or using known locations on the ground for obtaining rare map features for the accuracy assessment), the interpretation of the accuracy assessment metrics may be confounded.
2. Although the sample frame covers all vegetation types, trees are measured only on what FIA defines as forest land. Trees in nonforest areas are not recorded, so it is often difficult to classify FIA data into a nonforest vegetation type based on the ground plot data alone. There are, however, several areas where all vegetation on at least a subset of the plots is measured (see section 4.3 of the technical guide).
3. It is important to recognize that the year the FIA data (like other ground data) were collected needs to correspond as closely as possible with the date of the imagery used for the mapping to avoid violating the assumption that the sample and image data correspond.
4. Access to actual plot coordinates is restricted because of privacy concerns of private landowners and the need to ensure that FIA plots are not specifically targeted or avoided in land management activities. Therefore, field sampling protocols and data access permissions will need to address these issues when mapping outside Forest Service boundaries. Mapping efforts on Forest Service lands may have inclusions (i.e., private

landholdings) that would lower the expected number of available FIA plots, but this lower number may be overcome by intensification efforts.

5. Spatial and attribute mismatch issues exist between FIA plots and mapped features and map units. FIA plots are located randomly on a systematic grid (Bechtold and Patterson 2005), so their placement may straddle multiple map features or map units (called split plots), making them undesirable for use as accuracy data without further analyses. Additional analyses can include spatial and definitional crosswalks or appropriate filtering of FIA plots that have mixed conditions and thus do not represent a single map unit.

Despite these issues, FIA data represent a statistically valid sampling scheme and a very useful dataset for accuracy assessment of large areas. The potential savings in data collection costs and the rigor of the sample design and plot data merit serious consideration of FIA data for accuracy assessment purposes.

B.1.4 Applications and Use

Accuracy assessments of existing vegetation map products may be initiated to meet a number of Forest Service business needs, including the following:

- Accuracy assessments support the resource management decision process by providing a quantification of map accuracies that provide a scientifically sound and defensible analysis of the data and maps for use in management decisions and activity planning.
- Accuracy metrics and requirements are used during the planning process to 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.
- Accuracy assessments of completed map products enable the producer to compare different methods to determine the reliability and usefulness of alternative remote sensing techniques.

B.2 Methods

Conducting an accuracy assessment is a multistep process; successful completion requires a number of decisions and an awareness of the challenges previously described. The following steps are the general steps in accuracy assessment:

1. Develop the sample design.
2. Choose the appropriate reference data.
3. Delineate the accuracy assessment sites on the reference data.
4. Interpret the assessment sites from the reference data.
5. Compile the classified data for accuracy assessment sites.
6. Perform quality control.
7. Build the error matrix.
8. Summarize and present accuracy assessment results.

B.2.1 Step 1: Develop the Sample Design

The key to a valid accuracy assessment sample design is that it is based on sampling theory and each sample has a known, nonzero probability of selection (Foody 2002). Valid accuracy

assessment can be accomplished via a variety of sample designs. If the assumption of known, nonzero inclusion probabilities is not valid then the results of the accuracy assessment cannot be interpreted with the same level of confidence as an assessment designed with this assumption intact. Assumptions can be made concerning the similarity of areas with unknown selection probabilities to the rest of the mapped area, but results cannot be validly defended using the principles of sampling theory. A common example of a weak sample design is an assessment of a map covering various land ownership categories in which only Federal lands contain accuracy assessment points. Simple random and systematic sampling designs are common 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 miss sampling rare types. Systematic sampling, in which 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 (Stehman and Czaplewski 1998). The FIA program is an example of a systematic sample.

Stratified random sampling, in which the sample area is divided into strata or groups based on a priori knowledge, is commonly used to ensure representation of all strata. Stratified sampling with proportional allocation (i.e., creating an equal point density in each strata) maintains equal inclusion probabilities, but using equal allocation (the same number of points put in each stratum, regardless of size), or optimal allocation (allocating points based on some optimization criteria, like minimizing cost) will result in unequal inclusion probabilities. The main thing to remember is that as long as one can calculate the areas of each stratum from the map (either by counting pixels in each stratum or summing polygon areas), valid estimates can be calculated by using a weighted averaging procedure. A special consideration is if polygons are the sample unit. Larger polygons are more likely to be selected by a random point and thus have higher inclusion probabilities. One of the most common stratifications uses the mapped classes themselves, as described by Stehman (2004). Although this approach may ensure representation of all mapped classes, it can be completed only after the mapping is finished, which may result in longer timeframes and weather or phenological-related sampling issues. Another concern associated with stratifying by map classes is the situation in which, after the accuracy assessment is conducted or the map is updated, the updated strata no longer contain the initial sample intensities, necessitating a reallocation of plots to account for the new strata. If the proportions of the mapped classes are not represented similarly in the updated map, the producer's and consumer's accuracy may be biased.

Cluster sampling is a method that employs two types of sample units—the cluster or primary sampling unit (PSU), and the individual samples or secondary sampling units (SSU) that constitute the cluster. The PSU is used for identifying the SSUs, which are the units used for comparison with the mapped classification. The appeal of cluster sampling is the potential savings in sampling costs. The clustering of samples has the potential to decrease the information in the samples, however, because of spatial correlation of the samples. It is also recommended that a qualified statistician be a member of the mapping team, or consulted with to implement a complex estimator required for this method. The tradeoffs are specifically addressed in guidelines provided by Moisen et al. (1994).

Whichever sampling scheme is used, the requirement of known, nonzero opportunity of selection for accuracy assessment sites for each part of the study area can be expensive. This cost is the primary reasons that valid accuracy assessments are often not completed for mapping projects. Designing an efficient sampling strategy can address some of these issues, however, and if tradeoffs between cost and quality need to be made, they should be made with explicit understanding of the effect on interpretation of results. Stehman (2001) provides an excellent overview of these issues. Examples of tradeoffs for lowering costs include reducing sample size (and thus precision), lowering population representation, introducing assumptions, or collecting lower quality or more targeted reference data. A specific case of the latter might be using photo-interpreted data instead of ground-sampled data for the accuracy assessment. Whether this approach results in lower quality data will depend on the nature of the attributes being evaluated. Canopy cover, for example, may be more accurately determined from aerial photography than from ground plots, while the same may not be true of other attributes, such as tree diameter.

The appropriate sample number and size are other important considerations. The number of sample sites should be large enough to meet map accuracy requirements (e.g., is statistically sound, and confirms map objectives have been met) 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 (the off-diagonal elements in the error matrix). A general rule of thumb is that at least 20 sites are required for each category in the classification. Congalton and Green (1999) suggest 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.

The need for statistical validity should be balanced with practical considerations, such as time and budget constraints. Documentation should include an explanation of any statistical compromises. Accuracy assessment sites are expensive and time consuming to delineate, characterize, and ground check. In determining the number of accuracy assessment sites to investigate, a hybrid approach is recommended. By mixing two different approaches, the proportion of field-visited to photo-interpreted sites can be adjusted to balance statistical and practical considerations. For example, more photo sites may be collected than ground sites, and the ground-visited sites may be selected partly because of their accessibility.

B.2.2 Step 2: Choose the Appropriate Accuracy Assessment Reference Data

Data used for accuracy assessment include existing maps, existing resource inventory data, image interpretations of accuracy sites, or data collected on the ground. Because a major assumption in quantitative accuracy assessment is that the reference data are 100 percent correct, every effort should be made to secure the highest quality reference data. The analyst should be aware that, in many cases, reliable maps do not exist and inventory data do not match the temporal vintage of the geospatial data and imagery being used for mapping. Often, the available data are in a form that is incompatible with the classification scheme. To provide anything other than qualitative information, reference data are assumed to conform to the same classification scheme as the classified data.

Using imagery interpretations as reference data requires taking special care. Image-interpreted sites have traditionally been accepted as 100 percent correct when used to assess the accuracy of

digital classifications; however, as Biging and Congalton (1989) observed, perfect accuracy is rarely attributable to image interpretations. To help minimize errors, apply the following three principles:

1. The date of the imagery used for accuracy assessment should ideally be the same as the date of the digital imagery used for mapping.
2. Experienced interpreters familiar with both the vegetation and the classification scheme should conduct the image interpretations of accuracy sites.
3. To ensure the accuracy and consistency of the reference data, image interpretations should be closely inspected.

Using precise ground measurements or image interpretations as reference data are frequently used methods of assessing the accuracy of the classified map. To minimize costs and maximize efficiency, data from accuracy assessment sites can be collected during the same field visit for collecting training site data, albeit at different locations. Accuracy assessment sites should be independent of the training sites. Experienced interpreters with knowledge of the project area can collect additional image-interpreted sites after the field season. This combined approach can be a cost-effective means of acquiring accurate reference data.

Existing datasets other than FIA may also be used for accuracy assessment. The requirements of known, nonzero inclusion probabilities still apply, however. If these datasets do not meet these criteria, they may more appropriately be used for training samples. Stand exam data collected according to stratified random sample design would be an example of data suitable for use as training data but not accuracy assessment because of the selection of the stand/area being assessed to support a purposive objective. Another key issue is whether the information in an existing dataset is sufficient for the response design.

B.2.3 Step 3: Delineate the Accuracy Assessment Sites on the Reference Data

After the sampling scheme, sample size, and reference data requirements are determined, the accuracy sites can be delineated. For large projects, developing and maintaining a relational database is an efficient way of organizing and working with accuracy assessment data. Because pinpointing the location is critical to determining the accuracy of the classified image, all assessment site locations should be precisely delineated on base maps or high-resolution imagery, or they should be collected with a global positioning system (GPS). Sites should be assumed homogeneous regarding map category or modeling unit (e.g., homogeneous crown closure class or homogeneous species mix), and unambiguous delineation rules should be established. The sampling procedure should also be unbiased. For cases in which the accuracy assessment sample unit does not represent the entire map feature, an assumption of representativeness is required. It is imperative to recognize this assumption, document it, and ensure a bias or errors are not incurred because of this assumption.

B.2.4 Step 4: Interpret the Assessment Sites From the Reference Data

As mentioned in step 2, the same lookup table (map key) used in the map unit design process must be used to classify the accuracy assessment data, and accuracy assessment data must conform to the same classification scheme as the data used to produce the map. This need for conformity is true regardless of whether the process uses field-verified or image-interpreted sites. The same labeling rules (classification key) used to assign labels to features in the map must be

used to label accuracy assessment sites. To eliminate bias, the person collecting the reference data should be very familiar with the classification scheme, but not with the classified map. This person should have no prior knowledge of the map label for the corresponding accuracy assessment sites.

Response design is the protocol for determining the classification label that is assigned to each accuracy assessment sample (Stehman and Czaplewski 1998). Sampling undertaken specifically for a particular accuracy assessment involves identifying what data elements should be collected to allow for each sample unit to be assigned an appropriate label. When using an existing dataset, determine whether the existing information is sufficient for assigning a classification label that is consistent with the mapping classification, or if additional information or interpretations will be needed.

The advantages of collecting new data specifically for accuracy assessments are that the sample design and the data elements collected are under the user's control. The data collection can range from making a qualitative assessment of the sample unit and assigning an appropriate label to collecting quantitative information on vegetation type, tree canopy cover, or tree size class or other attributes to describe the sample unit. Quantitative information can take more time to collect but can provide more accurate, less subjective information, and it may be used for other applications or assessments.

Accuracy assessment data may be collected by visiting the sites on the ground or by interpreting aerial photography. Although use of image interpretation can greatly lower costs and decrease time required, it is important to consider three factors:

1. The acquisition date of the photography relative to the acquisition date of imagery used in the classification.
2. The scale of available photography.
3. Whether the information required can be interpreted from the photography with a very high degree of confidence.

Whether visiting the sites on the ground or interpreting aerial photography, the data collected can be used for accuracy assessment reference data.

B.2.5 Step 5: Compile the Classified Data for Accuracy Assessment Sites

Accuracy sites should be precisely located on the classified image or map coverage. Accuracy sites delineated on resource photography can be digitized directly over the satellite imagery or digital orthophotos. GPS data can be digitally transferred to the geographic information system, or GIS, environment. When cross-referencing the vegetation map with the accuracy assessment data, the accuracy assessment site may overlap more than one map feature. When this overlap occurs, determine if the reference site data can be subdivided to follow map feature boundaries. The spatial accuracy of the reference data relative to the spatial accuracy of the map features should be considered. If the reference site data cannot be confidently assigned to one or more map features, it should not be used to for map accuracy. The goal is to develop a label for the accuracy assessment site to compare with the map feature label corresponding to the exact location of the reference site.

B.2.6 Step 6: Perform Quality Control

Although quality control is listed as a separate task, in practice it is an ongoing and iterative process. Errors identified in accuracy assessments will appear as errors in the map classification. Some common errors include data entry mistakes, incomplete accuracy assessment forms, incorrect registration of accuracy sites to the thematic map, incorrect interpretation of the accuracy site, failure to enter accuracy sites into the database, and accuracy sites missing from the analysis.

B.2.7 Step 7: Build the Error Matrix

Tallying each accuracy site according to its accuracy assessment label and map classification creates the error matrix. A series of metrics (consumer's, producer's, and overall accuracy) that supports the determination of map quality for various uses can be calculated by using information found in the error matrix; a lower value represents lower spatial efficacy, while a higher value represents improved spatial efficacy. Table B-1 shows a simplified error matrix along with different metrics. See section B.3.2 for details on building and interpreting the error matrix using a fictitious mapping example.

Table B-1.—*Metrics created from the error matrix support a determination of map accuracy.* Note: The metrics include consumer's, producer's, and overall accuracies. The table shows accuracy and KHAT values.

		Observed			Mapped Distributio	Consumer's Accuracy	Consumer's KHAT
		Evergreen	Herbaceous	Deciduous			
Mapped	Evergreen	17	5	2	24	71%	0.5139
	Herbaceous	3	7	1	11	64%	0.4652
	Deciduousn	0	4	11	15	73%	0.6296
	Observed Distributio	20	16	14			
	Producer's Accuracy	85%	44%	79%			
	Producer's KHAT	0.7115	0.2788	0.6939			
					Total Samples		50
					Samples on Diagonal		35
					Overall Agreement		70%
					Overall KHAT		0.5410

B.2.8 Step 8: Summarize and Present Accuracy Assessment Results

The error matrix, a description of the design of the accuracy assessment, and an analysis and discussion of the accuracy results should accompany any use of the classified map.

A relatively recent innovation in accuracy assessment is the use of fuzzy sets for accuracy assessments (see Fuzzy Classification in section B.3.2) as defined by Zadeh (1965). Traditional accuracy assessments often suffer from certain limitations. First, is the assumption 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 "deciduous" carries the same weight as the error of misclassifying it as "conifer/hardwood mix." Fuzzy sets enable the user to account for ambiguities and magnitudes of error by allowing for more than one possible answer. For a complete description of applying fuzzy sets to accuracy assessment, see Gopal and Woodcock (1994).

B.3 Evaluation

B.3.1 Evaluating Producer's and Consumer's Accuracy

For many, producer's and consumer's accuracy seem intuitively to be the same thing. To better understand the difference, imagine that an entire map is labeled as "herbaceous." If one travels to every location on the ground that is mapped as herbaceous (corresponding with every location shown on the map), one will often find that the mapped and observed values are NOT in agreement, and thus consumer's accuracy will be very low. Conversely, if one travels to every location on the ground that is herbaceous, one will find that the map says that it is herbaceous, because ALL the points on the map are labeled as herbaceous. This situation gives us a 100 percent producer's accuracy.

In the preceding example, we have greatly overestimated the number of herbaceous locations on our map, and we have underestimated the number of locations that are evergreen or deciduous. The following relationships hold for consumer's accuracy and producer's accuracy:

- IF consumer's accuracy is GREATER THAN producer's accuracy for a given attribute, THEN we have underestimated the amount of that attribute on the map.
- IF consumer's accuracy is LESS THAN producer's accuracy for a given attribute, THEN we have overestimated the amount of that attribute on the map.
- IF consumer's accuracy is EQUAL TO producer's accuracy AND greater than 0 percent for a given attribute, THEN we have the correct amount of that attribute on the map.
- IF consumer's and producer's accuracy are BOTH 0 percent, THEN we cannot say anything about an overestimation or underestimation of the mapped and observed attribute by comparing the two accuracies.

The relationship between producer's accuracy and consumer's accuracy helps determine only if we obtained the proper proportions of the attributes on the map, not if point-by-point agreement of those attributes exists between the map and observations. For example, if both producer's and consumer's accuracies are 1 percent for herbaceous, we know that we have the same number of mapped and observed points for that attribute. Because the accuracies are extremely low, not many locations on the ground have mapped and observed attributes that are both herbaceous. Revisiting the mapping procedures used or reassessing the initial map unit design will enable the user to decide how to address the poor map quality for that class.

KHAT/Kappa

A commonly used but often misunderstood measure is the Kappa statistic, or KHAT, value. This value compares the results that were obtained from mapping with those results we would expect if the mapped and observed distributions are assumed to be statistically independent. The statistical independence criteria can be thought of as the error matrix one would obtain if one were to randomly draw samples from the marginal distributions, match them, and deposit that match in the core error matrix. This expected core error matrix is the one obtained on average from this experiment. The Kappa statistic is used to account for the chance that two observations may agree or disagree simply by chance as discussed in Viera and Garrett (2005).

KHAT can be considered to be a "chance agreement" of a row or column of overall agreement. It has been defined many times in the literature; two relevant considerations are presented here.

1. …the proportion of agreement after chance agreement is removed from consideration (Cohen 1960).

2. …the proportion of reduction in error generated by a classification process compared with the error of a completely random classification (Congalton 1991).

The value of Kappa typically ranges from 0 to 1, with a low value representing a less accurate map product. Kappa implies that a map is a percentage of improvement of an observed classification over that of a random classification.

B.3.2 Developing the Error Matrix for Accuracy Assessment

The Error Matrix

The Core Error Matrix

An error matrix is a two-dimensional table that summarizes the occurrences of mapped and observed pairs at singular locations on the ground. To create an error matrix, one starts with an input data table of ground locations, mapped and observed attributes, and weights (table B-2).

Table B-2.—*Mapped and observed samples.*

x	y	Mapped	Observed	Weight
0	87	Evergreen	Evergreen	1
1	23	Deciduous	Deciduous	1
2	22	Deciduous	Deciduous	1
2	54	Deciduous	Deciduous	1
6	36	Evergreen	Evergreen	1
11	69	Evergreen	Deciduous	1
18	63	Evergreen	Evergreen	1
19	59	Deciduous	Herbaceous	1
19	74	Evergreen	Evergreen	1
21	55	Deciduous	Deciduous	1
22	19	Herbaceous	Herbaceous	1
25	63	Deciduous	Deciduous	1
27	20	Deciduous	Herbaceous	1
28	70	Evergreen	Evergreen	1
33	39	Deciduous	Deciduous	1
33	78	Evergreen	Evergreen	1
35	81	Herbaceous	Herbaceous	1
36	7	Evergreen	Evergreen	1
37	17	Herbaceous	Herbaceous	1
38	18	Herbaceous	Herbaceous	1
41	82	Deciduous	Deciduous	1
43	20	Herbaceous	Evergreen	1
45	28	Evergreen	Evergreen	1
45	95	Herbaceous	Herbaceous	1
46	57	Evergreen	Herbaceous	1
46	85	Deciduous	Deciduous	1
47	63	Evergreen	Deciduous	1
54	15	Evergreen	Herbaceous	1
54	49	Herbaceous	Evergreen	1
55	78	Herbaceous	Deciduous	1
58	9	Deciduous	Herbaceous	1
59	39	Deciduous	Herbaceous	1
60	48	Evergreen	Evergreen	1
61	74	Evergreen	Evergreen	1
65	37	Evergreen	Evergreen	1
65	51	Deciduous	Deciduous	1
67	95	Evergreen	Evergreen	1
68	80	Evergreen	Evergreen	1
77	64	Herbaceous	Herbaceous	1
77	67	Herbaceous	Evergreen	1
77	68	Evergreen	Herbaceous	1
80	22	Evergreen	Evergreen	1
80	44	Herbaceous	Herbaceous	1
84	77	Evergreen	Evergreen	1
88	23	Deciduous	Deciduous	1
91	2	Evergreen	Herbaceous	1
97	25	Evergreen	Herbaceous	1
97	94	Evergreen	Evergreen	1
100	97	Deciduous	Deciduous	1
100	99	Evergreen	Evergreen	1

The “x,y” columns describe the ground locations in the data table. For each coordinate, the “mapped” and “observed” entries in the table describe the attributes that are assigned to that x,y location by the map, and what attributes were observed at that location, respectively. Depending on the sampling strategy, a weight may be assigned to each x,y location (if prestratification is used, a weight is assigned based on the area of each stratum).

