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Executive Summary

The Idaho National Laboratory (INL) Site is located in southeast Idaho and occupies 2,300 km^2 (890 mi^2) of sagebrush steppe. The INL Site is managed by the U.S. Department of Energy (DOE) and serves as a science-based, applied engineering national laboratory that supports the DOE missions in nuclear and energy research, science, and national defense.

The most recent vegetation mapping effort at the INL Site was almost twenty years ago and does not capture important habitat changes that have occurred since. Prior mapping efforts also lack assessments of accuracy, making it difficult to quantify uncertainty associated with habitat models. Accurate classification and mapping of vegetation communities have become increasingly important tools for conservation management.

The goal of this project was to develop an updated vegetation map defining the distribution of plant communities on the INL Site. Our specific objectives included: 1. characterize the vegetation community types present on the INL Site; 2. define the spatial distribution of those community types; and 3. conduct a quantitative accuracy assessment of the resulting map.

Objective 1 – Plant Community Classification

We completed two separate classification efforts to support this project. A preliminary classification was conducted using previously existing vegetation data from the INL Site. The purpose of the preliminary classification was to identify the range of vegetation types potentially occurring on the INL Site and to reconcile those types with the National Vegetation Classification. Results associated with the preliminary classification were used to generate a working list of plant communities and a key for field identification of those communities. The preliminary plant community list and key were also utilized to direct sampling efforts for subsequent vegetation data collection to support a final classification.

Vegetation data were collected on 314 plots for the final vegetation classification. Plots were initially selected according to a stratified random design using Geographic Information System (GIS) data layers including previous vegetation maps updated with current wildland fire boundaries. We used the preliminary plant community key to modify plot locations periodically during the field season, which ensured all potentially occurring vegetation types were adequately sampled. A quantitative final classification was completed using absolute cover by species data from each plot.

The analytical approach to classifying the vegetation cover data was a multi-step process. First, we identified the best classification model for describing the structure and pattern of species abundance and composition. Next, we determined the optimal number of clusters, or vegetation classes, within the dataset. Upon selection of the most appropriate classification, we re-evaluated several clusters within that classification to determine whether they should be further split. Finally, the classification and cluster summaries were updated to reflect additional cluster divisions.

The final classification combined with the subsequent iterations of classification refinement resulted in 26 vegetation classes for the INL Site. Of the 26 vegetation classes identified, two are wooded or woodland types, seven are shrubland types, four are shrub herbaceous types, five are dwarf shrubland or dwarf-shrub herbaceous types, five are herbaceous types, and three are semi-natural herbaceous types. Semi-natural types are generally defined as being dominated by non-native species. We classified 14 of the 26 classes at a hierarchical level comparable to an Association within the National Vegetation Classification (NVC), while the remaining 12 classes were classified at a level comparable to an Alliance. Upon completion of the final classification, we used the resulting plant community class list to identify polygons delineated through the mapping process. We also developed a dichotomous key based on the final classification to facilitate data collection and support an accuracy assessment of the final vegetation map.

Objective 2 – Vegetation Class Delineations and Mapping

In 2007, we had four-band color-infrared 16-bit orthorectified digital imagery collected at 1 m spatial resolution across the INL Site. This imagery served as the source dataset for map delineations. We also incorporated the 2004 and 2009 National Agricultural Imaging Program (NAIP) imagery to define class boundaries in the areas where clouds and cloud shadows obscured the ground, and to refine class boundaries where wildland fires burned in 2007-2008. To assist with the vegetation class delineations, we calculated two vegetation indices (i.e., the Normalized Difference Vegetation Index and the Soil-adjusted Vegetation Index), as well as a statistical texture layer (i.e., 3x3 Range) using the digital imagery. We also used ancillary GIS data layers (e.g., wildland fire boundaries, DEM, etc.) during the image delineation process.

We understood the possible limitations of automated classification methods in a semi-arid sagebrush steppe environment and conducted manual photointerpretation of digital imagery directly within a GIS. The initial draft delineations were produced through manual interpretation and digitizing at a 1:12,000 mapping scale. Occasionally, we adjusted the GIS display zoom to coarser scales (e.g., 1:24,000) where broad landscape patterns were more evident. We also considered DEM topographic contours which sometimes helped delineate class boundaries. There are five non-vegetation classes and one agricultural class we digitized at a 1:2,000 scale and included in the final map. The vegetation map data will contribute to a number of ongoing and future studies on the INL Site, and we wanted to make sure anthropogenic features are not included in the actual vegetation polygons where they could negatively impact other studies.