Tables B-3 through B-6 demonstrate how the input data table is transformed into an error matrix. Table B-3 provides a simple description of a sample taken from a map of evergreen, deciduous, and herbaceous. These samples were obtained by a random sample of 50 locations across the entire map area. Because this sample was a true simple random sample, the assigned weight for each sample was a value of 1. When the sample is something other than random (e.g., stratified), the weights can be values different from 1. Mapped observations are determined by identifying the features individual location on the map. In this example, each point is described as being

evergreen, deciduous, or herbaceous. This identification provides the entry into the "mapped" column of the table. In a similar way, one can visit each location on the ground, observe the vegetative features, and assign that attribute to the "observed" column in the table. This action completes the entry in the table for that particular location.

To transform this table into an error matrix, one looks at each and every cell in the error matrix.

Table B-3.—*An empty core error matrix.*

		Observed		
		Evergreen	Herbaceous	Deciduous
Mapped	Evergreen			
	Herbaceous			
	Deciduous			

For a given cell, say mapped = deciduous and observed = herbaceous, one creates a new table that has in it only those samples/rows/entries from the original table where mapped = deciduous and observed = herbaceous.

Table B-4.—*Deciduous-herbaceous combination table extracted from table B-2.*

x	y	Mapped	Observed	Weight
19	59	Evergreen	Evergreen	1
27	20	Deciduous	Deciduous	1
59	39	Deciduous	Deciduous	1
58	9	Deciduous	Deciduous	1
Sum of weights =				4*

*The value entered into this cell is simply the sum of the weights from this new table.

Table B-5.—*Deciduous-herbaceous entry into the core error matrix.*

		Observed		
		Evergreen	Herbaceous	Deciduous
Mapped	Evergreen			
	Herbaceous			
	Deciduous		4	

After this process is complete for all cells in the error matrix, one has a table that describes the number of occurrences of "mapped" and "observed" pairs.

Table B-6.—*The fully populated core error matrix.*

		Observed		
		Evergreen	Herbaceous	Deciduous
Mapped	Evergreen	17	5	2
	Herbaceous	3	7	1
	Deciduous	0	4	11

Marginal Distributions

After the core error matrix has been created, it is a simple matter to calculate the marginal distributions. These distributions are obtained by summing across the rows and down the columns (table B-7). These marginal distributions describe the proportions of mapped and observed data types in table B-2.

Table B-7.—*Creating marginal distributions.*

		Observed			Mapped Distribution
		Evergreen	Herbaceous	Deciduous	
Mapped	Evergreen	17	5	2	24
	Herbaceous	3	7	1	11
	Deciduous	0	4	11	15
	Observed Distribution	20	16	14	

Derived Values From the Error Matrix

Overall Agreement

Having created the error matrix and its associated marginal distributions, one is now in a position to derive a number of values that summarize the map accuracy (i.e., how well the mapped values agree with the observed values). A natural first question might be "What percentage of ground locations from the sample have mapped and observed attributes that agree?" In other words, "How often do the samples have mapped and observed attributes that are paired as deciduous-deciduous, evergreen-evergreen, or herbaceous-herbaceous?" One can easily find this value by summing all the elements along the descending diagonal in the error matrix (i.e., where the mapped and observed attributes are the same), and dividing by the total number of samples in the error matrix (i.e., the sum of all cell values in the matrix).

Table B-8.—*Computing overall accuracy.*

		Observed			Mapped Distribution
		Evergreen	Herbaceous	Deciduous	
Mapped	Evergreen	17	5	2	24
	Herbaceous	3	7	1	11
	Deciduous	0	4	11	15
	Observed Distribution	20	16	14	
		Total Samples			50
		Samples on Diagonal			35
		Overall Agreement			70%

Consumer's/User's Accuracy

For a given attribute (for example, herbaceous), it is often desirable to know:

> Of all the values marked on the map as herbaceous (in this example), how often will one actually find herbaceous if one travels to those locations?

This value is termed *consumer's* or *user's accuracy*. One can obtain this value by dividing the value in the mapped = "herbaceous" observed = "herbaceous" cell of the error matrix by the value of the herbaceous cell in the mapped marginal distribution. In statistical terms, this value is the probability (p) that the observed value is herbaceous GIVEN that the mapped value is herbaceous (p (observed = herbaceous | mapped = herbaceous)).

An error of commission occurs when the mapper incorrectly maps a class on a reference site where the class does not exist; this error leads to lower consumer's or user's accuracy.

Table B-9.—*Computing consumer's accuracy.*

		Observed			Mapped Distribution	Consumer's Accuracy
		Evergreen	Herbaceous	Deciduous		
Mapped	Evergreen	17	5	2	24	17/24=71%
	Herbaceous	3	7	1	11	7/11=64%
	Deciduous	0	4	11	15	11/15=73%
	Observed Distribution	20	16	14		
			Total Samples			50
			Samples on Diagonal			35
			Overall Agreement			70%

Producer's Accuracy

Producer's accuracy simply swaps the roles of mapped and observed attributes in the consumer's accuracy:

> Of all the places on the ground that are herbaceous (in this example), how often will the map indicate that it is herbaceous if one travels to those locations?

Again, one can simply obtain this value by dividing the value in the mapped = "herbaceous," observed = "herbaceous" cell of the error matrix by the value of the herbaceous cell in the observed marginal distribution. In statistical terms, this value is the probability that the mapped value is herbaceous GIVEN that the observed value is herbaceous (p (mapped = herbaceous | observed = herbaceous)).

An error of omission occurs when the map fails to agree with a reference site; this error leads to lower producer's accuracy.

Table B-10.—*Computing producer's accuracy.*

		Observed			Mapped Distribution	Consumer's Accuracy
		Evergreen	Herbaceous	Deciduous		
Mapped	Evergreen	17	5	2	24	17/24=71%
	Herbaceous	3	7	1	11	7/11=64%
	Deciduous	0	4	11	15	11/15=73%
	Observed Distribution	20	16	14		
	Producer's Accuracy	17/20=85%	7/16=44%	11/14=79%		
			Total Samples			50
			Samples on Diagonal			35
			Overall Agreement			70%

Kappa is a metric to verify that agreement exceeds chance. Researchers disagree about the usefulness of the metric. For example, some claim that Kappa is seldom comparable across study areas, Kappa may be much lower than the overall accuracy, or it is misleading and easily misapplied; hence, one should consider the use of the metric in accordance with its application. The following equation will support an overall value of Kappa.

Observed Distribution[Herbaceous] x Observed Distribution[Deciduous]/Total Samples = 11 x 14/50 = 3.08 (table B-11 and table B-12).

Table B-11.—*Computing expected statistically independent error matrix entry.*

		Observed			Mapped Distribution
		Evergreen	Herbaceous	Deciduous	
Mapped	Evergreen				
	Herbaceous			3.08	11
	Deciduous				
	Observed Distribution			14	
		Total Samples			50

Computing each of these statistically independent cells yields the numbers found in the following table B-12.

Table B-12.—*A fully populated statistically independent error matrix.*

		Observed			Mapped Distribution	Consumer's Accuracy
		Evergreen	Herbaceous	Deciduous		
Mapped	Evergreen	9.6	7.7	6.72	24	40%
	Herbaceous	4.4	3.5	3.08	11	32%
	Deciduous	6	4.8	4.2	15	28%
	Observed Distribution	20	16	14		
	Producer's Accuracy	48%	22%	30%		
			Total Samples			50
			Samples on Diagonal			17.32
			Overall Agreement			35%

Kappa (KHAT) defines a new scale that rescales each measured accuracy (table B-10) to a scale between 0 and 1. (In rare situations, a negative Kappa of KHAT is interpreted as an agreement between the map and accuracy assessment data that is less than would be expected just by chance.) A value of 0 indicates a result that is no better than the previous experiment (in this case, an accuracy of 35 percent; after rescaling), and a value of 1 indicates that we achieved perfection (an accuracy of 100 percent). Using overall accuracy as an example, this mapping can be described as follows:

KHAT = (actual overall accuracy - expected statistically independent accuracy)/(100% - expected statistically independent accuracy) = (actual overall accuracy - 35%)/(100% - 35%) = (actual overall accuracy - 35%)/65%.

In our mapping efforts, we achieved an actual accuracy of 70 percent, so our KHAT value is—

KHAT = (70% - 35%)/65% = 0.54.

In other words, our actual accuracy is about halfway between the expected statistically independent accuracy and 100 percent accuracy.

KHAT can be measured for producer's and consumer's accuracy and for overall accuracy (table B-13).

Table B-13.—*KHAT for all accuracies in the error matrix.*

		Observed			Mapped Distributio	Consumer's Accuracy	Consumer's KHAT
		Evergreen	Herbaceous	Deciduous			
Mapped	Evergreen	17	5	2	24	71%	0.5139
	Herbaceous	3	7	1	11	64%	0.4652
	Deciduousn	0	4	11	15	73%	0.6296
	Observed Distributio	20	16	14			
	Producer's Accuracy	85%	44%	79%			
	Producer's KHAT	0.7115	0.2788	0.6939			
					Total Samples		50
					Samples on Diagonal		35
					Overall Agreement		70%
					Overall KHAT		0.5410

KHAT values are best used when looking at the actual and statistically independent accuracies. A KHAT value less than 0 indicated that our mapping process had a performance poorer than a random draw. A low KHAT indicates that our mapping process did not perform much better than a mapping process that uses random draws from the mapped and observed distributions. If the map is dominated by a particular attribute, however, then the statistically independent agreement can be quite high. Achieving additional accuracy may be quite difficult. As a rule of thumb (Jensen 2004), KHAT values can be broken into the ranges depicted in table B-14.

Table B-14.—*KHAT strength.*

KHAT	Level of Agreement
KHAT < 0.4	Poor
0.4 < KHAT < 0.8	Moderate
0.8 < KHAT < 1.0	Strong

Fuzzy Classification

A fuzzy classification for accuracy assessment supports the notion that more than one possible answer exists for a point on the ground. This classification can relate to mixed types, potential

classification similarities, or recognition of remote sensing ambiguity (because of radiance issues; i.e., seedling undergrowth). The fuzzy assessment allows for the correct/relevant (on diagonal) classification, thus each assessment point with multiple/fuzzy calls moves to the most correct classification.

In the process of fuzzy classification, it is possible for each point on the ground to belong to multiple classes. The following example is derived from Jensen (2004). Table B-15 presents an error matrix that contains both "hard" and fuzzy information. In this example, the off-diagonal entries have a format of "3/1." This notation indicates that three samples were mapped as one type but observed to be another. The second number indicates that one of these samples is considered by the image analyst to be correct (perhaps because of the presence of mixed types). One can think of all samples contributing to an on-diagonal cell in the error matrix as a "good" attribute assignment, and certain (but not all) off-diagonal samples as an "acceptable" attribute assignment. In a similar way, notations such as "70%/76%" indicate that the "hard" accuracy is 70 percent and the fuzzy/soft accuracy is 76 percent.

Table B-15.—*Fuzzy classification example.*

		Observed			Mapped Distribution	Consumer's Accuracy
		Evergreen	Herbaceous	Deciduous		
Mapped	Evergreen	17	5/0	2/0	24	71%/71%
	Herbaceous	3/1	7	1/1	11	64%/82%
	Deciduous	0/0	4/1	11	15	73%/80%
	Observed Distribution	20	16	14		
	Producer's Accuracy	85%/90%	44%/50%	79%/86%		
			Total Samples			50
			Samples on Diagonal			35
			Overall Agreement			70%/76%

One obvious hazard exists when applying a fuzzy assessment. In the previous example, one could achieve 100 percent accuracy by allowing all off-diagonal samples to be classified as "acceptable." To avoid this temptation, Woodcock and Gopal (2000: 157) recommend the use of a "blind evaluation":

> A blind testing procedure is used, meaning the expert has no knowledge of the map data while assessing a site. The expert has to evaluate all map categories at each test site using the [agreed-upon] scale, so there is no need or temptation to provide the expert with the actual mapped category for each test site.

For additional examples of how fuzzy logic can be used in an accuracy assessment, see Jensen (2004).

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Appendix C. Principles of Remote Sensing for Vegetation Mapping

By Mark Riley and C. Kenneth Brewer

C.1 Overview

Models come and go, but a good dataset lasts forever. Accurate, defensible, and current thematic datasets of vegetation, vegetation structure, land cover, or land use provide baseline information for understanding the landscape and natural resources for land managers, decisionmakers, and resource specialists. Remote sensing is the art, science, and study of acquiring, interpreting, analyzing, and reporting information about the landscape and Earth surface features without being in physical contact (Avery and Berlin 1992, Jensen 2004, Lillesand et al. 2008). Remote sensing for mapping vegetation for land management planning, landscape assessment, inventory, and monitoring has historically been conducted at the stand level. Delineating and labeling floristically, physiognomically, and structurally homogenous patches across a large landscape extent have been and continue to be fundamental components of vegetation mapping. In addition, the exploitation of remotely sensed digital airborne and space-borne satellite imagery has greatly improved vegetation map product development. Remote sensing technology enables the resource specialist to map large, uninterrupted swaths of vegetation on the landscape with relative consistency, while providing information about vegetation composition.[2]

The uses of remotely sensed imagery for vegetation mapping anywhere in the world are essentially limitless as new uses continue to evolve, with new data and data exploitation methods constantly being developed to meet resource and management needs. The use of remote sensing data and technology is growing as the industry expands investments and resources to meet the growing need. Integrating remote sensing data and technology with geographic information systems (GISs) and global navigation satellite systems is now a commonplace and an essential multidisciplinary business need. Remote sensing data and image classification techniques, such as data mining, serve a fundamental business need for the Forest Service. Remote sensing provides the means to map existing vegetation and to identify and record land cover and land use information including change.

C.2 Introduction

All contemporary passive remote sensing systems are electro-optical, meaning they function based on the interaction between optical electromagnetism (e.g., sunlight) and the electronic state of the material in the sensor that records the optical signal. Although passive remote sensing systems are more advanced and costly than consumer-grade digital cameras, the basic operational premise is the same: sunlight is reflected off objects such as plants, people, or buildings and this reflected light is recorded by the sensor on the camera. The optical sensor in the camera is made from a material that is sensitive to reflected light. This same concept is true of photographic film. Airborne photographic film-based remote sensing products have been replaced in recent years, however, by direct digital as digital has met or exceeded the spatial, spectral, and radiometric qualities of film. Outdated film-based remote sensing will not be discussed in this appendix.

[2] *Resource specialist* is a general term used to describe several natural resource specialists, including remote sensing specialist, geographic information system specialist, silviculturalist, geologist, soil scientist, timber manager, hydrologist, ecologist, botanist, wildlife biologist, and statistician.

The primary purpose of this appendix is to provide a comprehensive description of the relationship between remote sensing and vegetation mapping. This appendix covers sensor system characteristics, remote sensing and the electromagnetic (EM) spectrum, and remote sensing vegetation-mapping applications.

Recent advancements in digital imaging technology have dovetailed with vegetation-mapping needs, resulting in a singular product for vegetation mapping that combines the high-spatial resolution of a large-scale aerial image with the geometric accuracy of an orthorectified image. This new image-based remote sensing product, when used with more powerful GIS computers and GIS and remote sensing software (e.g., ArcGIS and ERDAS Imagine), provides the resource specialist with a far more efficient means to plan, analyze, and produce geographically meaningful and geospatially accurate information. Scale is no longer as meaningful as it once was with photographic products. Today's user of remote sensing data relies on spatial resolution or resolving power, which provides the software or image interpreter the capability to see, identify, measure, and define objects as small as a branch or as large as a watershed. New spectral capacities of aerial and satellite imagery go well beyond natural color and into parts of the EM spectrum, such as far-infrared, that provide information about vegetation that was not previously available. Contemporary digital aerial and satellite product suites can include three-dimensional (3-D) stereo pair data that can be used in the desktop environment for enhanced image interpretation, vertical measurement capability, and digital elevation model (DEM) generation.

C.3 Characteristics of Remote Sensing Systems and Data

Remotely sensed imagery falls into one of two fundamental categories: (1) passive or (2) active. All passive remote sensing systems operate by recording sunlight or heat that has been directly reflected, transmitted, or absorbed and retransmitted from Earth surface features. Active remote sensing systems like Light Detection and Ranging (LIDAR) and RADAR transmit, receive, and record the reflected signal from the object on the Earth's surface. Whether a remote sensing system or device is active or passive, the basic principle that allows for the differentiation of vegetation, land use, and land cover types are the chemical, cellular, or physical properties of an object that reflect or transmit EM energy with a spectral signature. Because digital imaging systems do not have wings, this electro-optical instrumentation is supported typically on one of three types of platforms: (1) fixed-wing aircraft, (2) helicopter, or (3) satellite.

C.3.1 Remote Sensing System Resolution

Four characteristics define all remote sensing systems, whether active or passive: (1) spatial resolution, (2) spectral resolution, (3) temporal resolution, and (4) radiometric resolution. While each of these characteristics is independently measureable, they are also intransigently integral to a remote sensing imaging system.

Spatial Resolution

The spatial resolution is the maximum size of an object that can be resolved in an image and the area coverage on the ground (or the footprint) of the image. The spatial resolution of the Ikonos satellite is 1 meter, meaning that each pixel (picture element) is 1 meter planimetrically in size. It

is typical that the higher the spatial resolution is, the smaller the image footprint will be. For example, a high-resolution satellite image may have a 50-centimeter resolution but only a 10-kilometer footprint, whereas another satellite may have a 5-meter resolution but a 60-kilometer footprint. Spatial resolution has as much to do with the physical size of the actual imager that records reflected sunlight as it does with the physical dimensions of the actual pixel, focal length, and altitude above ground level of the instrument. Spatial resolution has a significant effect on the calculated values of landscape metrics, levels of detail, and measurable ecological landscape patterns. For example, a higher spatial resolution of 1 to 2 meters will produce a finer delineation than an image with a coarser resolution of 30 to 50 meters. Higher spatial resolution image data offer greater interpretive potential (figure C-1) but, from a mapping standpoint, the level of detail, which includes increased shadow, will need to be weighed against project needs.

For digital cameras, whether these are consumer-grade or designed specifically for airborne remote sensing, the megapixel (MP) designation is simply obtained by multiplying the actual number of rows and columns of imager pixels. For example, an imager with an array of 8,976 by 6,724 pixels (60,354,624 total pixels) is 60 MP. The number of pixels, actual physical size of the pixels, and physical size of the imager, regardless of platform type, when combined with focal length and altitude above ground, affect the spatial resolution and the spatial extent of image footprint size of resolvable features and landscape extent.

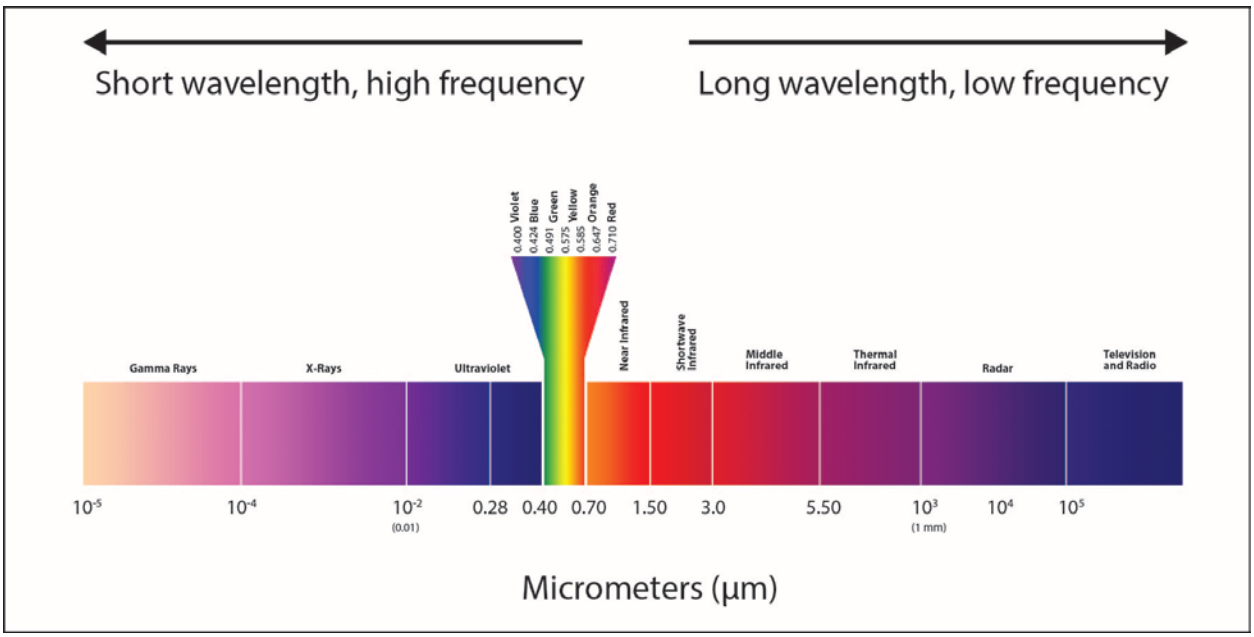
Spatial resolution is also sometimes referred to in terms of *granularity*. When selecting remotely sensed imagery, it is important to consider the relationship between the grain, or minimum resolvable landscape element on the image (Forman and Godron 1986, Turner 1989), and the size and shape of the 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 much coarser than the grain of the data, that pattern can be easily identified. This ease of identification is particularly true when the pattern is composed of spectrally homogenous units organized in regular shapes. It is also essential to consider the temporal and spectral characteristics of the imagery. Often spatially detailed imagery does not contain the spectral information that is needed to separate various map units. For example, information in the near-infrared range of the EM spectrum is useful for distinguishing between evergreen needleleaf and deciduous broadleaf vegetation.

Figure C-1.— *High-spatial resolution direct digital images are highly interpretable.* Note: Although high-spatial resolution images have greater interpretability, they tend to have a smaller footprint because of the physical limitations of imaging technology.

Spectral Resolution

Spectral resolution, or spectral sensitivity, is the bandwidth, number, and position of specific EM wavelengths (figure C-2) that a sensor is capable of recording. The greater the range and number of spectral bands a sensor has, the higher the spectral resolution. For example, a panchromatic sensor has very low-spectral resolution, whereas other sensors may have hundreds of bands with sensor sensitivity confined to very narrow wavelengths, thus a very high-spectral resolution (e.g., hyperspectral). The higher the spectral resolution, the greater the likelihood of spectral separability among various spectral values of land cover types.

Figure C-2.—*The electromagnetic spectrum.*

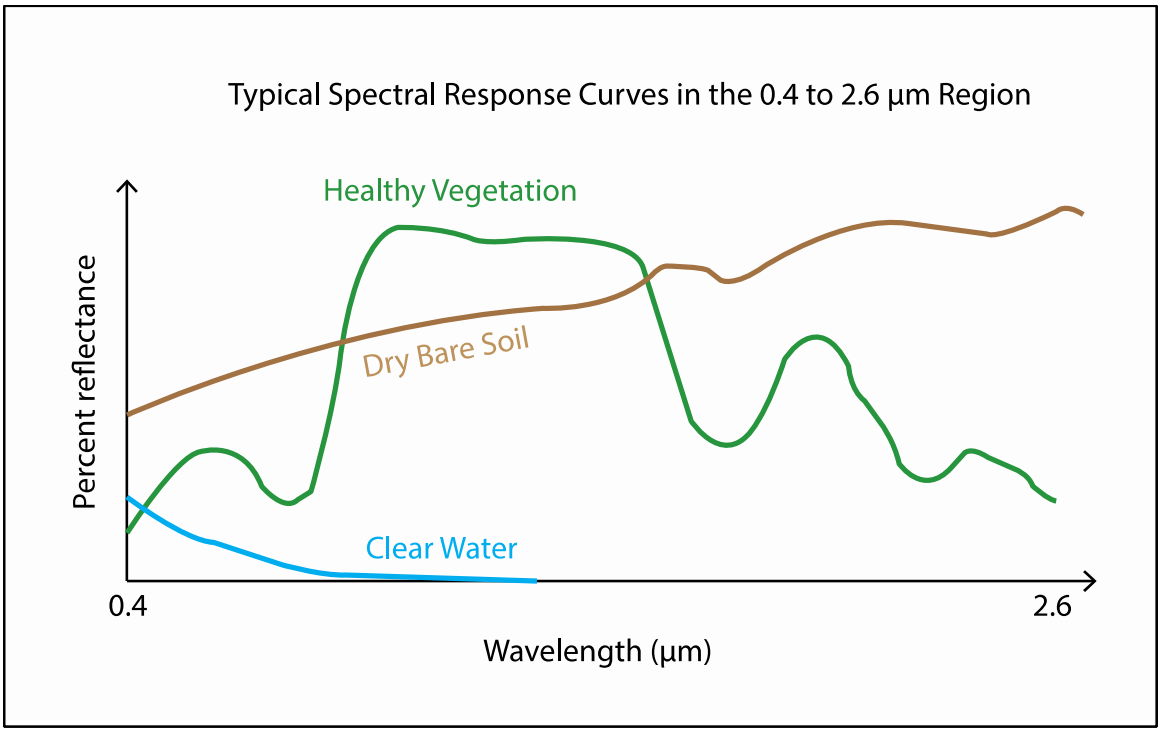


The visible region (blue, green, red) of the EM spectrum provides spectral information about cultural features, such as buildings and roads, soil and water differentiation, hydrography, and vegetation types. The near-infrared part of the spectrum allows for a high degree of vegetation differentiation, vegetation biomass estimates, and soil information. Shortwave-infrared and mid-infrared is partly reflected and partly emitted EM radiation that provides spectral information about moisture absorption, vegetation, and wildfire effects. Far-infrared (shown as thermal-infrared in figure C-2) includes emitted thermal imagery and is a good indicator of vegetation stress, thermal pollution, pervious and impervious layers, and wildfire activity.

Spectral Signatures

All Earth surface features reflect, absorb, transmit, and emit EM energy from the Sun. Spectral signatures (figure C-3) are the direct result of the spectral response that vegetation and other land cover types have with sunlight. Imaging sensors are capable of recording this transmitted and reflected energy. Sometimes multiple image dates are necessary to identify specific map units, such as deciduous forest types, that exhibit spectral similarity during certain times of the year but have different seasonal senescing periods that result in foliage distinguishable spectral signatures for foliage variation.

Figure C-3.—*An example of spectral signatures or spectral response curves for healthy vegetation, dry bare soil, and clear water.*



Temporal Resolution

Temporal resolution is the frequency at which a sensor can record image information over an area and the time of day that the information is recorded. For satellites, temporal resolution is usually measured in days with a fairly static repeat cycle. For example, the temporal resolution of a satellite may be three days until its orbit around the Earth brings it back to the same location at about the same time. Some satellites are pointable and may have increased temporal resolution. For airborne systems the temporal resolution can be at any time of day or any day and is usually weather dependent. Systems with a higher frequency of collection have a higher temporal resolution.

Radiometric Resolution

The number of potential intensity values that a remote sensor can record is the radiometric resolution. A system with 8-bit radiometric resolution means that it is capable of recording from 0 to 255 or 256 (2^8) possible different intensity values, where 0 is a low intensity and 256 is a very high energy or intensity. Most active and passive remote sensing systems have between 8-bit (2^8 or 256 possible values) and 16-bit (2^{16} or 65,536 possible values) radiometric resolution. A higher radiometric resolution generally provides better separation of subtle vegetation differences that may be obfuscated by Sun shading or variations in spectral response.

C.4 Passive Remote Sensing

The most common of remote sensing imaging systems are currently passive. Passive remote sensing systems receive and record sunlight that has been reflected, or absorbed and retransmitted as heat, from Earth surface features. Both aircraft (fixed-wing, helicopter, unmanned aerial systems) and satellites provide platforms for passive remote sensing instruments. Other, less common platforms are manned and unmanned balloons.

Until recently, what used to be very time-consuming and often frustrating work can now be done with a single product or with a more logically integrated and complementary suite of orthorectified remotely sensed products. Digital orthorectified imagery, whether it is from a satellite or aerial platform, provides the fundamental basis and augmented applicability for the efficient mapping of vegetation as it occurs on the landscape.

C.4.1 Digital Airborne Imagery

The Forest Service traditionally has had two formal and unique aerial photography products. These products are digital orthorectified imagery and resource photography. Both products are intended to be complementary, with one providing a high level of interpretability and the other providing the capacity to make accurate measurements. The finer scale (1:15,840) resource photography are prints that have a very high resolution that enables the resource specialist to identify, for example, individual trees or streams to a high level of detail. Making accurate measurements on a resource image, however, is a very difficult and time-consuming endeavor. Digital orthorectified imagery, delivered as digital orthoimage quarter quadrangles, or DOQQs, and orthorectified satellite imagery have been geographically corrected so that Earth surface features and terrain are accurately and geometrically represented, whereby the resource specialist can make accurate measurements of landscape surface features and distances between surface features. One key use of high-resolution (less than 50 centimeters) digital airborne imagery is for image interpretation. Although fieldwork is essential, making field observations on two-dimensional (2-D) or 3-D imagery can save a considerable amount of time and funding.

C.4.2 Satellite Imagery

Satellite imagery for vegetation mapping was first used in the 1970s by a very small, innovative group of scientists, managers, resource specialists, and researchers. The need, understanding, availability, and use of satellite imagery have grown tremendously since this time. In the past few years, satellite imagery has started to have a more critical role and has become far more available than it has been in the past. With more satellites being deployed annually than ever before, the options and availability of satellite-based remotely sensed imagery is more prolific than ever. Optical satellites have a wide range of spatial and spectral resolutions that can meet the needs of regional and project-level management activities. From the 50-centimeter spatial resolution of the 8-band Worldview-2 satellite and the 10- to 30-meter resolution of SPOT 5 and Deimos-1, to the coarse 250-meter, large swath width of the Moderate-Resolution Imaging Spectroradiometer, or MODIS, sensor, an image product is offered to suit most any need, from vegetation mapping and species-level interpretation to regional change detection and general land cover classification. Many of these systems are represented in table C-1.

C.5 Active Remote Sensing

An active remote sensing system transmits, receives, and records a signal. RADAR, SONAR, and LIDAR are the only active remote sensing system technologies being used today. SONAR technology, however, is currently well beyond the scope of vegetation mapping for this appendix and will not be addressed.

C.5.1 Aerial LIDAR and InSAR

The vegetation-mapping technical strengths of LIDAR and Interferometric Synthetic Aperture RADAR (InSAR) lies in the ability to better identify and accurately measure vertical and structural components of vegetation. An understanding of canopy structure is essential to understanding the composition of the landscape. Moreover, structure information obtained through LIDAR or InSAR technology can help users get to a better understanding of carbon stocks.

C.6 Digital Elevation Models

Also crucial to planning and management activities are DEMs. Whereas an optical satellite or aerial image provides information about vegetation and other surface features, a DEM provides information about elevation, slope, and aspect. DEMs are developed photogrammetrically from stereo pair imagery or derived directly from LIDAR or InSAR. DEMs have two categories: (1) digital terrain models that represent a bare, featureless Earth and (2) digital surface models (DSM) that represent the elevation of Earth surface features, such as forested landscapes. A DEM can help delineate vegetation types based on occurrence at different elevations. A DSM, in particular, can help delineate spectrally similar vegetation types, such as shrub and deciduous trees, by representing relative height differences.

C.7 Remote Sensing Data Types

C.7.1 Coarse-Resolution Optical Data

Coarse-resolution optical data are suitable only for broad-level mapping, unless they are coupled with other data that have better spatial resolution. When integrated with higher resolution imagery or field datasets, coarse-resolution imagery can effectively map land cover. The main advantage of coarse-resolution datasets is the short revisit time. The same scene may be available from daily to once every 10 days, depending on the sensor. When a specific area of interest has long periods obscured by clouds, it is important to have a multitude of available imagery dates to create a viable dataset. Often these data are free or inexpensive compared with higher resolution imagery. These data also cover large areas in one scene, as opposed to higher resolution data, which requires multiple scenes. Land cover maps created from coarse datasets contain far less detail than those created with higher resolution imagery. Coarse-resolution imagery also reduces the ability to identify small changes in land cover. The following paragraphs describe examples of coarse-resolution imaging sensors.

AATSR (Advanced Along-Track Scanning Radiometer) is a sensor onboard the Envisat satellite owned by the European Space Agency. Its primary purpose is to measure the temperature of the sea surface. The sensor revisits a scene every 3 days and records seven bands of data, ranging from visible to thermal. The spatial resolution is 1 kilometer and the swath width is 500 kilometers. See https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/envisat/instruments/aatsr.

ATSR (Along-Track Scanning Radiometer) is a combination of data from two sensors on the Earth Resources Satellite ERS-1 and ERS-2 satellites, one infrared radiometer that records visible bands, and one sounder that measures emitted microwave radiation. The European Space Agency administers these satellites and uses them for monitoring oceans, natural resources, and atmospheric phenomena. The imagery has 1-kilometer spatial resolution for visible and infrared data and 20-kilometer spatial resolution for the microwave sensor. The two satellites are in orbit exactly 1 day apart so that ERS-1 covers the same area that ERS-2 covered the day before. The total revisit time is variable and can extend to 35 days. The swath width is 500 kilometers. See http://earth.esa.int/object/index.cfm?fobjectid=4006.

MERIS (Medium Spectral Resolution Imaging Spectrometer) is a fully programmable instrument on the Envisat satellite owned by the European Space Agency. Data are collected in 15 bands in the visible and infrared regions of the EM spectrum. The sensor can collect data on any of the bands starting at 300-meter pixel resolution. The swath width is 1,150 kilometers and the revisit time is 3 days. See http://envisat.esa.int/instruments/meris/.

MISR (Multi-angle Imaging Spectroradiometer) is one of the instruments on the Terra satellite owned by National Aeronautics and Space Administration (NASA). It contains cameras pointed at the Earth from nine different angles. The primary purpose of this sensor is to understand what happens to sunlight as it interacts with the atmosphere. Data are recorded in visible and near-infrared bands. The spatial resolution ranges from 250 to 275 meters. The revisit time is between 2 and 9 days, and the swath width is 360 kilometers. See http://www-misr.jpl.nasa.gov.

MODIS (Moderate-Resolution Imaging Spectroradiometer) is on the Terra and Aqua satellites, both operated by NASA. It provides 36 bands of data in the visible to thermal range of the EM spectrum. The imagery has a spatial resolution of 250 to 1,000 meters, depending on the band. A unique feature of MODIS is that it has daily coverage of the entire Earth with a swath width of 2,330 kilometers. See http://modis.gsfc.nasa.gov/.

SeaWiFS (sometimes called SeaStar) was developed by Orbital Sciences Corporation to deliver daily images of the oceans, but it has proven useful in studying land phenomena. It has multispectral image datasets with a spatial resolution of 1 kilometer. It rides on NASA's OrbView-2 satellite with a revisit time of fewer than 3 days and a swath width of 2,800 kilometer. See http://oceancolor.gsfc.nasa.gov/SeaWiFS/SEASTAR/SPACECRAFT.html.

VMI (Vegetation Monitoring Instrument, also simply called VEGETATION) is on the SPOT-4 and SPOT-5 (Système pour l'Observation de la Terre) satellites, which were designed and developed by the French Space Agency with the participation of Sweden and Belgium. The VMI was developed for vegetation monitoring; the imagery has a spatial resolution of 1 kilometer and a swath width of 2,250 kilometers. Four bands of imagery from blue to mid-infrared are recorded by the VMI. The revisit time for the VMI is 1 day. See http://uregina.ca/piwowarj/Satellites/SPOT.html.

HRCCD (High-Resolution Charged Coupled Device) is a pointable sensor on the China Brazil Earth Resources Satellite, CBERS-2. The CBERS series of satellites was developed as a joint

effort between China and Brazil. It has a spatial resolution of 1 kilometer and a swath width of 113 kilometers. Spectral data in the visible to very-near-infrared range are recorded every 3 days. The primary goal of CBERS is to provide data to Brazil and China for land monitoring. See http://www.satimagingcorp.com/satellite-sensors/cbers-2.html.

WFI (wide-field imager) is mounted on the CBERS-2. This satellite was developed as a joint effort between China and Brazil and was launched in 2003. The WFI operates in the very-near-infrared region of the EM spectrum. The spatial resolution is 260 kilometers. This imagery is suitable for forestry evaluations over large areas. The revisit time is every 3 to 5 days, and the swath width is 890 kilometers. See http://www.eoportal.org/directory/pres_CBERSChinaBrazilEarthResourcesSatelliteZiYuanSatelliteSeries.html.

C.7.2 Moderate Resolution Optical Data

These data types, in general, are higher spatial resolution than the coarse optical systems and can map land-cover change more accurately. They have a revisit time ranging from 5 to 26 days. Moderate-resolution imagery is usually free or less expensive than high-resolution data, while also providing more detail than coarse-resolution sensors. Fewer scenes for a given location because of less-frequent revisit times can be a drawback, however, if an area is frequently cloud covered. These data should still be combined with ground or higher spatial resolution data to create detailed mapping products.

AWFI (Advanced Wide-Field Imager, also referred to as WFI-2) is an instrument aboard the CBERS-4 satellite, scheduled to launch in 2014. Four bands of imagery from green to mid-infrared are recorded with 64-meter spatial resolution. Scenes are revisited every 5 days, and the swath width is 866 kilometers. See http://www.cbers.inpe.br/ingles/satellites/cameras_cbers3_4.php.

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is a sensor riding on the Terra satellite. ASTER is a cooperative effort among NASA, Japan's Ministry of Economy, Trade and Industry, and Japan's Earth Remote Sensing Data Analysis Center. Data are collected in the very-near-infrared, shortwave-infrared, and thermal-infrared portions of the EM spectrum. The datasets' spatial resolutions range from 15 to 90 meters. The sensor's primary purpose is to support the study of change in the Earth's systems. The revisit time is 4 to 16 days, and the swath width is 60 kilometers. ASTER is currently plagued by faulty shortwave-infrared sensors that do not properly collect data. See http://asterweb.jpl.nasa.gov/obtaining_data.asp.

AWiFS (Advanced Wide-Field Sensor) rides on the IRS-P6, also known as the ResourceSat-1, which is operated by the Indian Space Research Organization. The pointable sensor records four spectral bands with a spatial resolution of 56 meters. Its applications include forestry, agriculture, topography, water, and tectonics. The swath width is 370 kilometers and the revisit time is 5 days. See http://www.isro.org/satellites/irs-p6resourcesat-1.aspx.

DMC (Disaster Monitoring Constellation) is designed to provide data comparable with Landsat to leverage the expertise of those familiar with that system. The sensors are housed in a series of satellites operated by several countries, including Algeria, Nigeria, and Turkey. Multiple sensors in orbit give the constellation a better opportunity to capture imagery over areas affected by

natural disasters, which is the primary mission of the DMC. Any other time available is focused on capturing data for sale. The DMC collects data in only the green, red, and near-infrared wavelengths at a resolution of 22 or 32 meters. See http://www.dmcii.com.

ETM+ (Enhanced Thematic Mapper+) is on board the Landsat 7 satellite operated by NASA, and the data can be downloaded from the U.S. Geological Survey. Eight bands of data are recorded from the blue to the thermal zones of the EM spectrum. The visible and near-infrared imagery is available in 30-meter spatial resolution. The panchromatic band has a 15-meter spatial resolution while the thermal band has a 60-meter spatial resolution. The swath width is 185 kilometers and the revisit time is 16 days. Landsat 7 is currently plagued by a scanner malfunction that results in a banding effect that may render resulting imagery unusable. See https://lta.cr.usgs.gov/LETMP.

HRG (High-Resolution Geometric) is an instrument on board the SPOT-5 (Système Pour l'Observation de la Terre) satellite, which was designed and developed by the French Space Agency with the participation of Sweden and Belgium. The spatial resolution is between 5 and 20 meters, depending on the band of data. Information is collected in the visible, near-infrared, shortwave-infrared, and panchromatic ranges. The revisit time is 2 to 3 days; this satellite has a pointable design, so data requests can easily be filled for a specific location. This sensor has a high degree of geometric fidelity. It can create a paired set of images that can be viewed in stereo and used to create DEMs. The swath width is 60 kilometers. See http://www.spot.com/?countryCode=US&languageCode=en.

HRV (High-Resolution Visible) is mounted on the SPOT-2 satellite, and collects visible and near-infrared data with a spatial resolution of 20 meters and panchromatic data with a 10-meter resolution. This sensor also has a pointable design, a revisit time of 2 to 3 days, and a swath width of 60 kilometers. See http://www.spot.com/?countryCode=US&languageCode=en.

HRVIR (High-Resolution Visible Infrared) rides on the SPOT-4 (Système pour l'Observation de la Terre) satellite. Data are recorded in the visible, near-infrared, shortwave-infrared, and panchromatic ranges. Spatial resolution for these data is 20 meters except for the panchromatic band, where it is 10 meters. This pointable sensor was developed with vegetation monitoring in mind. It has a revisit time of 2 to 3 days and a swath width of 60 kilometers. See http://www.spot.com/?countryCode=US&languageCode=en.

IRMSS (Infrared Multispectral Scanner) is on CBERS-2 (China Brazil Earth Resources Satellite) and collects three bands of infrared and a band of panchromatic data. The spatial resolution is 40 meters except for the thermal band, where the resolution is 80 meters. Its revisit time is 26 days, and the swath width is 120 kilometers. See http://www.cbers.inpe.br/ingles/satellites/cameras_cbers3_4.php.

Landsat 8 (formerly called the Landsat Data Continuity Mission) is a sensor and platform that are became operational in 2013. The purpose is to continue the global coverage and historical record of imagery offered by previous Landsat systems. The sensor is planned to have nine bands, including visible, aerosol, near-infrared, two mid-infrared, thermal, panchromatic, and cirrus. The sensor and its platform were launched in December 2012. Landsat 8 is the most

current satellite in the Landsat continuity mission. After a shakedown period, it officially began operations on May 30, 2013, when operations transferred from NASA to the U.S. Geological Survey. See http://ldcm.nasa.gov/.