After we completed the draft delineations for the entire INL Site, we made numerous visits to the field to investigate the communities present on the ground. The first important observation we made in the field was the initial draft delineations captured too much detail and many times the same vegetation community extended across multiple map polygons. Another important observation we made was that the majority of mapped polygons contained multiple vegetation communities present on the ground forming multi-class complexes. We edited the draft delineation boundaries and assigned each map polygon to a vegetation class or two-class complex.

The final vegetation map contains a total of 2038 polygons, of which 1964 (96.4%) represent vegetation communities. The remaining 74 polygons (3.6%) represent non-vegetation or agriculture classes we included in the map. The smallest mapped polygon, not part of a special feature or at the edge of the INL Site, is 0.0021 km2 (0.52 acres). The largest polygon we mapped is 236.3 km2 (58,399.6 acres) located in the undisturbed interior portion of the INL Site. The mean area for all vegetation map polygons is 1.1 km2 (286.8 acres).A total of 127 vegetation map classes were produced when including all two-class complexes. Twenty-two map classes were stand-alone classes as originally defined through statistical analysis. Nearly half the INL Site area was mapped as single vegetation classes and the most common stand-alone class was the (2) Big Sagebrush Shrubland class. Of the 127 total map classes, 30 classes (23.6 %) contain only a single polygon and 76 map classes (59.8%) contain five or fewer polygons. Even though there were a large number of vegetation classes and complexes mapped, the majority of those classes are limited in frequency and distribution. The remaining 51 map classes contain the majority of mapped area on the INL Site (about 85%).

Objective 3 – Vegetation Map Accuracy Assessment

We sampled 502 validation plots in 2009 using a plot array design where five subplots collectively represented a single accuracy assessment location. The rationale for multiple subplots was an attempt to capture vegetation class variability across an extent that bridged the gap between the 1:12,000 mapping scale and the original vegetation classification scale. Each validation plot array was treated as a single validation point, but because we implemented a multiple subplot design, assigning validation plots to a vegetation class or two-class complex required the development of rule sets.

We used an error matrix to calculate accuracy metrics such as user's/producer's accuracy, overall accuracy and the kappa statistic. Given that we had to accommodate two-class complexes in both the map polygons and the validation plot data, we devised alternative methods for populating the error matrix. The first method was a direct comparison where if a single map class within a complex matched the ground data, regardless if the validation plot was a two-class complex, it was marked correct. The second method requires both communities in a two-class complex from the map to be present in the validation plot data.

Fuzzy set theory provides an avenue to embrace multiple class membership at a single location and allows for more meaningful interpretations of the map accuracies and errors. We wanted to minimize the subjective decision making process and selected a Bray-Curtis community similarity threshold of 0.35 to identify classes eligible for fuzzy membership (Level 4 Good Answer)

Of the 502 validation plots, 186 plots (37.1%) had all five subplots key to the same vegetation class. The majority of plots that had homogenous subplot classes were in big sagebrush dominated classes. There were 226 plots (45%) that were assigned to a single class with at least three of the subplots representing the same vegetation class. Ninety plots (17.9%) were assigned as two-class complexes.

The error matrix assessment resulted in an overall map accuracy of 70.7%, a Kappa of 0.65, and individual vegetation class accuracies varied greatly. The fuzzy error matrix assessment showed substantial improvements to overall map accuracy and also individual class accuracies. The overall map accuracy increased to 94.2% and Kappa increased to 0.93.

The vegetation accuracy assessment found highly accurate results for the overall map and also individual class accuracies for most vegetation classes. Although there has never been a quantitative evaluation of previous INL Site vegetation maps, the new map is the most detailed and likely the most accurate ever produced.

Of all the vegetation map classes, the three big sagebrush-dominated classes may be some of the most important vegetation classes on the INL Site. The two most common big sagebrush classes ([2] Big Sagebrush Shrubland and [7] Wyoming Big Sagebrush Shrubland) had the largest validation sample sizes, and were found to be very accurate with the fuzzy assessment ranging from 96%-100% for both user's and producer's accuracy in each class. Big sagebrush communities support sagebrush obligate species (e.g., greater sage-grouse [*Centrocercus urophasianus*]), many of which are declining range-wide. The ability to accurately identify the distribution of sagebrush habitat has important implications for conservation management planning and the development of predictive species models on the INL Site.