LISS-III (Linear Imaging and Self-Scanning sensor) is on the IRS-P6 satellite, also known as the ResourceSat-1, operated by the Indian Space Research Organization. Data are recorded in four bands: green, red, near-infrared, and shortwave-infrared. The spatial resolution is 23.5 meters with a revisit time of 24 days. The swath width is 70 kilometers. See http://www.isro.org/satellites/irs-p6resourcesat-1.aspx.

MSS (Multispectral Scanner) rides on board the Landsat 5 satellite operated by NASA. This sensor records two bands of visible data and two bands of infrared data with a spatial resolution of 57 by 79 meters. The revisit time is 16 days. The properties of this MSS sensor are consistent with those aboard previous Landsat satellites. See http://landsat.gsfc.nasa.gov/.

TM (Thematic Mapper) is also on the Landsat 5 satellite operated by NASA. This instrument records six bands of data, from blue to shortwave-infrared, with a 30-meter spatial resolution. The seventh band, the thermal band, has a 120-meter spatial resolution. The revisit time for this data set is 16 days with a swath width of 185 kilometers. The TM sensor was developed for use as a more advanced Earth-resources sensor than the MSS. Although TM failed in November 2011, and is no longer collecting imagery, an archive of 30-plus years of TM data is available for retrieval and analysis. See http://landsat.gsfc.nasa.gov/.

C.7.3 Fine-Resolution Optical Data

Fine-resolution sensors have a spatial resolution of 10 meters or less. These data are more expensive but provide the highest amount of detail possible for space-borne optical sensors. One drawback to fine-resolution data is the greatly increased processing volume. The amount of imagery needed for complete coverage of a given area is often far greater than for a moderate-resolution sensor. The amount of data and the cost associated with their fine resolution make them impractical for most countries to use for wall-to-wall coverage.

LISS-IV (Linear-Imaging and Self-Scanning sensor) is mounted on the IRS-P6 (ResourceSat-1) satellite owned by the Indian Space Research Organization. Data are recorded in the green, red, and near-infrared locations of the spectrum. These three bands are useful for land cover mapping. The spatial resolution of the data is 5.8 meters. The sensor is pointable, so the revisit time is as little as 5 days with a swath width of 23.9 kilometers. See http://www.isro.org/satellites/irs-p6resourcesat-1.aspx.

CARTOSAT-1 is aboard the IRS-P5 satellite, built and operated by the Indian Space Research Organization. The sensor on this satellite records panchromatic data in stereo pairs in 0.50 to 0.85 micrometer wavelengths. The revisit time for this sensor is 5 days. The primary use for these data is creating DEMs, based on the 3-D data from stereo pairs. See http://www.isro.org/satellites/cartosat-1.aspx.

IKONOS is a commercial satellite owned and operated by GeoEye. The data are collected in the multispectral range with a 4-meter resolution and panchromatic with a 1-meter resolution. The

sensor is pointable, and, therefore, the revisit time is 1 to 3 days; it can also create stereoscopic images. The swath width for this sensor is 11 kilometers. See http://www.digitalglobe.com/resources/satellite-information.

PANMUX is currently in development and will be mounted on the CBERS-3 satellite. The data collected will be in the visible and near-infrared range at 10-meter spatial resolution and panchromatic with a resolution of 5 meters. With a swath width of 60 kilometers, these data can be used for land cover mapping. See http://database.eohandbook.com/database/instrumentsummary.aspx?instrumentID=700.

QuickBird is a commercial satellite owned by DigitalGlobe. Visible and near-infrared data are collected with a spatial resolution of 2.4 meters. Panchromatic data have a spatial resolution of 0.61 meters. This sensor is also pointable with a revisit time of 2 to 3 days and a swath width of 16.5 kilometers. See http://www.digitalglobe.com/resources/satellite-information.

WorldView-2 is a commercial system owned and operated by Digital Globe. This sensor has eight multispectral bands, including coastal blue (narrow band in the low blue wavelength), visible, red-edge, near-infrared, and panchromatic bands. The multispectral spatial resolution is 2.0 and 0.5 meters for the panchromatic band. Revisit time for this sensor is 3.7 days, and the swath width is 16.4 kilometers. See http://www.digitalglobe.com/resources/satellite-information.

Pléiades-1A and **Pléiades-1B** are owned by the Astrium. The two satellites were launched in 2012. Together they provide visible and infrared data with 2-meter resolution and a daily revisit time. The satellites also collect a panchromatic band with a resolution of 0.5 meters. This constellation offers excellent locational accuracy of 3 meters before orthorectification. The swath width for these sensors is 20 kilometers. See http://www.astrium-geo.com/pleiades/.

AVNIR-2 (Advanced-Visible and Near-Infrared Radiometer type 2) was on the Advanced Land Observing Satellite (ALOS) developed by the Japan Aerospace Exploration Agency. This sensor provided data in the visible and near-infrared zones of the EM spectrum for land and coastal observation. The spatial resolution of the data was 10 meters with a revisit time of 2 days. The swath width for this sensor was 70 kilometers. The ALOS satellite ceased operation in May 2011, and only archived data is available from the AVNIR sensor. See http://www.eorc.jaxa.jp/ALOS/en/about/avnir2.htm.

C.7.4 Active Sensor Data

Active sensor systems produce the energy they are recording. All the sensors discussed in the optical sections are passive; they record energy that was created by the Sun and have interacted with the Earth in some way. Active systems transmit energy to a surface and record the energy that is reflected back to the sensor. Radar systems provide information about the target's moisture content and structure. The major benefit of active sensors is the ability of the wavelengths of the energy produced to penetrate clouds, allowing for them to be used at any time. Because the sensors do not depend on the Sun's energy, they work at night as well as during the day. Also, depending on the wavelength of the radar system, problems with the presence of aerosols in the atmosphere can be eliminated.

C.7.5 Coarse-Resolution Passive Microwave Data

AMSR-E (Advanced Microwave Scanning Radiometer for the Earth Observing System) was developed by the National Space Development Agency of Japan and is mounted on the Aqua satellite developed by NASA. It is a passive microwave radiometer that records data that are emitted from the Earth in six locations of the EM spectrum. It has a spatial resolution ranging from 6 to 74 kilometers depending on the data band. Its primary objective is to provide information about precipitation, water vapor, sea-surface temperatures, soil moisture, and snow cover. Possibilities for land cover mapping with these data are marginal, although research continues to investigate how moisture information relates to vegetation health and amount. See http://aqua.nasa.gov/about/instrument_amsr.php.

C.7.6 Multiresolution Passive Microwave Data

PALSAR (Phased-Array L-band Synthetic Aperture Radar) was on the ALOS satellite, which was launched by Japan. PALSAR collected data in single-, dual-, or quadrature-polarization. The polarization allows for greater interpretability of the data. The spatial resolution varies accordingly from 10 to 100 meters. In the quadrature-polarization mode, this sensor produced data suitable for global or regional scale land use classifications. These data have a spatial resolution of 7 to 100 meters and were collected in the L-band at 1.3 gigahertz (GHz). The ALOS satellite ceased operations in May 2011, and only archived data is available from the PALSAR sensor. See http://www.eorc.jaxa.jp/ALOS/en/obs/palsar_strat.htm.

SAR (Synthetic Aperture Radar) is available from the RADARSAT-1 and RADARSAT-2 satellites developed by the Canadian Space Agency. These sensors were developed to monitor land resource changes. The sensor's beam can be steered to different incident angles, creating swath widths of 45 to 500 kilometers. The spatial resolution, therefore, varies between 1 and 100 meters. The revisit time depends on the swath width, with the standard 100 meters width covering the Earth every 24 days, and its steerable mechanism allowing for a fewer number of days between acquisitions of a single place on Earth. The EM data recorded are at 5.3 GHz, also referred to as the C band. The system is horizontal transmit, horizontal receive (HH) polarized, which means energy emitted from and recorded by the sensor is polarized in the horizontal direction. The type of polarization has an effect on the interpretability of the data. The data are quadrature polarized, rather than HH polarized, which means they are polarized in HH; horizontal transmit, vertical receive; vertical transmit, vertical receive; and vertical transmit, horizontal receive directions. This difference in polarization provides greater object discrimination. See http://gs.mdacorporation.com/SatelliteData/Radarsat2/Features.aspx.

SAR from ERS-2 (European Remote Sensing Satellite) is mainly used to observe the arctic regions. Data are collected in the C band at 5.3 GHz, with a spatial resolution of 30 meters. The swath width is 100 kilometers and the revisit time is 3 days. This system is vertical transmit, vertical receive polarized, meaning both the energy emitted and recorded by the sensor is vertically polarized. Data are collected in image form only when the vehicle is within line-of-sight communication with an ERS ground location. Therefore, this system's range of usability is limited to those ground locations. See http://southport.jpl.nasa.gov/polar/ers1.html.

C.7.7 Other Data Types and Sources

InSAR (Interferometric Synthetic Aperture Radar) is a specialized radar technique that uses two or more SAR images to generate digital surface models (DSMs) and digital terrain models (DTMs). The two SAR images are often collected simultaneously aboard the same platform; however, they can be collected at different times. A number of different radar bands with different characteristics are used, including X-band, P-band, and L-band. The bands affect the sensor's ability to penetrate surfaces such as tree canopy. The generated DSM is a topographic model of the Earth's surface and includes vegetation, buildings, and other cultural features. The DTM is a topographic model of the bare Earth, where the vegetation, buildings and other features have been removed. Both are typically provided as off-the-shelf products. Subtracting the DTM from the DSM provides vegetation height information—useful for vegetation and biomass mapping. The unit cost of InSAR is much less than LIDAR, but the minimum project size is much larger. In some areas in Europe, the United States, and Asia, large inventories of InSAR data are available to purchase.

LIDAR (Light Detection and Ranging) is an active remote sensing technique that sends a light beam to the target and measures the time it takes to return to the sensor and how much intensity is lost. This system requires a specific type of aircraft and equipment. The laser scanner, an onboard GNSS (global navigation satellite systems; the U.S. version is known as GPS, or global positioning system), an inertial measurement unit, and a very accurate clock are necessary to collect LIDAR data. Post spacing (i.e., how far apart each light pulse is) and flying height determine the spatial resolution of the data collected. LIDAR usually provides better than 1-meter accuracy. Several returns can be recorded per pulse, which provides information about forest structure. The first return is assumed to be from the canopy top, the last return from the ground, and any other returns indicate some part of the canopy structure. LIDAR offers a lot of detail but at a fairly high cost. Transporting the aircraft and needed instruments to a study area can be very expensive. Actual data collection costs are not significant considering the amount of detail provided, so a LIDAR system and aircraft that are located near a study site can be more cost effective. LIDAR does require specific image-processing methods and knowledge to extract information from the data, which can substitute for ground data by applying calibrated conversion factors. These conversions should be created through ground data validations, and for now LIDAR remains cost prohibitive compared with ground data acquisition and cannot replace an actual forest inventory.

Aerial photography historically was used heavily for remote sensing. This type of data is still collected for many regions of the world. It provides an excellent source of map validation data because of the fine-spatial resolution (typically less than 0.5 meters). Data collection of this type can be very expensive, so one should determine if the project justifies the expense. A significant number of photographs are usually needed to achieve adequate area coverage, which can create data management issues. Until recently, aerial photography was limited to the acquisition of frame-based photographic images (similar to those from a hand-held film camera) and three bands of information, typically red, green, and blue. To be used in resource management, a technician needed to scan the film-based images into the computer and go through a lengthy process of geocorrecting them. Newer direct digital collections can take advantage of GNSS (global navigation satellite systems) and inertial measurement unit data to help automate the geocorrection process. In addition, modern sensors allow for direct to digital collection of several

bands concurrently, including hyperspectral imagers, which can collect hundreds of bands simultaneously.

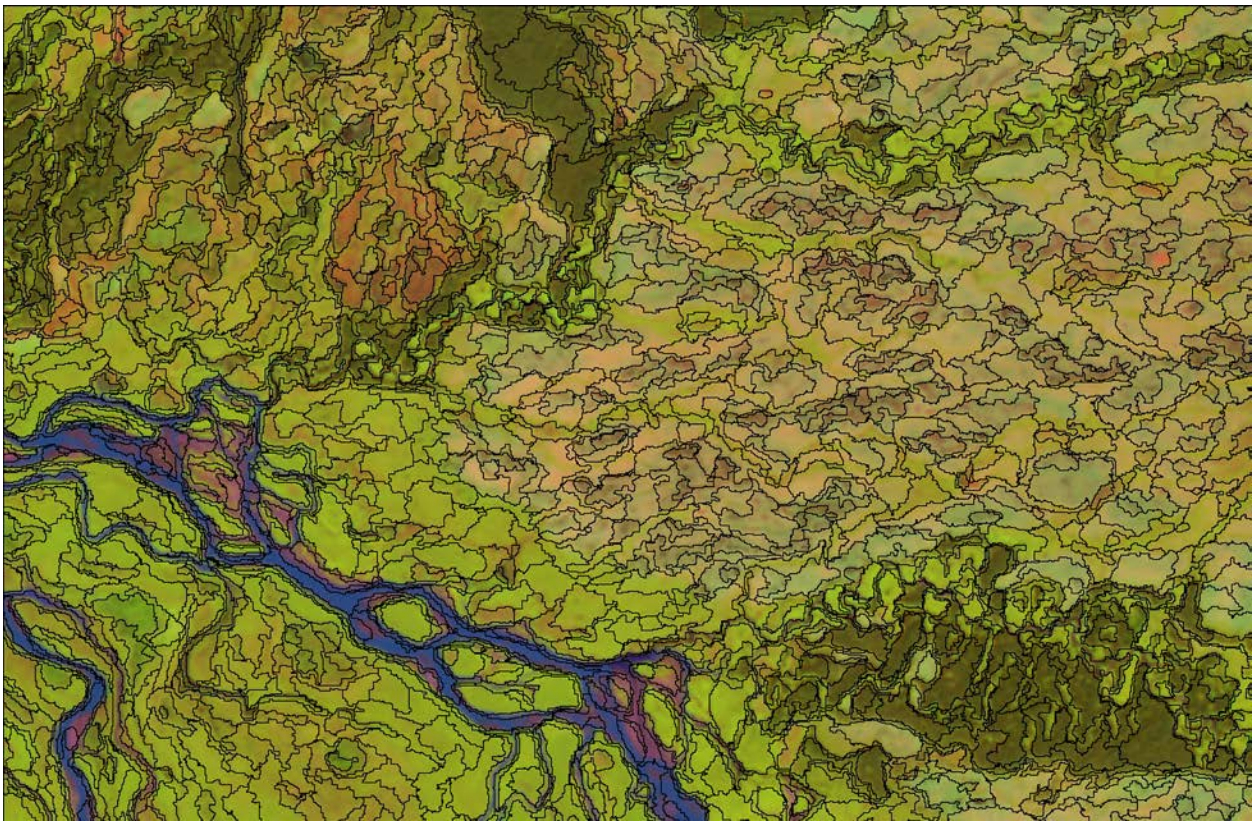
Aerial videography is the collection of full-motion video from an airborne vehicle. This method is expensive, but it provides high-resolution data, even less than 1 meter. It is common practice to use videography in place of ground data to validate coarser map products, particularly in systems that use cameras pointed both forward and aft. This set-up allows for the data to be viewed in stereo. An advantage of this type of system over aerial photography is that recording the data continuously makes it possible to match the location where ground data have been collected more accurately. In addition, videography is also useful for forest cover mapping.

C.8 Remote Sensing and the Vegetation-Mapping Processes

C.8.1 Image Segmentation

Image segmentation is the mathematical process of the polygonal delineation of floristic, textural, physiognomic, and structurally homogenous patches of landscape elements using statistical clustering techniques. Subtle spectral, spatial, and textural differences and those not visually apparent are typically captured during the segmentation process. These segments are the fundamental modeling units that are later labeled during the data mining, classification and regression tree process (figure C-4). For most vegetation-mapping applications, the landscape should be over-segmented to capture variations that are not obvious. Over-segmented is when segments are created at a resolution and scale finer than the intended map feature size, resulting in “more” segments, and therefore termed *over-segmented*.

Figure C-4.—*Example of image segments that delineate structural, textural, physiognomic, and floristic patterns on the landscape.*



C.8.2 Image Classification and Data Mining

Simply put, data mining is a statistical process of sorting and analyzing data, examining relationships, and selecting relevant information. It is the process of using the modeling units, reference data, and geospatial layers to predict the occurrence of classes on the landscape. Although models can be manually built, the semiautomated CART (classification and regression tree) analysis expedites the process.

Data mining algorithms are capable of handling large data sets and forming relationships between variables. Data mining programs are ideal for creating classifications involving remote sensing and GIS data because these types of data sets tend to be large. This approach can reduce error and improve accuracy.

Data mining programs are abundant and include Cubist, See5, Orange, Random Forest, rpart, support vector machines, and many others.

Digital 3-D Imagery for Generating Reference Data

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

Although resource specialists have used stereoscopes and photographic aerial analog prints for decades to characterize terrain, digital imagery has recently opened up innovative, more efficient possibilities. New Forest Service software tools like Stereo Analyst provide access to digital versions of 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, had been unavailable. Planning and measurements are directly portable to a GIS, in which new data can be analyzed, reviewed, and easily shared. No longer does the resource specialist have to search through cabinets and set up photographs under a stereoscope.

In most situations business needs drive technology development. In the case of the digital 3-D image environment, the business needs are adapting existing technology, contracting specifications are changing, and delivered products provide a whole suite of new information. Solid fieldwork and onsite visits are still needed. The digital 3-D environment will supplement fieldwork and reference data collection through other means by effective planning and analysis, in the preassessment and postassessment environment. The resource specialist can see the landscape in full color, high-resolution, 3-D at his or her desktop by using special lightweight glasses and a transmitter. This technology is a vast improvement over outdated stereoscopes and the red-blue anaglyph glasses. The new digital 3-D environment provides measurement capability similar to LIDAR but with greater interpretability for the vast majority of resource specialists and at a significantly reduced cost. This 3-D technology does not have the eye strain and fatigue associated with older 3-D stereo technology and the 3-D glasses can be worn over eyeglasses. Digital stereo 3-D is growing as a useful tool not only for collecting reference data, but also for validating reference data and existing vegetation map products.

Table C-1.—*Sensors used for remote sensing.*

Sensor name	Satellite name	Temporal resolution (days)	Coverage (swath width)	Sensor type	Spatial resolution	Spectral resolution	Appropriate map level	Cost
AATSR	ENVISAT-1	3	500 km	Multispectral	1 km	G, R, NIR, SWIR, MIR, TIR	Broad, National	Low
ATSR	ERS-1, ERS-2	2-35	500 km	Multi/ Micro-wave	1 km to 20 km	G, R, NIR, SWIR, TIR / 23.8 & 36.5 GHz	Broad, National	Low
AVHRR	NOAA-#	Daily	2400 km	Multispectral	1.1 km	R, NIR, SWIR, 3 TIR	National	Free
MERIS	ENVISAT-1	3	1,150 km	Multispectral	300 m land, 1200 m ocean	B, G, R, NIR (15 programmable bands 390 - 1040 nm)	Broad, National	Low
MISR	TERRA	2-9	360 km	Multispectral	4 at 250 to 275m	B, G, R, NIR	Broad, National	Free
MODIS	TERRA & AQUA	Daily	2,330 km	Multispectral	2 at 250m / 5 at 500m / 29 at 1000m	B, G, R, NIR, Mid IR, Far IR, TIR	Broad, National	Free
SeaWiFS	OrbView –2	Less than 3	2,800 km	Multispectral	1 km	V, V-B, B, G1, G2, R, NIR1, NIR2	Broad, National	Low
VMI Vegetation Monitoring Instrument	Spot 4 & 5	1	2,250 km	Multispectral	1 km	B, R, NIR, SWIR	Broad, National	Low
Wide Field Imager (WFI)	CBERS-2	5	890 km	Multispectral	260 m	R, NIR	Broad, National	Free**
Adv. Wide Field Imager (AWFI)	CBERS-3*	5	720 km	Multispectral	60 m	B, G, R, NIR	Base, Mid	Free
ASTER	TERRA	4-16	60 km	Multispectral	3 at 15m / 6 at 30m / 5 at 90m	VNIR / SWIR / TIR	Mid, Broad	Low
AWiFS	IRS-P6, RESOURCE-SAT-1	4^{p}	370/740 km	Multispectral	56m to 70m	G, R, NIR, SWIR	Mid, Broad	Low
Disaster Monitor-ing Constellation (DMC)	Alsat-1, UK-DMC2, Ni-geriasat-X, Beijing-1, DEIMOS-1	Daily for the constellation	600 km	Multispectral	22 m	G,R, NIR	Base, Mid	Med
CCD	CBERS-2	3^{p}	113 km	Multispectral	20 m	pan, R, G, B, NIR	Base, Mid	Low
Enhanced Thematic Mapper+ (ETM+)	Landsat 7	16	185 km	Multi / Pan	6 at 30m / 1 at 60m / 1 at 15m	B, G, R, NIR, SWIR / TIR / Pan	Mid, Broad, National	Free
HRG	Spot 5	$2\text{-}3^{p}$	60 km	Multi / Pan	3 at 10m / 1 at 20m / 2 at 5m / 1 at 2.5m	G, R, NIR / SWIR / Pan-chromatic	Base, Mid	Med
HRV	Spot 2	$2\text{-}3^{p}$	60 km	Multi / Pan	3 at 20m / 1 at 10m	G, R, NIR / Pan	Mid, Broad	Low
HRVIR	Spot 4	$2\text{-}3^{p}$	60 km	Multi / Pan	4 at 20m / 1 at 10m	G, R, NIR, SWIR / Pan	Mid, Broad	Low
IRMSS	CBERS-2, -3*	26	120 km	Multispectral	3 at 40m / 1 at 80m	pan, 2 SWIR / TIR	Broad	Free**

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Appendix D. Image Interpretation

By Don Evans and C. Kenneth Brewer

D.1 Introduction

Image interpretation is the use of certain image attributes, together with knowledge of the objects and conditions imaged, to identify features and judge their significance. Our brain-eye system is unsurpassed at interpreting high-resolution imagery, if we first possess the ground-based knowledge about the resources to measure or map. With a small investment in your time, you can become a skilled image interpreter, but you should first have that ground-based resource knowledge.