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List of Acronyms

ASW	Average Silhouette Width
ATRC	Advanced Test Reactor Complex
BLM	Bureau of Land Management
BLR	Big Lost River
CFA	Central Facilities Area
CMP	Conservation Management Plan
CRMO	Craters of the Moon National Monument and Preserve
DEM	Digital Elevation Model
DOE	Department of Energy
DOE-ID	Department of Energy, Idaho Operations Office
ESA	Endangered Species Act
ESER	Environmental Surveillance, Education, and Research Program
ESRI	Environmental Systems Research Institute
ESRP	Eastern Snake River Plain
FGDC	Federal Geographic Data Committee
GIS	Geographic Information System
GPS	Global Positioning System
ICDC	Idaho Conservation Data Center
ISA	Indicator Species Analysis
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
MFC	Materials and Fuels Complex
LTV	Long-term Vegetation Transects
NAIP	National Agricultural Imaging Program
NED	National Elevation Dataset
NDVI	Normalized Difference Vegetation Index

NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NVC	National Vegetation Classification
NVCS	National Vegetation Classification Standard
PARTANA	Partition Analysis Ratio
PAM	Partitioning Around Medoids
PBC	Point Biserial Correlation
QA/QC	Quality Assurance/Quality Control
SAVI	Soil-adjusted Vegetation Index
TNC	The Nature Conservancy
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
USGS	United States Geological Survey

1.0 Introduction

1.1 INL Site Description and Background

1.1.1 INL Site Description

The Idaho National Laboratory (INL) Site is located in southeast Idaho, and occupies 2,300 km^2 (890 mi^2) including portions of five counties: Bingham, Bonneville, Butte, Clark and Jefferson (Figure 1-1). The INL Site is managed by the Department of Energy (DOE) and was originally established in 1949 as the Arco Reactor Test Site. The area has also been known as the National Reactor Test Site, Idaho National Engineering Laboratory and the Idaho National Engineering and Environmental Laboratory. The initial purpose for the facility was the testing and design of nuclear reactors. The INL Site now serves as a science-based, applied engineering national laboratory that supports the DOE missions in nuclear and energy research, science, and national defense.

1.1.2 Land Use History

Prior to occupancy by the DOE during World War II, the area was used for military training and testing. The central portion of the INL Site had been used as a proving ground by the U.S. Navy to test artillery, and the Army Air Corp used at least two aerial bombing ranges on land now part of the INL Site.

Earlier uses of the land were primarily for livestock grazing although there were numerous attempts to homestead. Homesteading in this area resulted from the Homestead Act of 1862, the Desert Claim Act of 1877 and the Carey Land Act of 1894. In 1904, the Reclamation Act brought funds to Idaho to construct diversion structures and canals. Substantial diversion structures and canals on the INL Site were built to bring water from the Big Lost River and Mud Lake. Many of these structures remain today but never provided the promised irrigation water.

Livestock grazing continues on about 60 percent of the INL Site, and is managed by the Bureau of Land Management (BLM). Eight BLM grazing allotments partially overlap with the INL Site. Depending on the allotment and permit, grazing is by sheep and/or cattle.

1.1.3 Topography /Landforms

The INL Site is located on the Eastern Snake River Plain (ESRP) in a large basin around 1,500 m (4,921 ft.) elevation. This basin is generally bordered on the west by the Lemhi and Lost River mountains and on the north by the Beaverhead and Centennial Mountains (Figure 1-1).

Three prominent buttes mark the southern boundary of the basin (Figure 1-2). Two of these are on the INL Site and the third, and largest of the three buttes, is immediately south of the INL Site. East Butte formed as a result of lava rising through a fissure about 600,000 years ago and has a summit elevation of 1,966 m (6,450 ft.). Middle Butte was formed as volcanic activity below forced up a block of basalt, and has a summit elevation of 1,948 m (6,391 ft.). Big Southern Butte is just south of the INL Site boundary. It is 300,000 years old and has a summit elevation of 2,301 m (7,550 ft.)