A skilled image interpreter will discriminate features of interest and their attributes from other features in the imagery. For example, an image interpreter would use his or her experience to discern between species and size classes of trees of interest. To be successful, he or she would need to relate their ground knowledge to the imagery (figure D-1). The interpreter *should* spend significant time on the ground with the imagery in hand.

Figure D-1.—*Image interpreter taking imagery into the field.*

Although this document provides useful tips and techniques for interpreting imagery, the only

way to become a skilled image interpreter is to take your imagery into the field and learn to bridge the gap between what you know and see on the ground to what you can see on the images. A suggested workflow for building image-interpretation skills—and interpreting imagery—is provided at the end of this appendix.

D.2 Image Characteristics—Fundamentals of Image Interpretation

An image interpreter will use elements that are inherent in imagery to recognize and identify objects of interest. These image characteristics are composed of seven elements that we use to derive information about objects in the image. These image characteristics are size, shape, tone and color, texture, shadow, association, and pattern.[3] Although it is beneficial to understand these image characteristics, most image interpreters will use them subconsciously in practice. A description of each image attribute with examples is provided on the following pages.

The relative importance of each of the seven image characteristics is not constant. The importance of any characteristic can depend significantly on the scale of the imagery and the properties of the feature of interest. For example, the shape of a tree crown can be a very important indicator of tree species on high-resolution imagery. On coarser resolution imagery, individual crowns may not be easily distinguishable and texture may become a much more important image characteristic.

D.2.1 Size

Size is usually evaluated by looking at objects that the interpreter may be familiar with and comparing their relative size with less familiar objects. For example, an interpreter might look at the discrete vegetation features in the red rectangle in figure D-2 and interpret those features to be trees. By comparing the relative size of the vehicle and the paved road, in the yellow rectangle, with the vegetation features, however, it becomes obvious that the trees are actually shrubs (in this case, sagebrush). If the scale of the imagery is known, objects can be measured directly—rather than relying solely on relative size.

[3] Some experts also identify other image attributes like place/location and height. Although these are legitimate image characteristics, they are not considered in this document.

Figure D-2.—*Size is usually evaluated by looking at objects that the interpreter may be familiar with and comparing their relative size with less familiar objects.*

D.2.2 Shape

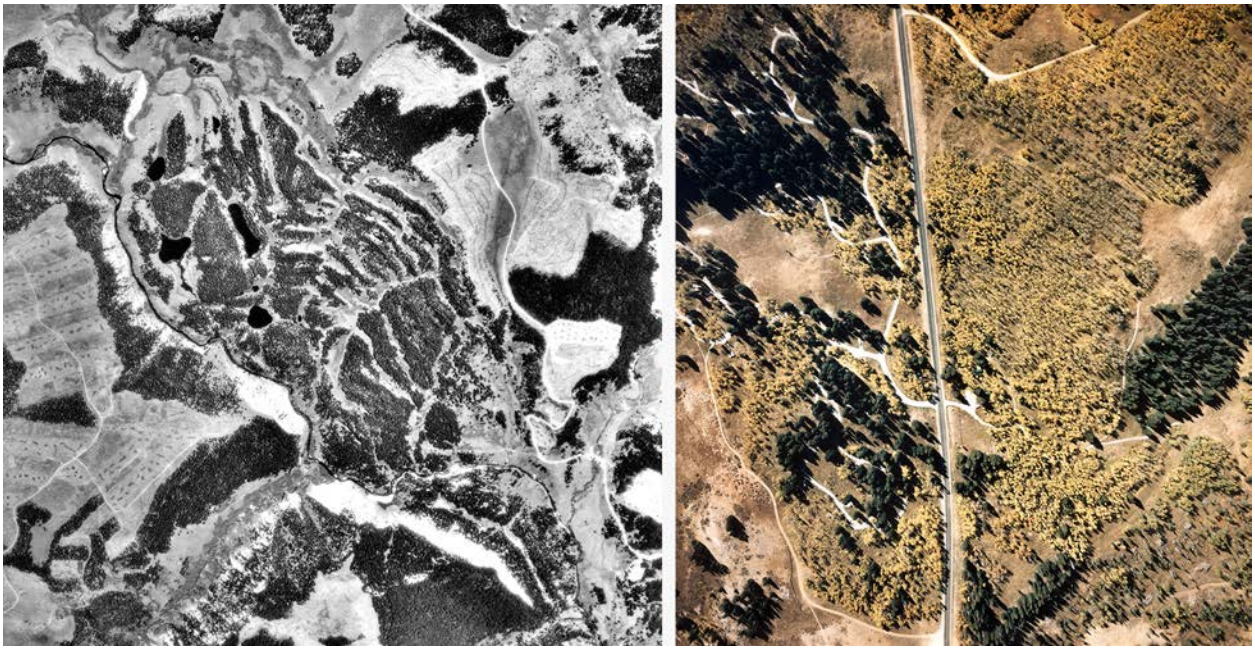
Every imaged feature has a shape. Shape is not necessarily diagnostic for interpretation, however (i.e., the same type of feature may have different shapes, and different features may have the same shape). Man-made features, such as the vehicle and road (figure D-2), tend to be more rectilinear than natural features. Natural features, such as trees and shrubs, have more subtle shapes (figure D-3). Referring to the image at right, the shape of the tree crowns is indicative of the type (deciduous/conifer) or even species of tree.

Figure D-3.—*Every object has a shape, but the shape may not be diagnostic. If individual tree crowns are visible in the imagery, their shape or texture can be important clues to type or species.*

D.2.3 Tone and Color

Tone (in the panchromatic image) allows for easy distinctions among roads, forests, harvest areas, water, and other things. Color (figure D-4) allows for easy distinction among coniferous trees, deciduous trees (in yellow fall colors), senesced grasses, and road surface types.

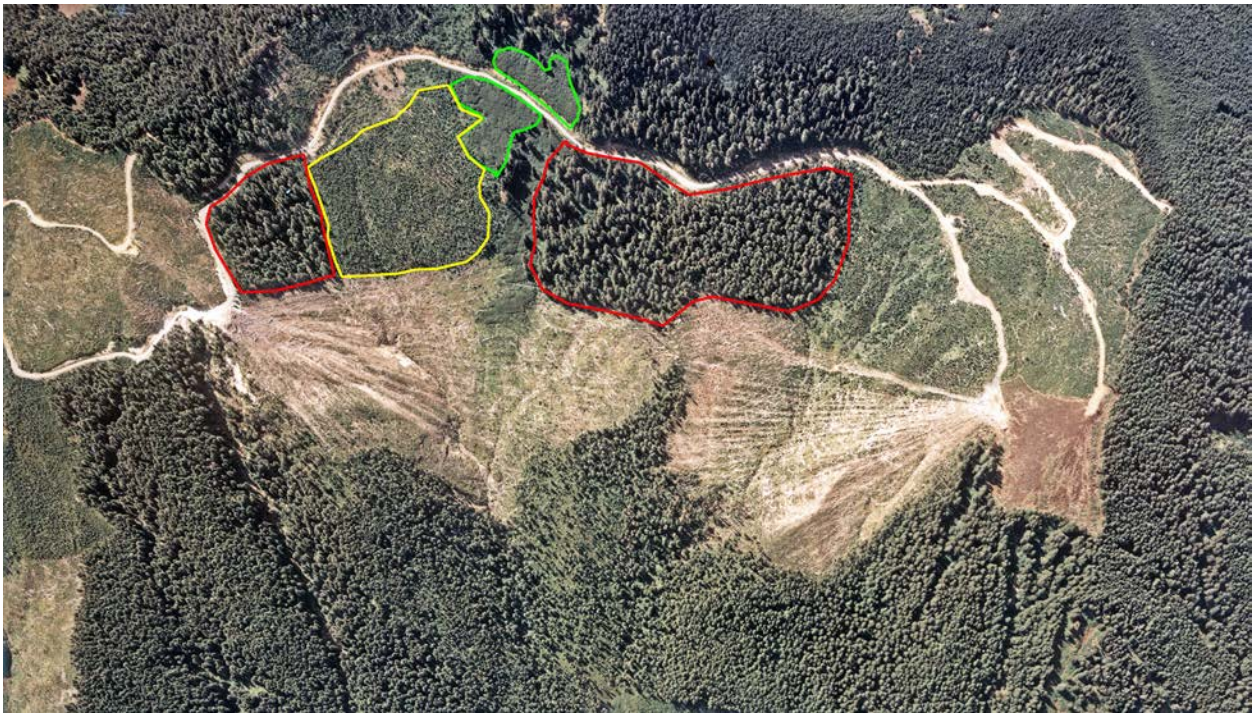
Figure D-4.—*Different features have different reflectance properties—light-toned areas reflect more electromagnetic energy (sunlight) than dark features—and thus appear differently on the imagery, enabling the interpreter to tell things apart on the imagery.*



D.2.4 Texture

Image texture refers to the apparent roughness and smoothness of an image region created by the frequency of tonal change on the image. Texture can offer the interpreter clues about the density, age, and type of vegetation present (figure D-5). Note that texture interpretation becomes increasingly important when the image resolution becomes coarser.

Figure D-5.—*Coarse- (red polygons), medium- (yellow polygon), and fine- (green polygons) textured areas. Coarse-textured areas represent larger and older trees with canopy gaps. Fine-textured areas usually connote young, even-age vegetation.*



D.2.5 Shadow

Imagery is usually acquired within a few hours of solar noon to minimize shadows. Shadows obscure features and are a detriment to interpreting features within shadow. On the other hand, shadows cast by objects in the image can give the interpreter information about the shape and size of those features. It can also provide an indication of the relative height of features. For shadows to be most effective, the entire shadow should be visible in the image (figure D-6). In some cases image acquisition might be timed to ensure shadows are present to enhance interpretability of features that may be difficult to see otherwise (e.g., a fence line in open rangelands).

Figure D-6.—*Shadow is an especially important clue in interpreting objects.* Note: Shadows of buildings, trees, and other objects reveal characteristics that are not obvious from the overhead view alone. Edges, such as forest boundaries, often have characteristic shadows.

D.2.6 Association

By observing objects in the image and observing the objects that are around objects, the interpreter can make inferences about what the objects really are. In figure D-7, the presence of a dam suggests that this water body is a reservoir. Without that association, the water body cannot be further classified as a reservoir.

Figure D-7.—*Association refers to the typical co-occurrence of certain features.* Note: Vegetation species are often associated with one another or with topographic characteristics (slope, elevation, aspect, etc.). Complex features, such as campgrounds or forest management activities, frequently have associated components that individually may lead to one conclusion but, considered together, lead to a more informed interpretation.

D.2.7 Pattern

In remote sensing, pattern is a recognizable repetition of particular shapes. In figure D-8, the checkerboard pattern of rectangular shapes suggests that this once forested area has been harvested along regular boundaries.

Figure D-8.—*Pattern refers to the arrangement of individual objects into distinctive, recurring forms that permit recognition.* Note: Different patterns may become more or less apparent at different viewing magnifications.

D.2.8 Change Over Time

In addition to using these seven image characteristics, when two sequential sets of imagery are available, we can also add these additional image characteristics: (1) discernible differences in any of the previously mentioned characteristics found in the images that were acquired at different times; (2) presence or absence of features in successive imagery; and (3) change of location, position, or extent of features.

D.2.9 Convergence of Evidence

Convergence of evidence is the mental (but usually subconscious) summation of all the interpretable image characteristics that are present in the imagery to derive a confident interpretation of an imaged feature. In other words, it is the bringing together of several types of information so that a conclusion may be drawn in light of all available data. It is essentially what an interpreter infers from all the image characteristics, together with field site data and value judgments derived from previous training and experience. Interpretation is then made on the basis of what the interpreter thinks are the overridingly important criteria. It is this summation of all the interpretable image characteristics that makes this a logic exercise that is inherently inductive (subjective) and not easily replicated in a deductive logic (objective) algorithm in an image-processing program. This difficulty has made automation of the image-interpretation process elusive for pattern recognition software.

If the interpreter considers all the image attributes that are present for a given feature, and all the attributes of that feature lead to the same interpretation, the interpreter will have confidence in the interpretation (the evidence converges on the same conclusion). Misinterpretation increases when the interpreter does not consider all available image attributes or when the interpretation(s) from the individual image attributes conflict. (An example of a potential misinterpretation is described in the size characteristic section, D.2.1.)

D.2.10 Interpretation Is an Art

It is important to remember the difference between interpretation and identification. Identification assumes objective accuracy and completeness of description within the confines of a problem; it is a definitive answer. Interpretation involves judgment, experience, familiarity with a problem, and a host of other factors. It is subjective, but it is based on a set of skills that can be developed in time. Most of us use the seven image characteristics subconsciously. To improve our image-interpretation skills, however, we should consciously examine the image characteristics associated with the themes we are interested in interpreting, and ensure that the discernible characteristics are leading to the same interpretation. Again, this approach requires taking the imagery into the field.

D.3 Image-Interpretation Tools

The most efficient image-interpretation tool currently is the human eye-brain system of a skilled image interpreter. Manual interpretation, however, is subjective and can lack rigor. Although still based on image interpretation, image keys and software products, such as Image Sampler and Digital Cover Interpreter, are examples of tools that help provide consistent and objective results.

D.3.1 Image Keys

Image keys can take many forms. They essentially are a set of guidelines designed to aid the interpreter in correctly applying the classification scheme during the interpretation. Image keys also help to ensure that consistency is maintained throughout the interpretation process. Keys may also be valuable teaching aids for people who lack field experience, yet who should be trained quickly to identify features on a given type, scale, and quality of imagery.

One of the simplest and most effective image keys consists of saving a copy of previously interpreted imagery (carefully ground-checked for accuracy) as a “training set” or “reference set” to which unknown areas of the imagery may be compared. Although this type of image key is simple and effective, it may have limited utility with different types of imagery, different magnification of inspection, or with very complex keys.

It also can be very helpful to include written descriptions of the features of interest that can inform the interpreter of what to look for in the imagery. Tips such as “…this class is sometimes confused with class X, however, they can usually be differentiated by…” are often useful. Additional habitat information can also help the interpreter. For example, “species X typically occurs between 4,700 and 6,200 feet (1,430 and 1,890 meters) in elevation—slightly higher on south facing slopes and lower on north facing. This species is often co-dominant with species Y.”

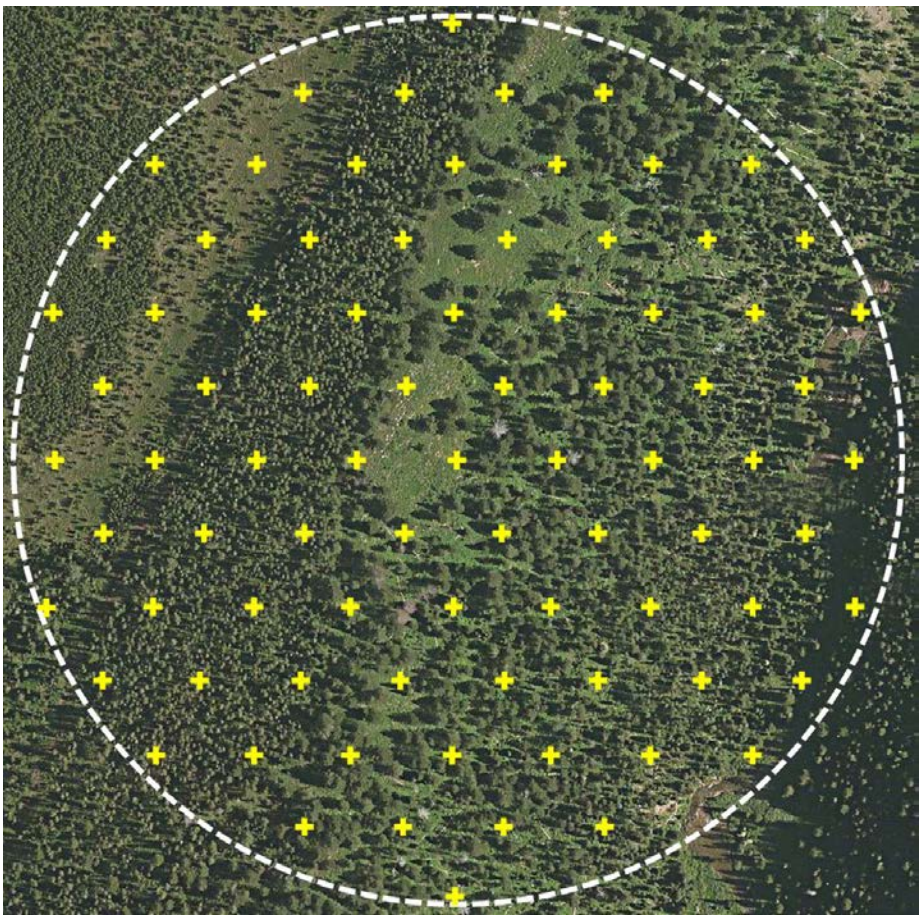
It is valuable to make keys because they can be used as a learning exercise. They are great training aids for specific projects when several interpreters should be trained to consistently identify a specific and restricted set of tree/stand conditions. One of the best ways of learning to differentiate the details of tree species at any scale is to make a key to the species imaged. Making such a key requires several field identified examples of each species. Using such a key for training purposes requires reference to the same set of field identified examples. It is advisable to collect a personal "portfolio" of examples from a range of conditions. Fieldwork is crucial for developing image-interpretation skills and for training others.

D.3.2 Image Sampler and Digital Cover Interpreter

The following examples of digital tools (ArcMap Add-Ins) can help provide consistency and objectivity to your ocular interpretations.

Image Sampler creates sample points within a user-specified polygon and provides a toolbar interface for attributing those sample points (figure D-9). These sample points can then be used to generate statistical estimates of the cover types within the polygon(s).

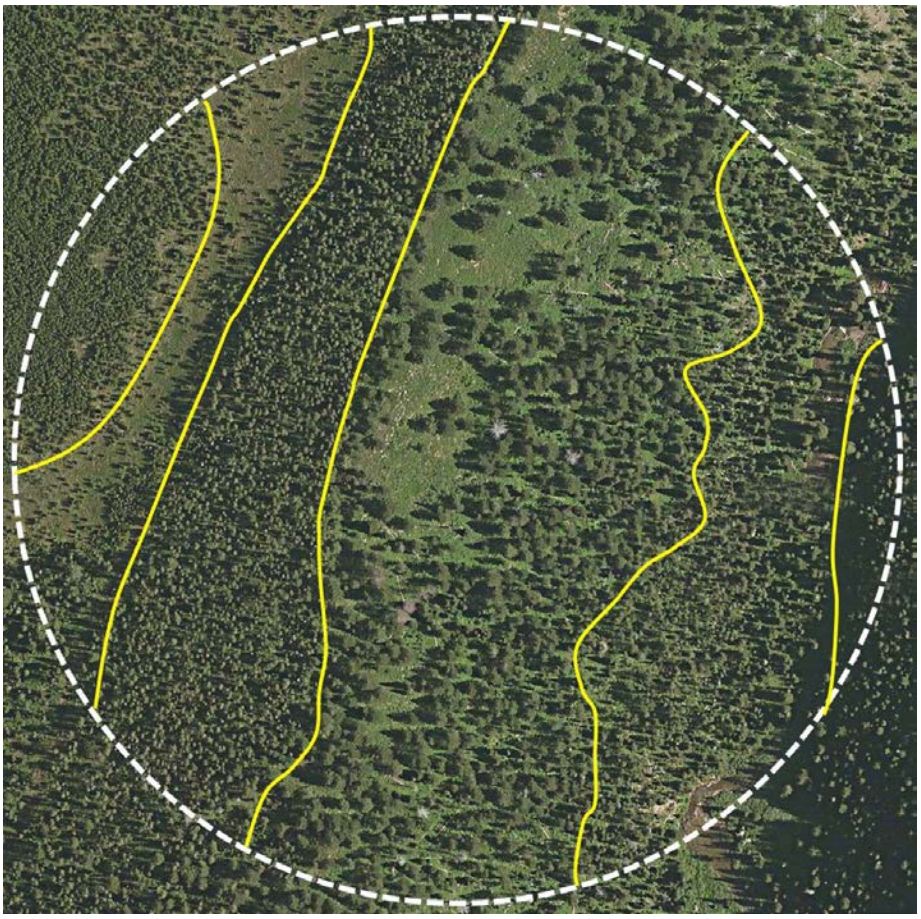
Figure D-9.—*Image Sampler Tool. Dot grid can be systematic (as shown) or random.* Note: The number of dots within the polygon is user defined. After each dot is attributed, proportions can easily be calculated for the polygon.



Cover Interpreter was designed to help users adhere to established mapping standards and produce existing vegetation geographic information systems (GIS) layers. It enables the user to assign cover attributes (canopy cover and size class) to polygons by comparing the underlying image with a series of transparent digital image chips that can be moved over the image (figure D-10).

These digital tools, although consistent and objective, are slower than ocular interpretations. Perhaps the best way to use them in a large project is more at the start of a project to grow confidence and interpretation skill and sparingly thereafter for occasional recalibration of our eye-brain system.

Figure D-10.—*Cover Interpreter Tool quickly assesses percentage of canopy cover.*



D.4 Suggested Image Interpretation Workflow

As you prepare to engage in image interpretation, use of this workflow will help build skills and maintain consistency throughout the interpretation process. The workflow assumes that you have adequate ground-based knowledge about the resource you wish to interpret from the imagery and that your objective is a continuous (wall-to-wall) polygon-based classification.

Use the following suggested steps for interpretation of vertical, high-resolution[4] orthocorrected digital imagery.

1. Define and be very familiar with the classification scheme (see section D.5).
2. Prepare the imagery.
    a. Imagery should be accurately orthocorrected and displayed in your corporate GIS/image-processing software.
3. Segment the image into appropriate mapping polygons by using heads-up digitizing, existing polygon data or image segmentation software. Determine a minimum mapping unit (MMU) and ensure that few, if any, polygons are smaller than the MMU—unless the segmentation has been deliberately designed to oversegment the landscape. If the landscape has been oversegmented, many segments will need to be merged later.
4. Take the imagery with overlaying segment boundaries into the field (hardcopy prints or on a digital mobile device). The purpose of this visit is to start the familiarization process and to test the classification scheme and image capabilities.
    a. Select several polygons with different characteristics to visit.
        i. If you are already familiar with the area, select the polygons based on known differences in your classification scheme (e.g., big trees, small trees, or evergreen, deciduous). Try to visit polygons that represent all the classes in your classification scheme (the complexity of your classification scheme will drive the number of polygons you should visit).
        ii. If you are unfamiliar with the area, visit the polygons with differences in the image characteristics that you suspect portray differences in the feature(s) of interest. You should eventually visit polygons that represent all the classes in your classification scheme.
    b. For each visited polygon—
        i. Try to classify the polygon based solely on ground observations.
        ii. Carefully inspect the same polygons in the imagery while you are within each polygon. Try to build the bridge from what you have seen on the ground to what you can see on the image. Consider making notes on your field form; otherwise, write notes on the field maps for that polygon.
    c. After visiting the selected polygons on the ground, classify the same polygons based solely on your interpretation of the imagery.
    d. Check your image-interpreted classifications against your ground-based classifications.
        i. If results indicate you can successfully interpret the imagery, proceed to the next step in this process.
        ii. If results indicate you cannot successfully interpret the imagery, however, determine if the problem is a classification-imagery mismatch (i.e., no discernible image characteristics permit interpretation of the feature[s] of interest). If you have a hierarchical classification, can you collapse it a level to be less detailed and still have an acceptable product? Would more image-interpretation practice sufficiently solve the problem?

[4] High-spatial resolution imagery in this case indicates a 1-meter ground sample distance (pixel size) or finer.

e. Interpret and classify polygons on the imagery that you have not visited on the ground—try to include all the classes in your classification scheme.
f. Visit those remaining polygons on the ground and check your image-interpreted classification.
    i. If results indicate you can successfully interpret the imagery, proceed to the next step in this process.
    ii. If results indicate you cannot successfully interpret the imagery, however, determine if the problem is a classification-imagery mismatch (i.e., no discernible image characteristics permit interpretation of the feature[s] of interest). If you have a hierarchical classification, can you collapse it a level to be less detailed and still have an acceptable product? Would more image-interpretation practice sufficiently solve the problem? Make sure the issue is addressed before proceeding further with this project.

5. With success to this point, you should develop image keys, field forms, and image training sets.
6. Classify polygons on the digital imagery.
    a. Attribute easy features first (e.g., water versus forest) and go from the known to the unknown.
    b. After initial broad classification, further subdivide by using more subtle features.
        i. For timber mapping: first, type density (canopy cover); next, species (dominance class); and then, size class.
        ii. Use both high- and low-zoom magnification. Different magnifications can accentuate different image attributes.
    c. You undoubtedly will encounter polygons that need to be split or joined—make sure you are familiar with these digitization techniques. If you are splitting a polygon, make sure that all parts exceed the MMU size.
7. Check your work and frequently recalibrate your interpretations. It is common to have "classification drift," which means that, as the project progresses, the way you interpret features changes. Classification drift occurs during the course of an individual day (usually occurs in a bad way because of fatigue) and also over the course of weeks and months as you become more skilled.
    a. Frequently refer to your image keys and training sets.
    b. Occasionally use a tool such as Image Sampler after you have classified a polygon by eye to test your determinations. It is preferable for efficiency to have the confidence and skill to manually perform (by eye) the classifications rather than using Image Sampler. Image Sampler is more consistent and unbiased than a human interpreter but it is slower. Its best use in this workflow is as a recalibration tool for your manual interpretations.

D.5 Classification Scheme

Classification schemes categorize and label the variation in land cover that you want to capture. A classification scheme is analogous to the legend of the final map you wish to produce. A workable classification scheme is the first step in a successful image-interpretation project and should not be taken lightly.

High-resolution imagery has a tremendous amount of information—often too much information to process efficiently. You need to extract and summarize the information to make it manageable. Thus, image-interpretation projects focus on a particular type of information—themes—to extract from the imagery. For example, a given project may focus on gathering information about varying levels of vegetation information despite the imagery having a nearly unlimited number of other potential themes—other examples of themes might include forest health, transportation features, water features, cultural surveys, and many more.

Use the following five rules and three suggestions to keep in mind a workable classification scheme. First, the rules—

1. The classification scheme must meet the information needs of the intended user.
2. The classification scheme must be based on what can be interpreted from the imagery. This requirement may conflict with the previous requirement in some cases.
3. Continuous classification schemes must be exhaustive.
4. The classification scheme must be mutually exclusive.
5. The classification scheme must be composed of labels and rules for labeling.

In addition to these rules, the classification scheme should—

1. Follow a hierarchical (nested) classification scheme. This type of scheme provides for more flexibility and better support to multiple and diverse users.
2. Use measurable land cover (not the specific land *use*) characteristics.
3. Avoid subjective interpretive classes such as “old growth” or “suitable habitat.” These items in the classification scheme should be derived by definitions based on measurable feature characteristics.

The complexity of a classification scheme ultimately will affect the project accuracy and cost. The more complex the scheme, the more expensive and the less accurate the final product will be. A good and workable classification scheme is not a guarantee of success, but a poor and unworkable scheme is a guarantee of failure. Give it the time and attention it deserves for your project.

Appendix E. Regional Resources for Mid-Level Existing Vegetation Mapping Projects

The Forest Service Intranet (fsweb) pages listed here include regional tools for vegetation mapping, project examples, and protocols.

Region 1. Renewable Resources, Forest Inventory and Analysis
http://fsweb.r1.fs.fed.us/forest/inv/index.htm

Region 2. Geospatial Services
http://fsweb.r2.fs.fed.us/eng/staff/geo/

Region 3. Remote Sensing
http://fsweb.r3.fs.fed.us/eng/MID-SCALE_VEG/index.html

Region 5. Resource Management, Vegetation Classification and Mapping
http://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192

Appendix F. Design and Analysis Toolkit for Inventory and Monitoring

By Charles T. Scott

The Design and Analysis Toolkit for Inventory and Monitoring (DATIM) project is a joint effort between the Forest Inventory Analysis (FIA) program and the National Forest System (NFS) regional FIA coordinators to improve inventory and monitoring designs and data analyses by developing nationally consistent tools and by leveraging existing data. The FIA's National Inventory and Monitoring Application Center (NIMAC) and the NFS's Ecosystem Management Coordination, or EMC, Staff sponsor this effort. DATIM's design is modular so that new calculations, additional datasets, and cutting-edge techniques may be easily incorporated. The tools described in the following section address the sample design phase, data storage, compilation, and data analysis steps outlined by NIMAC (Scott 2012, Scott et al. 2009). This application is currently under development but will be available at http://apps.fs.fed.us/datim. A subset of the modules is available in draft form for use today. Contact your NFS regional FIA coordinator or NIMAC for further information about using this system.

The **Design Tool for Inventory and Monitoring (DTIM)** helps determine cost-effective, statistically valid inventory and monitoring sample designs. DTIM will provide NFS the means to determine if existing data can address specific monitoring questions. If estimates of current conditions and trends based on available data are inadequate according to statistical power analysis, DTIM can help you determine the additional sampling needed to meet their precision requirement and cost objectives.

The **Compilation Tool** can use data coming from both Natural Resource Manager (NRM) FSVeg and FIA's National Information Management System, or NIMS. This tool computes attributes that are derived from other attributes, such as biomass and canopy base height, and stores them in the FIA DataMart. The graphical user interface, or GUI, allows for selecting data for compilation based on population, spatial attributes, temporal attributes, columnar attributes, and geographic information systems, or GIS. In the future, the tool will link to other regional and corporate datasets, including others in NRM, where colocated inventory data may be found.

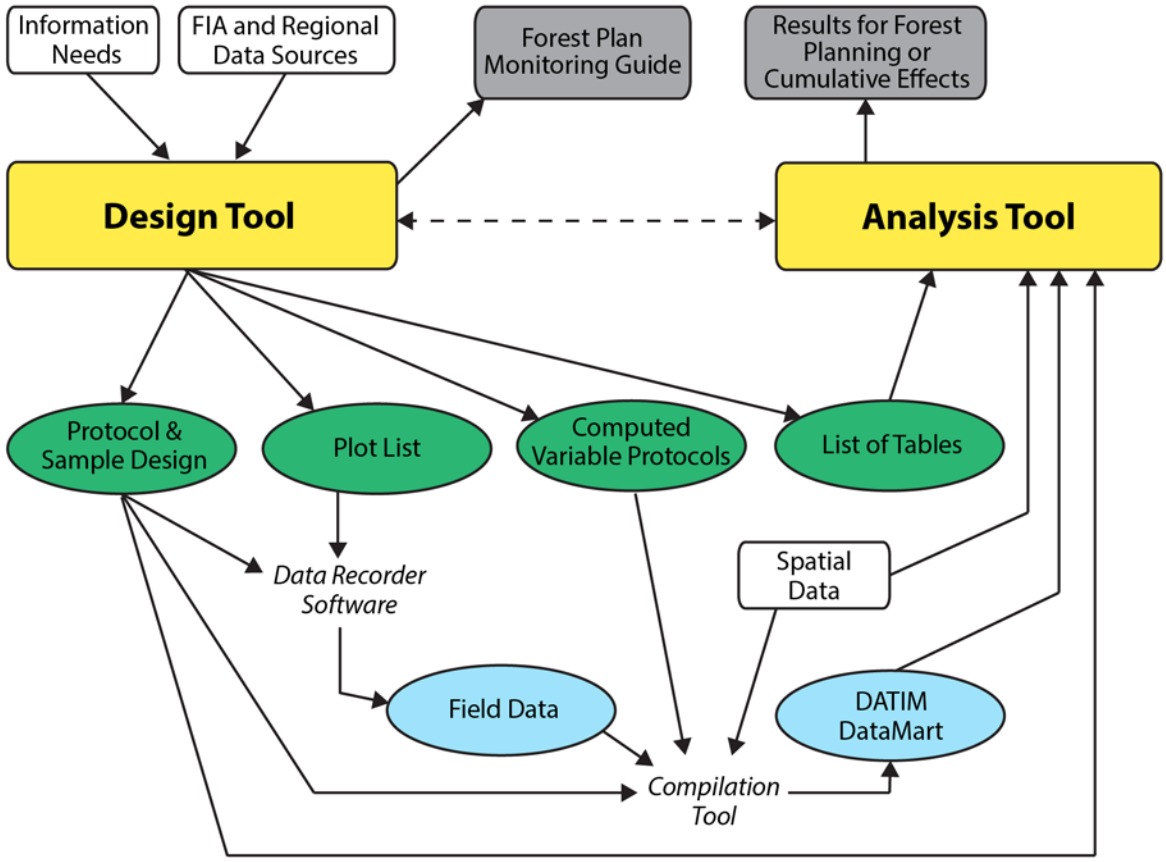
The **Spatial Intersection Tool** (SIT) selects a subset of inventory data to derive estimates for spatial layers, such as ownership, cover-type maps, and ecological classification maps. Selections can be made by features (polygons), user-defined polygons, features from a table, or distance from linear features. SIT returns a list of plots and polygon areas for the analysis phase, which then produces estimates for attributes of interest. SIT incorporates the NRM geospatial interface (GI) functionality and operates within ArcMap. Because SIT is integrated with the GI, you can integrate activities that have occurred in the inventory plots since time of inventory into the analysis by using NRM Forest Service Activity Tracking System, or NRM FACTS, information. Identify changes in administrative boundaries by using Automated Lands Project, or ALPS.

The **Analysis Tool for Inventory and Monitoring** (ATIM) provides NFS a consistent interface with inventory and monitoring data and assists with producing estimates with confidence intervals and associated map-based products. ATIM can help you determine if FIA or other

existing data are sufficient to answer the monitoring questions or to assess data variability if they are deemed inadequate. ATIM can link to the spatial data using SIT; both can be used in the compilation and analysis of data and in the production of maps.

Additional information is available on the DATIM Web site at http://www.fs.fed.us/emc/rig/DATIM/index.shtml.

Figure F-1.—*Relationship of Design and Analysis Toolkit for Inventory and Monitoring tools and functions.*



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Appendix G. Methods To Spatially Distribute Sample Locations

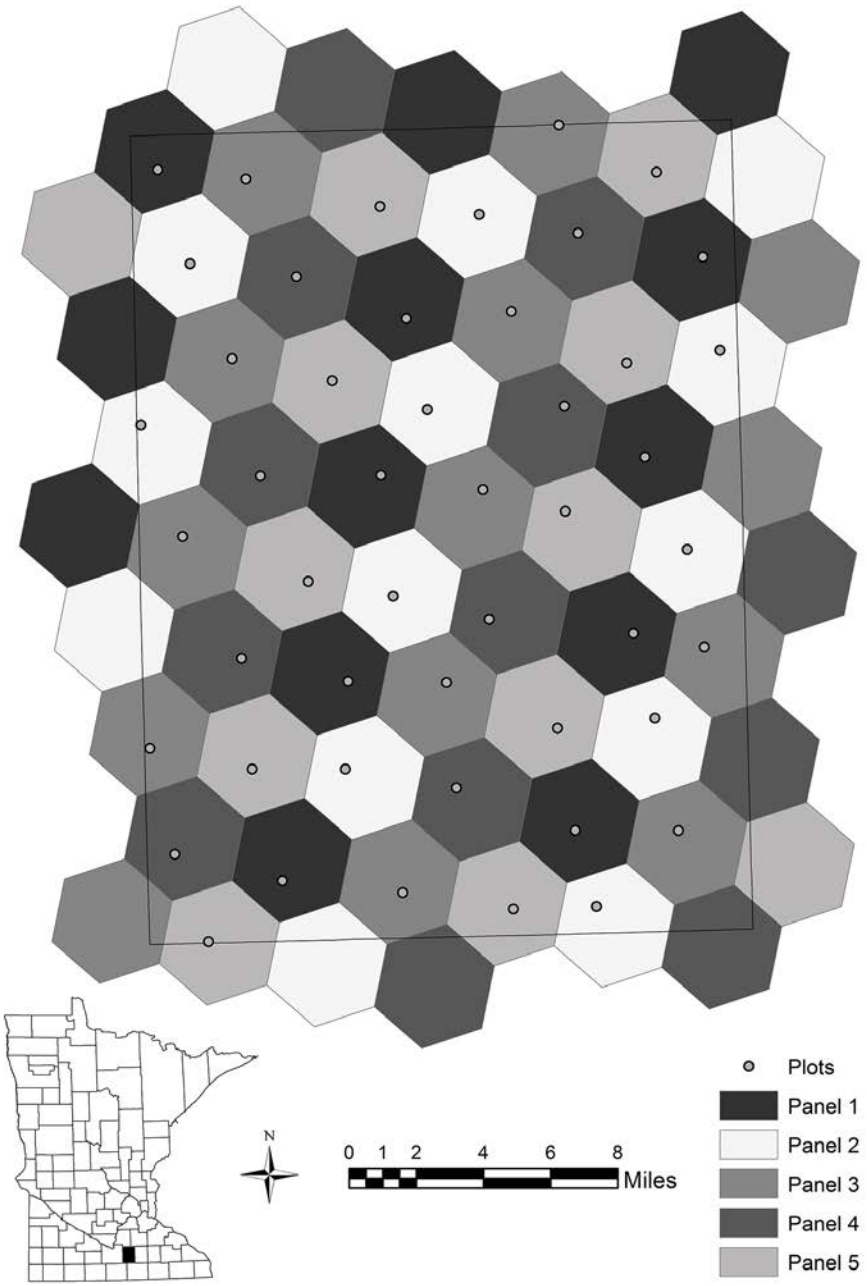
By James Gerleman

The following description focuses on those methods that are appropriate for mid-size areas of interest. This description includes use of the Forest Inventory and Analysis (FIA) base grid and use of computer programs and geographic information systems (GISs) to locate a given number of plots in a spatially balanced manner. The methods described in the following section can be used for systematic sample designs and stratified sample designs. When designs are stratified, each system described should be applied within every stratum of the sample.

Use Forest Inventory and Analysis Program Grid for Spatially Balanced Plot Locations

The FIA program grid is based on a sampling frame developed by the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program and is based on a systematic tessellation of hexagons to spatially balance plot locations across the United States. The sample frame is summarized as a base hexagon centering over the conterminous United States, then from that tessellating across the entire planet (Bechtold and Patterson 2005). Each hexagon is then divided into smaller (approximately 94,992 acres) and smaller (approximately 5,937 acres) hexagons to create sample frames to satisfy intensity requirements of FIA and Forest Health Monitoring (Bechtold and Patterson 2005). One FIA plot is randomly located in each 6,000-acre hexagon on the base national FIA program grid (figure G-1). Plots measured in a given year are in the same "panel," so remeasuring plots in the Western United States every 10 years creates 10 panels of data.

Figure G-1.—*An example of selected FIA plots: Phase 2 hexagons from Waseca County, MN, and the selected Phase 2 plots for each cell by panel (Burkman 2005).*



For mid-level or finer scale information needs, it might be necessary to intensify the base FIA grid to achieve estimates with the precision specified by the information needs assessment. The Forest Service Northern Region (Region 1) Vegetation Analysis Team developed a tool to intensify the plots through the use of the Region 1 Intensification Plot Locator, or RIPL, software.

Use Geographic Information Systems To Generate a Random, Spatially Balanced Set of Locations

One disadvantage of the regular tessellation system used by FIA is that partial cells (polygons) are created by population boundaries (Lister and Scott 2009). This system creates a situation in which the probability for selecting a sample in a partial cell is unequal for all partial cells and results in bias estimates of population totals (Gregoire and Scott 2003) if the appropriate statistical estimator is not applied. To avoid problems with systematic and semisystematic sample networks, several alternative sample selection methods have been proposed (Cotter and Nealon 1987, Olea 1984, Olsen et al. 1999, Saalfeld 1998, Stevens 1997). This section describes those alternative methods that employ use of GIS to generate the plot locations, based on spatially balanced systems.

Grid with random start. Systematic, or grid sample, is one of the simplest methods for sample unit distribution and may form the building blocks of more complicated stratified designs. It is also apparent from the spatial distribution of plots that it fairly represents the study area, a quality that is not apparent to the casual observer with a random sampling design. Designing a grid sample is relatively easy and can be accomplished with GIS. The key decision in designing a grid is to determine sample intensity, or the distance between sample points, that will make up the grid. Grid spacing not only determines the smallest possible sample unit, but also, more importantly, determines the total number of sampled points (McDonald et al. 2002).