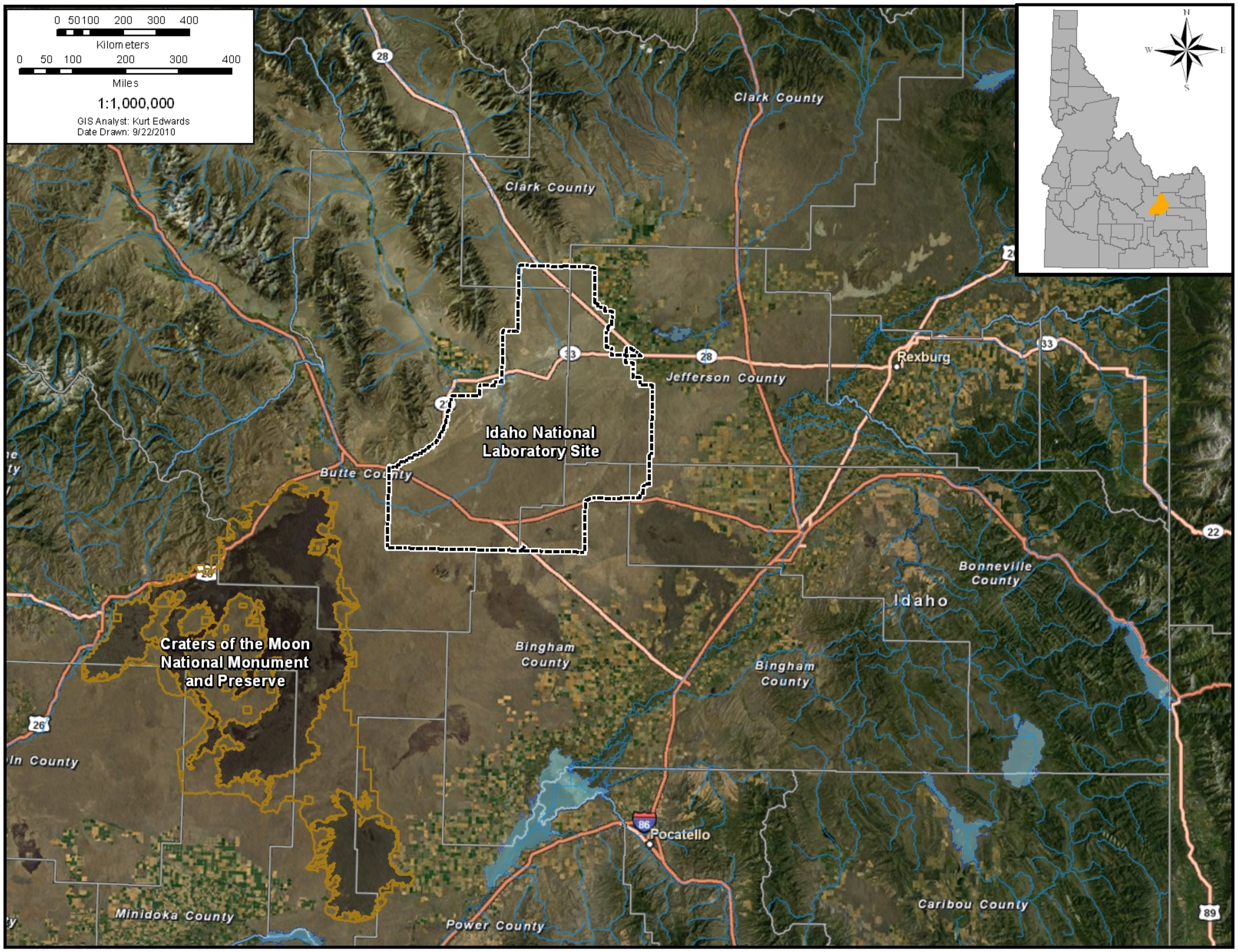


Figure 1-1. Map of southeast Idaho showing location of the Idaho National Laboratory Site.