After grid spacing is determined, the grid can be constructed by randomly determining the origin of the grid. For example, two random numbers are chosen between 0 and y, which are labeled as $m1$ and $m2$ (McDonald et al. 2002). Assume the origin of the geographic coordination system is in the lower left corner of the area of interest, the site at the lower left-most point is the point ($m1$, $m2$) that shifts the grid north and east by a random amount (McDonald et al. 2002). All other points on the grid are placed north and east, a predetermined spacing from the origin and subsequent points.

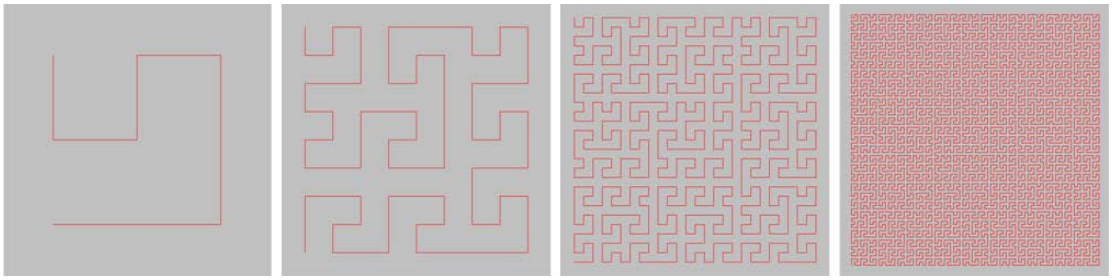
Advantages to this type of design are that sample points are placed uniformly across the population of interest, and are unbiased in their placement. A disadvantage of this type of sample is that small areas of interest may be missed during the sample, unless the sample size is large. For example, riparian areas tend to occupy small areas; they may be missed with this type of sample. In addition, systematic designs do not take into account different costs for travelling from one site to another because all the distances are equal. A separate sampling frame should be considered for discrete resources, like riparian areas and wetlands, to supplement a systematic sample.

Space-filling curves. A number of space-filling curves techniques can be used, but only two are described in this appendix. The first method for selecting plot locations is the use of the space-filling curves technique, as described by Lister and Scott (2009), to generate a spatially balanced sample. This approach uses GIS to divide the population area into pixels, aggregate the pixels into equal area groups (clumps) based on their location along a fractal curve, then randomly sample a point (or pixel) within each clump (figure G-2; Lister and Scott 2009).

Figure G-2.—*Example of a spatially balanced sample using pixel groups from Lister and Scott (2009).* Note: Each element in the sample frame is grouped into a class based on its spatial address assigned by the fractal curve (figure G-3).

The second technique using space-filling curves are curves or a shape that completely occupies an area of interest (Bartholdi and Platzman 1988). A specific type of space-filling curve is the Peano curve fractal, which is a type of repeating self-similar shape that is repeated recursively and fills a planar surface (figure G-3). In effect, each point on the Peano curve creates a one-dimensional (1-D) spatial reference for each point in two dimensions (2-D), thus representing locations in 2-D space as locations along a line (Lister and Scott 2009). This portioning of space creates a de facto tessellation that can divide the sampling frame into an infinite number of regions of equal size.

Figure G-3.—*An example of one type of Peano Curve.* Note: Four levels of recursion are shown, demonstrating its self-similar, space-filling properties. The intensity of recursion affects the density of the curve within the sample frame. Figures generated by Java applet constructed by V.B. Balayoghan, retrieved December 1, 2006, from http://www.cs.utexas.edu (Lister and Scott 2009).



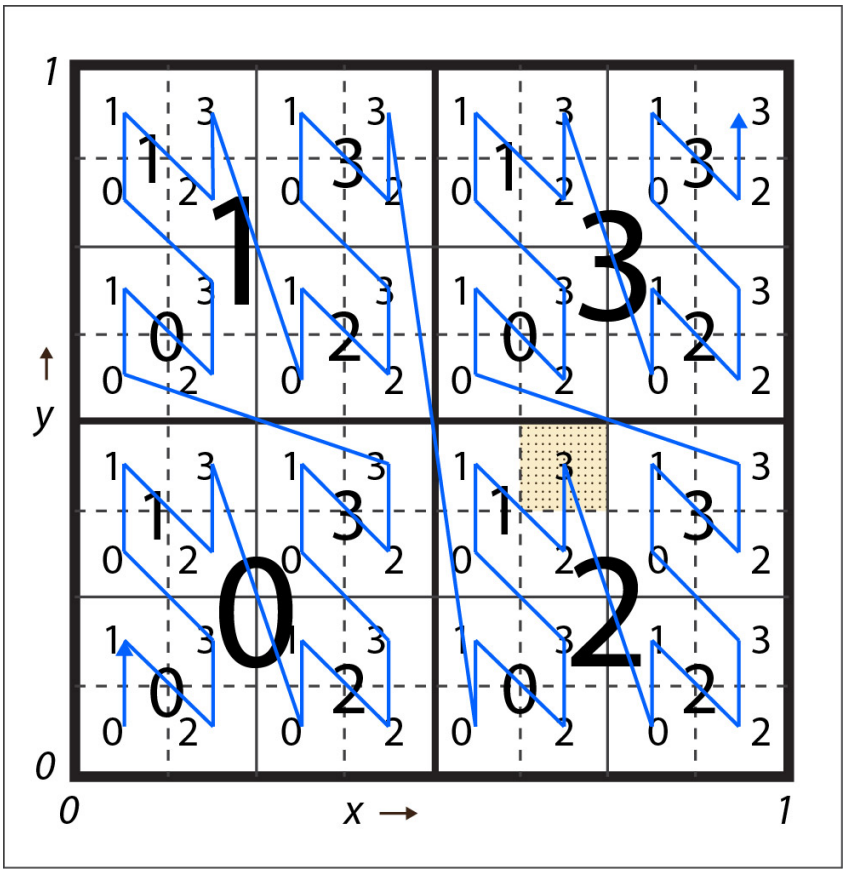
The use of space-filling curves presents a way to translate the location of each element in a 2-D sample frame to a 1-D address, group these addresses into contiguous or semicontiguous groups of potential sample locations, and randomly select samples from within these groups (Lister and Scott 2009). This approach offers the benefits that most other approaches offer, and has the added advantage of transparency and intuitive clarity (Lister and Scott 2009). In addition, it can be easily implemented with the native functionality of a commonly used GIS.

Generalized Random Tessellation Stratified (GRTS) design. One approach described by Stevens and Olsen (1999, 2004) is to recursively divide the area of interest into quadrants, make an ordered spatial address to each quadrant, and reorganize the spatial address such that samples can be randomly selected in a spatially uniform way (Lister and Scott 2009). This procedure has several desirable properties, including applicability of standard design-based estimation procedures, spatial balance, ability to assign differential selection probabilities to elements in different areas, and ability to create subsets of plots that have the same properties as the full set of plots (Lister and Scott 2009).

A good summary of GRTS is found in an online article on the Web site http://www.landscapetoolbox.org (The Nature Conservancy and Jornada Experimental Range 2012). The article describes the following procedure for locating samples within an area:

1. Assign the sample units an order according to a recursive, hierarchal, randomization process (figure G-3). In the example in figure G-4, the main quadrats and subquadrats have the same number ordering, but, in practice, random numbering is assigned for each quadrat or subquadrat. This process preserves the spatial relationships of the sample units.
2. Arrange the sample units in order.
3. Divide the line of sample units into a number of equal length segments, depending on the desired number of total samples.
4. Select one sample unit from each segment for sampling. The GRTS method produces samples that are spatially balanced.

Figure G-4.—*An example of Generalized Random Tessellation Stratified process applied to an area to be sampled (Stevens and Olsen 2004).*



Several computer-based programs will generate GRTS-like sample selections (Kincaid 2012, Theobald et al. 2007, West Inc. 2006). Some of the disadvantages of this system are that current GRTS implementations will select sample points that are located in areas that are not feasible for a crew to access, such as hazardous areas or denied access areas, in a spatially disjointed manner because of the randomization process used (Stevens and Olsen 1999, 2004; Theobald et al. 2007). Randomly selecting replacement plots near the original may alter selection probabilities, possibly affecting decisions to use classical statistical estimators (Lister and Scott 2009).

Use Hawth's Analysis Tools for ArcGIS and Geospatial Modeling Environment in R

Other tools that could be used for selecting plot locations are Hawth's Analysis Tools, an extension for ESRI's ArcGIS software designed to perform spatial analysis that cannot conveniently be accomplished by the base ArcGIS program (Hawthorne 2012a). This extension performs many spatial analyzing tasks, including pertinent sampling tools, that may be of use.

- Generates random points. Enables the user to generate a total number of random points or a constant number per polygon. Also, enables the user to prohibit random points from being placed in certain areas, such as "No Data" cells.

- Generates sample shapes. Enables the user to generate polygon sample points around each point based on a polygon shape.
- Generates conditional point sample. Enables the user to generate random points based on a unique feature.
- Generates three-dimensional (3-D) sample. Enables the user to generate a random sample of 3-D locations in a volume of space specified by the user.

This tool contains many other uses for sampling and other uses for spatial analysis. Hawth's Tools are free for use and are found on the Web site <http://www.spatialecology.com>. According to this Web site, as of June 2012, Hawth's Tools are being formally replaced with the Geospatial Modeling Environment (GME), which is an improved version of its predecessor, designed for complex spatial analysis and modeling. GME is a standalone program that runs with the open-source software, R, and works with ArcGIS. This platform has better analysis and modeling tools; has features such as batch processing, new graphing functionality, and support of geodatabases; and can be accessed programmatically (Hawthorne 2012b). Strengths of the R software include that it is free to use, it has a large user community, and many packages are well documented for users' reference (Hawthorne 2012b).

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Appendix H. Recommended Field Gear

The following list of field gear identifies many items that are necessary to conduct an existing vegetation field inventory. This list may not include all the equipment necessary to collect all attributes as per the field manual. A final check between the protocols and the list of field gear should be done.

General Field-Going Equipment Needs

- Vehicles.
- Backpack—with a comfortable fit; sturdy enough to carry 35 to 50 pounds (lbs) of field gear.
- Overnight backpack (to use for remote plots that require camping), with a comfortable fit; sturdy enough to carry 60 to 80 lbs of field gear, including a sleeping bag, cook stove, utensils, water purification system, warm clothing, and food.
- Hiking boots—with a comfortable fit; it is highly recommended that the top of the boots extend above the ankle (to provide adequate protection to the feet and ankle).
- Rain gear.
- Hard hat.
- Timber cruising vest.
- Water bottles.

Vegetation Measurements Equipment

- Logger's tape—50 or 100 feet (ft).
- Diameter tape—generally in inches and tenths of inches.
- Carpenter's tape—25 ft, with 0.1 ft and inch marks.
- Increment borers—length of borer needed depends on size of trees that will be cored (for measuring tree age/radial growth).
- Relascope, angle gauge (for selecting trees when doing variable radius plot sampling).
- Cloth tape—100 ft and/or 200 ft (for traversing from the reference point (RP) to the plot center (PC) and sample transects).
- Hatchet with flat back and/or small hammer (for nailing RP/witness tree tags, hammering sample tree nails at diameter at breast height (d.b.h.)/diameter at root collar (d.r.c.), and sounding for defect).
- Lumber crayons (for d.r.c. stem measurements).
- Paint pen (for marking d.b.h. on all aspen trees and marking trees less than 3.0-inches d.b.h./d.r.c.).
- Clipboard (for paper field forms).
- Mechanical pencils and/or pens.
- Compass.
- Clinometer—preferably with a slope correction factor, or SCF, for measuring tree heights and adjusting for slope distance.
- Ruler—with 1/10-inch (in) and 1/20-in scale (for measuring radial growth and duff/litter).
- Flagging—one type with a solid color and another type with a pattern; for example, one with orange flagging and one with blue/white striped flagging. Check protocols to see if specific colors are specified.

- Calculator—with the following function keys: MRC, M-, M+, and square root (highly recommended for calculating d.r.c. on woodland species).
- "Write in the rain" notepad.
- Digital camera (if required for photographing plot).
- Black felt-tip marker for photo placard.
- Plant identification books (to aid in vegetation composition sample—tree, forb, shrub, and graminoid identification).
- Laser range and height measurer; for example, Laser 200 and OPTi-LOGIC 400LH units.
- Global positioning system (GPS) unit capable of field averaging and navigation, including a distance or route function, with a stated accuracy of ± 10 meters (m) (49.2 ft) in the horizontal dimension and digital compass accuracy of ± 5 degrees; for example, Garmin GPSMAP 62st w/ WAAS capability.
- Portable data recorders (PDRs) that have the following features:
    - Is weatherproof.
    - Can be charged from AC or DC (vehicle cigarette lighter socket) or can run on alkaline batteries so it will still work in remote environments.
    - Has rugged field case.
    - Can run the software program for acquiring data; for example, Exams software.
    - Consider PDRs that link to or have built-in GPS.

Communication Devices

Note: In many Forest Service locations, cell phones do not provide a reliable means of communication.

- Forest Service radios with frequencies set.
- Satellite phone.
- GPS tracker.

Safety Items

- First aid kit.
- Bear pepper spray.

Plot and Tree Monumentation Equipment

- RP tags–to mark reference point.
- Witness tree tags–aluminum tags for X witness trees.
- PC stakes–to mark plot location centers.
- Aluminum nails–to mark d.b.h./d.r.c.—do not use steel nails.
- Popsicle sticks—to mark ends of transect lines.

Appendix I. Data Validation and Reconciliation

By Jim Alegria

The question of what constitutes a value that should be changed remains. Two rules of thumb can be used: (1) values that are fundamentally impossible, such as trees coming back to life, and (2) variables that are so implausible to be beyond belief. The differences between measurements of an attribute can be described as a random process with three components: (1) random error, (2) systematic error, and (3) gross error.

Random error is the distribution of measurements around their true value that occurs if many people take the same measurement. The mean of measurement error is often considered to be 0. Not all measurements will be the identical because of individual techniques or environmental factors that will add variation. Although significant effort is made to reduce this type of error through better training and equipment, it is inherent to all types of measurements.

Measurements made on the same attribute at two different points in time have errors for each occasion, plus a real change in the attribute value. Examples are height measurements of the same tree or forest type classified at each measurement occasion. Note that the measurement error associated with the change estimate is additive. This additive error means that if the attribute has a relatively large measurement error in relation to the change in attribute value between the two occasions, it will be very difficult if not impossible to separate the measurement error from real change.

The second type of error is called systematic error. Rather than varying around the true value, systematic errors result when the measured value tends to one side of the true value. They are often the result of miscalibrated instruments, procedural errors, or observer bias. Because these errors result in biased estimates, considerable effort should be made to routinely calibrate instruments, to perform both hot and cold checks, and to conduct “refresher” trainings.

The third type of error is called gross error. Such an error may be the result of instrument failure or observer carelessness, thus they may be large in size and have a substantial influence on estimates made with the data. It is this type of error that the validation process attempts to identify and replace with a value that possesses the following properties:

- **Does not bias the estimate of the population mean.** To be unbiased means that if the substituted value were to be replaced many times with similar substituted values, the mean of all the datasets would equal the true population mean.
- **Preserves the underlying variability of the data.** The variance is a measure of the variability of an estimate. If a substituted value does not replicate the variability of similar data, then the estimated variance will be biased. A common example is when missing heights are replaced with a constant for a given diameter. Using constants for heights will underestimate the true variability of tree height in the population. To prevent this underestimation from happening, the substituted value should emulate the inherent variation that is found in the population with similar characteristics.

Now that we have discussed types of errors, how do you identify gross errors and how do you substitute a value with one that is unbiased and preserves the variability of the underlying population?

I.1 Identifying Gross Errors

By far, the best method for identifying gross errors is to incorporate error-checking routines (i.e., screening for allowable values) into field data recorder software so that unusual data could be verified in the field. In the office, you do not have the advantage of double-checking whether the value entered is real or a data entry error.

In the office, methods for detecting gross errors vary from visually inspecting graphs of data points to standardizing the residual error produced from a model in which standardized residuals greater than a predetermined percentage of deviates are treated as gross errors; for example, less than 5 percent. The model does not have to be complex but should fit the data reasonably well. Often the model is based on ordinary least squares, typically called "linear regression." Statistical textbooks that contain a section on regression analysis will have a discussion on residuals, and many textbooks will discuss standardized residuals. All statistical software packages (e.g., SAS or SPSS) have options for outputting standardized residuals.

Reconciliation is a comparison between two measurements of the same attribute at two points in time; however, identifying the gross error is only the first step. Next, a determination must be made regarding whether the first or the second measurement is likely in error. Other values collected on the same plot often can provide evidence regarding which sampling event is suspect. For example, if you have a plot with several subplots and all the measurements for physiographic position are on the lower one-third of the slope but the second measurement of the suspect subplot is on the ridgetop, it is a good bet that the second measurement is in error. Another example is that the diameter growth of a tree is abnormally large. To determine which occasion should be changed, examine the other trees on the subplot to identify the error.

When it is not clear which sampling event to change, one option is to randomly pick a sampling event. Another option is to think about the quality of the data collection algorithms or the data collection training at those two points in time. It is often believed that the quality of the data improves over time because of better data editing routines or training. If you believe that this assumption is true, then the older data are changed in the belief that the more recent data are probably "more correct."

For categorical data, the process for identifying which sample event should be changed can be used to reduce the number of values that make sense. If the list cannot be reduced to a single logical choice, then simply randomly choose one from the reduced set of possibilities.

I.2 Generating Substitute Values

Two common methods of generating a substitute value for continuous variables are discussed in the following paragraphs.

- **Modeling.** Develop a simple model that predicts the variable based on other related attributes using data that have had the outliers removed by one of the methods described

in the previous section. For example, tree heights are often modeled as a function of species and diameter. If it is the difference between the two measurements that is in question, then the diameters at each occasion can be used to check the heights or to determine the probable change in height. After a model is developed, enter the independent values for the data element in question to predict the difference. Remember that the equation will predict exactly the same value whenever the same independent values are entered into the equation. This prediction approach violates the desired property #2 above in that it will reduce underlying variability of the data of the original population. To remedy the problem, a random number should be generated from a distribution with the same shape (parameters) of the residual errors. It is most common to assume that the residual errors are distributed like a normal distribution, but other residual error distribution can be modeled. It is most common to generate a random number with a mean of 0 and a variance that is estimated by the model. Add the random residual number to the predicted value of the sample event that is believed to be most reliable. Remember because the mean is 0, the random number could be positive or negative, so adding it to the predicted value will result in a substitute value either larger or smaller than the predicted value.

- **Imputation.** Imputation is a method of substituting values from similar data for missing or erroneous data. Many people think that this approach is simpler than the modeling method. Identify clean data that are similar to the data element. You can identify similar trees by identifying trees of the same species, within a diameter range that includes the diameter of the tree in question, and maybe some measure of site quality. The collection of data that fits the definition is often called a "bin" or more formally a "cohort." From the bin, randomly select a tree. Substitute the chosen observation for the suspect one. This method relies on the assumption that the original data are a random sample from the population so a random draw from a pool of cohorts will nearly preserve the variation from population. The term *nearly* means that this method is slightly biased, but the "proper" method, called *multiple imputations*, is cumbersome to employ for all but the most demanding surveys.

The original data should be archived in a database that identifies the specific data cell changed and is backed up to a corporate drive. Keep a complete record of changes, methods used, and dates on which the changes were made in case questions arise about the data editing method applied or if a better method for generating substitute values is developed at a later time period.

Appendix J. Imputation of Inventories

By C. Kenneth Brewer

Imputation is the process of estimating missing data (Schreuder et al. 1993). Although a detailed discussion of the types of missing data and the various approaches to imputation is beyond the scope of the *Existing Vegetation Classification, Mapping, and Inventory Technical Guide*, Version 2.0, Schreuder et al. (1993) presented 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 I. Within appendix J, however, the production of nearest neighbor (NN) imputation-based data surfaces (i.e., geospatial modeling of design-based inventory data; hereafter, NN data surfaces) 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 the *Existing Vegetation Classification, Mapping, and Inventory Technical Guide*, Version 2.0.

The 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 of the technical guide for a discussion of spatial modeling surfaces). For planning purposes, it would be convenient to operate as if detailed inventory information were available for all modeling units in the planning area. Therefore, a methodology is needed to populate vegetation delineations or raster data surfaces with detailed, designed-based inventory data (i.e., plot-level tree list data).

Imputation is an alternative to historically common stand-based statistical approaches (e.g., regression estimates or stratum averages) to populating unsampled units with data. 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, Van Deusen 1997).

Imputation of inventory data from sampled areas to similar unsampled areas produces datasets that function like “wall to wall” data for planning purposes. There are many methods and variations of imputation, both univariate and multivariate. Eskelson et al. (2009) provide a good summary of common imputation approaches and summarize variable-space NN methods compared with other estimation methods.