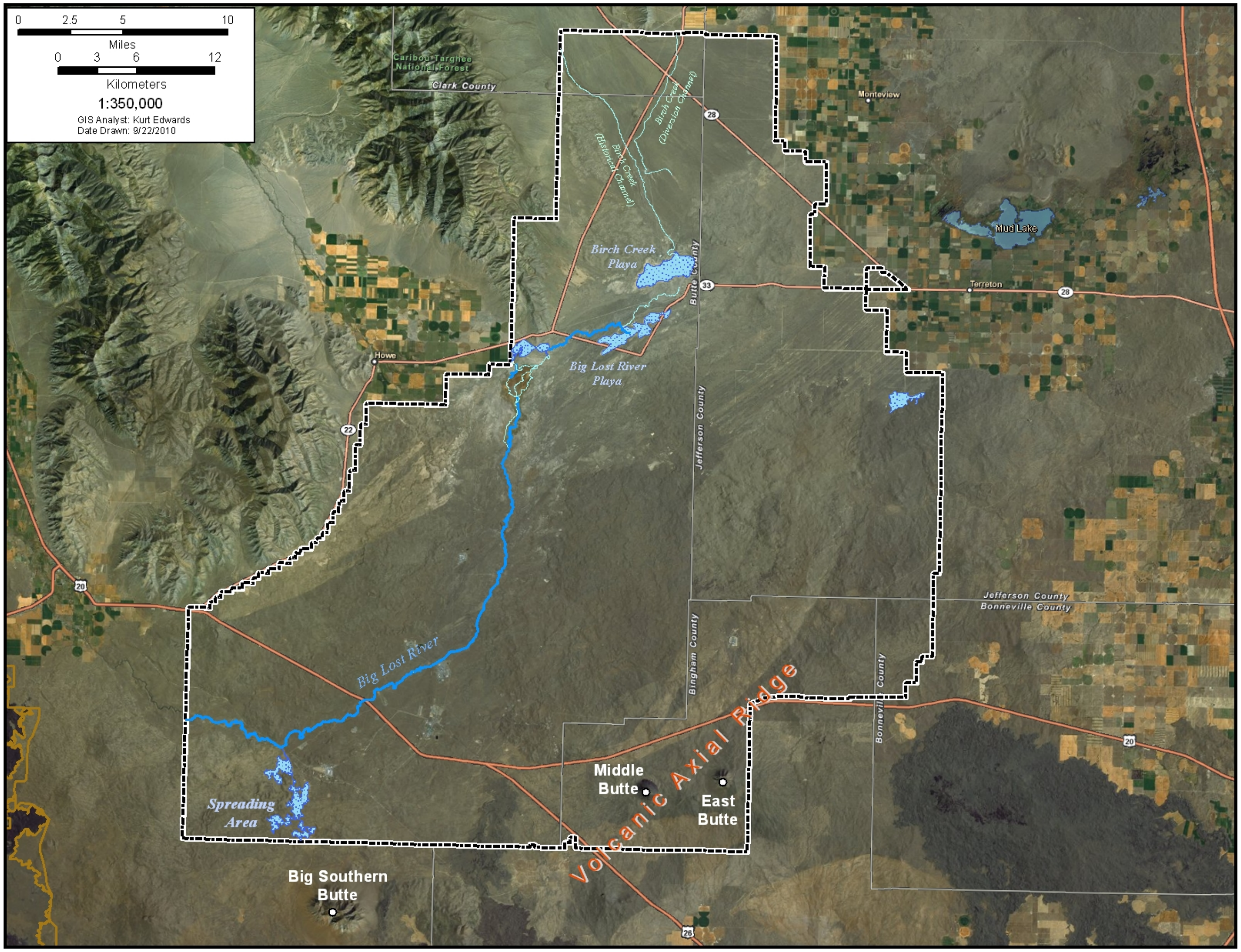


Figure 1-2. Map of the Idaho National Laboratory Site showing locations of the major buttes, volcanic axial ridge, and major water courses.

These three buttes together with many small volcanic cones are part of a volcanic axial ridge that extends from near Craters of the Moon National Monument and Preserve (CRMO) toward the northeast and separates the Lost River drainages from the Snake River (Figure 1-2).

1.2 Hydrography

There are three major drainages that enter or approach the INL Site: Big Lost River, Little Lost River and Birch Creek. Although formerly perennial, the Big Lost River and Little Lost River flow on to the INL Site only in wet years and much of the flow infiltrates into the streambed. The Big Lost River enters from the west near the southwest corner the INL Site where it curves back to the north and continues another 48 km (30 mi.) to the Big Lost River and Birch Creek Playas (Figure 1-2). The Little Lost River terminates near the town of Howe just before reaching the INL Site.

In order to provide flood control and protect the Advanced Test Reactor Complex (ATRC) and the Idaho Nuclear Technology and Engineering Complex (INTEC) facilities, the Big Lost River flows are altered by a diversion structure on the INL Site. The flood water is diverted along an earthen dike into low-lying basins called the Spreading Areas. Below the diversion structure, the Big Lost River enters an area dominated by fluvial deposits and numerous former channels are apparent.

Birch Creek originates from springs in the Birch Creek fen and historically entered the northwest corner of the INL Site (Figure 1-2). Birch Creek has been diverted from its original channel before reaching the INL Site for agricultural use and power production and no longer flows in its original streambed on the INL Site. During the non-irrigation season, water from the power plant enters a diversion canal that brings the water through the northern boundary of the INL. This return channel parallels Highway 22 for approximately 8 km (5 miles) where the water is eventually spread across the desert along a dike.