NN 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. These NN methods include; Most Similar Neighbor (MSN; e.g., Moeur and Stage 1995, Moeur 2000), k nearest

neighbor (kNN; e.g., Maltamo and Kangas 1998), and tabular imputation methods (Ek et al. 1997, Hassani et al. 2004).

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. Forest Inventory and Analysis (FIA) data are commonly used reference data and Gradient Nearest Neighbor (GNN; Ohmann and Gregory 2002) is a commonly used NN method (Grossmann et al. 2009, Wilson et al. 2012).

With an understanding of both the strengths and weaknesses of NN approaches, the spatial and temporal dimensions of land management planning benefit from their application. This application is particularly beneficial when various management alternatives or disturbance scenarios are considered. It is important, however, to carefully assess the model outputs to ensure reasonable correspondence between model-based estimates (from the imputation process) and designed-based estimates (from the inventory) for the variables of interest (e.g., Riemann et al. 2010).

Three primary imputation modeling approaches have been developed that could potentially address this important need. These approaches are based on variations of kNN methods developed for the imputation of strategic forest inventory data and increasingly used worldwide (Haara et al. 1997, Maltamo and Kangas 1998, McRoberts 2009, McRoberts et al. 2002, Tomppo 1991). Although based on the kNN methods, these new approaches were developed for generating data surfaces primarily for mapping and simulation modeling rather than traditional estimation of missing inventory data. These methods also differ from kNN and from each other with respect to how neighbor plots are identified, ranked, and selected by using the X variables.

The first of these approaches, MSN, was developed by Moeur and Stage (1995) and further developed by Crookston et al. (2002). The second, GNN, developed by Ohmann and Gregory (2002) follows the same general analytical logic. GNN, however, uses a different distance metric, constrained ordination. The third uses the Random Forest algorithm (Breiman 2001) adapted for imputation (Random Forest NN) by Crookston and Finley (2008). The adaptation of Random Forest was part of a broader imputation software development package named yaImpute (Crookston and Finley 2008). Within this software package users have options for using different values of k and various strategies for finding neighbors (e.g., MSN, GNN, and Random Forest NN).

The MSN, GNN, and Random Forest NN approaches are most often implemented by assigning a single nearest neighbor to function like “wall-to-wall” data for planning purposes. Assigning a single NN maintains the original covariance structure in the data and ensures that the imputed values can (and do) actually exist. Thus, the resulting NN data surface can be used in simulation models and projected into the future.

These various imputation approaches are promising techniques, with potential for generating spatially explicit, border-to-border information on forest composition and structure across the United States. Spatially explicit data of this type has the potential to address a wide variety of

business needs for the agency and others in the natural resource community. The Nationwide Forest Imputation Study (NaFIS) was conducted with the intent of serving as a pilot project to further assess that potential (Grossmann et al. 2009). The objective of NaFIS was to highlight the data needs for such a project, highlight the choices to be made throughout the process, and identify potential pitfalls to be avoided by a national implementation.

NaFIS examined the process of NN imputation adapting the operational approach used by Ohmann et al. (Ohmann and Gregory 2002, Ohmann et al. 2012). This adaptation included integrating FIA's annual inventory plots with spatially explicit climate, topography, and Landsat image data. NaFIS evaluated issues of scale in summarizing reference plot data, compared four distance metric choices (i.e., Euclidean, MSN, GNN, and Random Forest NN model types), and tested the number of neighbors integrated to make each model prediction by using five different values of k.

In addition to the NaFIS work described in the previous section, Wilson et al. (2012) developed an NN imputation approach to mapping tree species over large areas by using FIA plots and moderate resolution raster data. The method efficiently integrates vegetation phenology derived from Moderate-Resolution Imaging Spectroradiometer, or MODIS, imagery and raster data describing relevant environmental parameters with extensive field plot data of tree species basal area to create maps of tree species abundance and distribution at a 250-meter pixel size. The approach uses the techniques of kNN and canonical correspondence analysis (adapted from the GNN approach described in the previous section). The approach also uses a stratification derived from the 2001 National Land Cover Database, or NLCD, tree canopy cover layer.

The suite of assessment procedures (Riemann et al. 2010) applied to each of the modeled datasets indicate high accuracies, at the scales of assessments used, for total live-tree basal area per hectare and for many of the most common tree species. This approach allows for the mapping of individual tree species distributions, while preserving much of the species covariance found on the forest inventory plots, at a level of spatial detail approaching that required for many national and regional applications supporting resource plans and decisions. This work has recently been extended to provide the analytical basis for an NN imputation approach for spatially extant estimates of forest carbon (C) density for the conterminous United States (Wilson et al. in review). Results suggest that a forest inventory plot imputation approach can provide pixel-based maps of C density across a range of pools (e.g., live tree to forest floor) and spatial scales (e.g., subcounty to biome).

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Appendix K. Example of a Job Hazard Analysis From the Forest Inventory and Analysis Program

Table K-1.—*Example of a job hazard analysis from the Forest Inventory and Analysis Program.*

U.S. Dept. of Agriculture Forest Service **JOB HAZARD ANALYSIS (JHA)** References-FSH 6709.11 and-12 (Instructions on reverse)	1.WORKPROJECT/ACTIVITY Field Data Collection	2. LOCATION NRS FIA	3.UNIT NRS-05
	4. NAME OF ANALYST NRS FIA Safety Committee	5. JOB TITLE	6. DATE PREPARED September 2013
Read current SPOT monitoring protocols and Time Limit in Woods as part of this JHA.			
7. TASK/PROCEDURES	8. HAZARDS	9. ABATEMENT ACTIONS	
1. Driving from either official or temporary duty station to field plot location.	a. Hazardous road conditions during inclement weather and some portions of the year	* Drive with extreme caution. * All personnel who drive on duty must complete defensive driving class renewed at least every three years. * See "Winter Travel" and "General Driving" JHA.	
	b. Driving in off-road situations with or without four-wheel drive	* All new personnel receive training on the use and operation of 4-wheel drive vehicle operation. * Review the '4WD Awareness Class' pdf or ppt document. * Drive with extreme caution.	
	c. Vehicle becomes stuck or mired	* Avoid standing directly behind or directly in front of wheels to avoid flying mud or debris. See Come Along Information in Section 11.	
	d. Vehicle breakdown and unable to get to shelter	* Ensure that each vehicle is equipped with a seasonal survival kit that has been inspected and includes all items that are necessary.	
2. Foot travel	a. Slips, trips, falls; cuts, scratches, sprains	* Wear ankle supporting, non-skid boots appropriate for conditions. * Wear sturdy, long pants to reduce skin abrasions * Watch where walking. * Stay on trails when able. * Use a walking stick when necessary. * Carry an appropriate first-aid kit and compression wrap. Kit should include gauze, bandages, butterfly strips, pain reliever, tape, moleskin, antiseptic cleaner.	
	b. Allergic reaction to insect bites (e.g. bee stings)	* Ensure that all personnel with known allergic reactions to insect bites carry appropriate medication. Also, the individual should make sure that their partner knows where the medication is kept and can administer it in an emergency situation. * In case of a bite or sting, watch subject closely for any allergic reaction. Call 9-1-1 or local emergency number and evacuate immediately if any reaction away from injury site is observed	
	c. Branches striking eyes	* Keep a safe distance from partner. * Wear protective eyewear.	

Table K-1 (continued).—*Example of a job hazard analysis from the Forest Inventory and Analysis Program.*

10. Installing and Measuring the Plot	a. Use of forestry tools such as logger tapes, D-tapes and increment borers	* When spooling up logger tape, control speed of returning tape, to avoid injury from the spiked end of the tape. * Keep tools in good condition by oiling and other appropriate maintanance. * Do not push objects into increment borer backwards to loosen a stuck core, instead, drill into a new tree or soft bark and remove stuck core in the usual manner. * Wear gloves and eye protection.
	b. Use of hand tools such as hand axe, pruning saw and shovel	* When traversing slopes, carry hand tools on the downhill side. * Hand axes should always be carried sheathed with leather flap snapped shut. * Do not carry long handled tools over shoulder, or hatchets unsheathed in belt-loop.
	c. Use of tree marking paint	* Have MSDS available and read them. * Use safe products with managable risks. * Store and use paints in accordance with MSDS recommendations.
	d. Dehydration	* Consume (in addition to regular meals) fruit and liquids that replace the loss of carbohydrates and maintain blood sugar levels at normal limits. Drink water regularly. Make sure you carry enough water. Take frequent breaks. Avoid open sunny areas if weather is extreme. Seek out shaded areas.
	e. Hypothermia	* Prevent hypothermia by planning ahead and using your gear to stay warm and dry. * On cool days be aware of overheating and then rapidly cooling down. * Dress appropriately and in layers to account for temperature extremes. * Stay hydrated and eat high energy foods. * See "Winter Travel" JHA for more detailed information.
	f. Poisonous plants present (e.g. poison ivy, poison sumac, poison oak, giant hogweed)	* Make sure that crew members can identify poisonous plants in their work area. * Wear gloves, pants and long-sleeve shirts. * Wash affected area with soap and water as soon as possible or use ivy off products when water is not available * Wash potentially contaminated clothing as soon as possible after returning from the field.
	g. Working in areas where there is potential for head injuries	* Wear a hardhat * In all stand types, be viligant of widdowmakers, dead trees, and other falling objects. * Take additional precaution during high winds and heavy snow.
	h. Insect bites	* Use appropriate insect repellent. * Wear pants and secure the cuff to reduce the ability for ticks to access your lower leg. Wear tick and chigger guards to reduce the number of bites. Where appropriate, wear rubber boots. * Thoroughly examine your body for ticks when returning from field. If a tick is found, fully remove it using tweezers or fingernails. Do not use petroleum or try to burn the tick off. Save the tick for confirmation of Lyme disease. Monitor the area on body where tick was attached watching for irritation or rash. If rash or flu-like symptoms develop, visit doctor and inform them of tick bite.
	i. Sun Exposure	* Use sun screen on exposed skin to prevent sunburn and skin damage.
	j. Threatening individuals	* Use positive communication and conflict management behaviors in early stages of conflict situations to prevent or diffuse low level hostile behavior. * If threatened in any way by members of the public, withdraw and report the incident to your supervisor. * Always have landowners permission before entering private property.

Table K-1 (continued).—*Example of a job hazard analysis from the Forest Inventory and Analysis Program.*

	k. Illegal activities such as drugs, stills, harvesting forest products	* Always be aware of the potential for illegal activities. * Leave the area immediately by the same route taken to enter if an area appears to be used for illegal activities such as a marijuana plantation or methamphetamine lab. * Know how to recognize mobile methamphetamine labs and the dangers associated with the chemicals and mixing of chemicals used to produce methamphetamines. * Marijuana plantations on public land are characterized by irrigation lines, garbage piles, small clearings, mobile camps, and armed guards. * Report suspicious activity to your supervisor and write detailed plot notes. Note location, time of encounter, and any other pertinent information. * If on public land, report activity to the local LEO or local law enforcement. * If on private land, report to your supervisor. * Always have a landowners permission before entering private property. * Follow state laws including laws pertaining to reporting illegal activity and consider present and future safety.
	l. Wild animals such as black bears, wolves, bison, elk, deer, moose, bobcats, mountain lions, poisionus snakes, feral swine etc.	* Make noise by talking loudly or using a noise maker such as a bell or whistle to reduce the chances of surprising an animal. * Immediately leave the area by backtracking if you encounter any animial that appears injuried or sick, or may be feeding, mating, or have young nearby. Report the incident to the proper authorities if the animal acted aggresively without provocation. * Learn the appropriate actions to take if you are approached by any of the animals that may inhabit your work location. These actions differ depending on the type of animal. * Learn to identify dangerous animals in your working area and never harrass or provoke wildlife. * Avoid walking blindly through thick vegetation by using a stick or pole in front of you to part the brush or grass. * In areas with poisonous snakes, tap the ground in front of you with a pole or stick as you walk to help you see snakes before you get too close. * Wear snake-proof chaps when appropriate.
	m. Domestic animals such as dogs, cattle, swine, etc.	* If an animal is acting aggressive or skittish, stay in the vehicle and wait for the landowner to come outside. Honk your horn if necessary to alert the landowner that you are there. * Ask landowners over the phone about the location of potentially dangerous domestic animals and request that they be moved or tied up while you are visiting the location, or plan to visit when the animal will not be there. * Make sure that landowners know when you are working in the area if you believe they may have an aggressive or protective animal.
	n. Hazardous materials	* Identify if a direct hazard is posed to conducting plot work. If so, do not work in the area. Likely areas are military grounds including munitions plants, blasting grounds, and gun ranges, old construction sites, mining and drilling sites, old homesteads, farms, and public lands. * Whenever encountering containers of unidentified liquids or powders, stay clear of the site. Do not walk into or touch spilled material. Avoid inhalation of fumes, smoke and vapors, even if no hazardous materials are known to be involved. Do not assume that gases or vapors are harmless because they do not smell. Odorless gases or vapors may be harmful. Drums may contain toxic materials, leak and contaminate their immediate surroundings. * Know how to recognize mobile methamphetamine labs. * Note location, time of encounter, and any other pertinent information. If it's possible to read any labels without risk of contaminating yourself, do so and write the information down. * Report it to your supervisor and write detailed plot notes. * If on public land, report to the local LEO or local law enforcement. Follow state laws. * Identify if the public is at risk if the hazard is on private land, e.g. contaminated water-way. Report to your supervisor and determine a course of action.

Table K-1 (continued).—*Example of a job hazard analysis from the Forest Inventory and Analysis Program.*

	d. Crossing shallow streams and wetlands such as bogs, marshes, swamps, fens and meadows	* Always work with a partner when planning stream/river crossings with water depths over the knees or when traveling through wetlands with deep water/mud holes. * Choose crossing sites with shallow water, slow current and gradual slopes. Avoid crossing sites with water over mid-thigh depths or swift current. * Use pole or walking stick to help maintain balance with 3 point support. Move one foot or pole at a time. Use the pole to probe for deep holes and mud. * In streams, watch for and avoid large, wet, rounded rocks, as they may be slippery. In wetlands, avoid open water with no vegetation and holes under the roots of uprooted trees. * Be especially alert in streams of the possibility of one foot becoming entrapped in rocks or branches and current forcing individual off balance and under water. In wetlands be alert for spongy soil and deep soft mud. * Carry a rope/throw-rope long enough to reach across the entire width of the crossing. *Cross streams one person at a time with one person on the bank at all times. Stretch the safety rope between the person on the bank and the person crossing. When crossing wetlands, maintain a sufficient distance from the other person to avoid both becoming hopelessly mired. * Logs should be used as last alternative to cross streams and should be of sufficient size, dry and algae free. * When crossing streams/rivers leave vest unbuttoned; remove workbelt from waist; disconnect waist and sternum straps on pack. Be prepared to ditch any equipment if you are unable to recover from a fall. Keep life-saving equipment such as the SPOT, rope, first aid kit, etc, handy and outside of your pack. * Protect feet with proper footwear, such as knee boots or waders. Bring dry socks and footwear to wear during field work and hiking. * Do not cross streams during unfavorable weather.
	e. SPOT use, Unexpected delay/ Employee unaccounted for	* Always use the approved check-in/check-out system whether working alone or with a partner. * Carry a cell phone and attempt to call your contact if your SPOT message doesn't go through or if you have a situation. * If you have limited cell reception, send a text to update your contact. Go to higher ground if in a valley or ravine. * Use your SPOT device to if you need help or have an emergency. Attempt to send a text message to give them more information. * Always keep the SPOT device on your person, even when working with a partner or in a group. * Follow current allowable time limits for being in the woods * As a contact, be certain to make sure all employees have made it in safely at the end of the day. * Update the Crew Status Board with your daily agenda at the beginning of the week, following current procedures.
3. Use of snowmobile to travel to the plot.		* See "Snowmobile Use" JHA
4. Use of boat to travel to the plot.		* See "Boat Travel" JHA
5. Use of ATV to travel to the plot.		* See "ATV Travel" JHA
6. Use of mountain bike to travel to the plot.		* See "Mountain Bike" JHA
7. Driving FS/GSA Vehicles		* See "General Driving" JHA
8. Overnight Travel		* See "Extended Travel" JHA
9. Office Work		* See "Office Work" JHA

Table K-1 (continued).—*Example of a job hazard analysis from the Forest Inventory and Analysis Program.*

	o. Encountering Hunters	* Plan field work appropriately given area hunting use and seasons. * Wear blaze orange vest or clothing. * Make sure landowners know where you will be and when you will be there. * Inform hunters of where you will be and how long you expect to be there, find out where they plan to hunt. * If someone is hunting near your plot and is there first, return at a later date.
	p. Difficult access , new install, other hazards	* Identify plots requiring two people to access and make appropriate arrangements to have a partner. * One pay period per quarter is the minimum requirement to work with a partner.
11. Using a come-along	a. Hand injuries	* Always wear cut resistant gloves when handling the come-along to avoid pinches from moving parts and cuts from the cable
	b. Cable under tension	* Receive proper training before using a come-along. Regularly refresh yourself of the proper protocols so you're prepared in the event of getting stuck. Keep general instructions in the vehicle. * Inspect the cable before using a come-along. Look for possible weak spots indicated by excessive fraying or kinks. Replace frayed or kinked cables before using the come-along. * Use only the tow hooks or trailer hitch to recover a vehicle. DO NOT use trailer hitch ball to connect the vehicle to the come-along. The ball could break causing serious injury or death. * Use only the handle that was manufactured for the come-along. It is designed to hold only the amount of weight that the cable can hold. * Attach cable to a strong anchor point. Inspect the item you plan to use as your hold to be sure that it is strong enough and solid enough to endure the weight of the vehicle as it is towed. * A cable under tension is dangerous. Place a blanket over the cable while in use. Do not step over the cable when it is under tension. * Clean and oil come-along after use to keep cable and parts from rusting and weakening.

10. LINE OFFICER SIGANATURE	11. TITLE	12. DATE
/s/ Dennis May	Program Manager	10/24/2013

Previous edition is obsolete

Table K-1 (continued).—*Example of a job hazard analysis from the Forest Inventory and Analysis Program.*

JHA Instructions (References-FSH 6709.11 and .12)

The JHA shall identify the location of the work project or activity, the name of employee(s) involved in the process, the date(s) of acknowledgment, and the name of the appropriate line officer approving the JHA. The line officer acknowledges that employees have read and understand the contents, have received the required training, and are qualified to perform the work project or activity.

Blocks 1, 2, 3, 4, 5, and 6: Self-explanatory.

Block 7: Identify all tasks and procedures associated with the work project or activity that have potential to cause injury or illness to personnel and damage to property or material. Include emergency evacuation procedures (EEP).

Block 8: Identify all known or suspect hazards associated with each respective task/procedure listed in block 7. For example:

a. Research past accidents/incidents.

b. Research the Health and Safety Code, FSH 6709.11 or other appropriate literature.

c. Discuss the work project/activity with participants.

d. Observe the work project/activity.

e. A combination of the above.

Block 9: Identify appropriate actions to reduce or eliminate the hazards identified in block 8. Abatement measures listed below are in the order of the preferred abatement method:

a. Engineering Controls (the most desirable method of abatement). For example, ergonomically designed tools, equipment, and furniture.

b. Substitution. For example, switching to high flash point, non-toxic solvents.Work Leader

c. Administrative Controls. For example, limiting exposure by reducing the work schedule; establishing appropriate procedures and practices.

d. PPE (least desirable method of abatement). For example, using hearing protection when working with or close to portable machines (chain saws, rock drills, and portable water pumps).

e. A combination of the above.

Block 10: The JHA must be reviewed and approved by a line officer. Attach a copy of the JHA as justification for purchase orders when procuring PPE.

Blocks 11 and 12: Self-explanatory.

Emergency Evacuation Instructions (Reference FSH 6709.11)

Work supervisors and crew members are responsible for developing and discussing field emergency evacuation procedures (EEP) and alternatives in the event a person(s) becomes seriously ill or injured at the worksite.

Be prepared to provide the following information:

a. Nature of the accident or injury (avoid using victim's name).

b. Type of assistance needed, if any (ground, air, or water evacuation).

c. Location of accident or injury, best access route into the worksite (road name/number), identifiable ground/air landmarks.

d. Radio frequencies.

e. Contact person.

f. Local hazards to ground vehicles or aviation.

g. Weather conditions (wind speed & direction, visibility, temperature).

h. Topography.

i. Number of individuals to be transported.

j. Estimated weight of individuals for air/water evacuation.

The items listed above serve only as guidelines for the development of emergency evacuation procedures.

JHA and Emergency Evacuation Procedures Acknowledgment

We, the undersigned work leader and crew members, acknowledge participation in the development of this JHA (as applicable) and accompanying emergency evacuation procedures. We have thoroughly discussed and understand the provisions of each of these documents:

SIGNATURE	DATE	SIGNATURE	DATE