1.3 Geomorphology

1.3.1 Lithospheric Geological Processes

The Snake River Plain is thought to have been formed as the North American tectonic plate moved to the southwest, crossing over the Yellowstone “hotspot” presently believed to be under the Yellowstone caldera. The hotspot was believed to have been under the ESRP about 6.5 to 4.5 million years ago. Most of the material filling the eastern Snake River Basin resulted from basalt lava flows that erupted from broad, low shield volcanoes. These repeated eruptions coupled with accumulation of sediments in the low-lying areas resulted in the relatively flat but gently rolling terrain. See Hackett et al. (1995) for a complete description of these processes.

1.3.2 Surficial Geologic Processes

There is no evidence of glaciation on the ESRP; however glacial activity in the surrounding mountains played a large role in the surficial geology of the INL Site. Higher stream flows associated with mountain glaciers likely led to the growth of alluvial fans on the west and north portions of the INL Site (Pierce and Scott 1982). Much of the alluvium on the INL Site was likely deposited during the upper Pleistocene at the end of the last glaciations when discharge and sediment supply were increased.

There is also evidence of very large glacial floods on the Big Lost River (Rathburn 1993). The most recent glacial outburst flood on the Big Lost River likely occurred during the late Pleistocene dated at 20,500 years before present (Cerling et al. 1994). Peak discharge was estimated to be 57 to 114 thousand cubic meters per second (2 to 4 million cubic feet per second). This flooding resulted in the deposition of a large portion of alluvial material along the lower Big Lost River on the INL Site. The post-glacial river is much smaller and has incised the Pleistocene sediments.

Glaciation was the source of the loess material that blankets most of the INL Site. Loess is one of the primary sediment types on the INL Site and is up to several meters thick on the oldest lavas. Wind erosion and deposition played a large role in shaping the landscape as sediments are moved by wind especially following disturbances that remove vegetation (e.g. fire). Holocene wind erosion resulted in mixing of sands into the surface loess and produced sandy-loess deposits on the lee side of lava ridges. Following the end of loess deposition about 10,000 years before present, it appears that erosional processes affected only the upper 10 cm to 20 cm (3.94 to 7.87 in.) (Hackett et al. 1995).

Pluvial Lake Terreton covered a large area of the lower elevations of the INL Site. The lake likely originated in the Pleistocene and captured runoff associated with seasonal patterns of glacial melt. Lake Terreton re-expanded most recently about 700 years ago (Bright and Davis 1982). Longitudinal dunes in the central and northeastern portions of the INL Site likely originated from sediments that were exposed as Lake Terreton receded and dried (Hackett et al. 1995) and were then subjected to the prevailing southwest winds.

Undisturbed areas exhibit a mounded microtopography (mima mounds) (Hackett et al. 1995). These earthen mounds are generally 10 m (32.8 ft.) in diameter and 0.5 m (1.64 ft.) high. There have been a number of competing hypotheses regarding their origin. However, there is now strong evidence suggesting they formed by frost heaving during the late Pleistocene or early Holocene (Tullis 1995). The frost heaves were caused by the growth of segregated ice lenses during intense seasonal freezing and thawing. Formation of the mounds occurred prior to pedogenesis. These mounds exhibit long-term and repeated burrowing by mammals.

Basin derived flooding is another geomorphic process that affects the surface sediments. This flooding mostly results from snow melting over frozen soil or rain on snow events. These events result in runoff accumulating in low-lying basins. Ponding in these internal drainage basins resulted in the formation of small playas and accumulation of fine silts and clays (Nace et al. 1975).

1.4 Soils

A comprehensive soil survey has not been conducted on the INL Site. Olson et al. (1995) used information from surrounding county soil surveys and other sources to compile descriptions of soils that likely occur on the INL Site and produced the most recent general soils map of the INL Site. This general soils map represents a Soil Survey Order 4 or 5, which is generally suitable for only broad-scale interpretation, and presents only soil associations and some consociations. Soil surveys at the county-level are generally Order 2 and are appropriate for more detailed site-specific descriptions of soil characteristics.

Olson et al. (1995) also began the compilation of more detailed soil mapping information that would provide an Order 3 survey. This effort has not been completed and no interpretation at that level is available. Limitations in that survey include discontinuities in soil series map units where county lines meet. These kinds of discrepancies will require that delineations across county lines be correlated. Additional field survey work would be required to refine extrapolations of surrounding county and BLM surveys into the interior of the INL Site.

The general soil map (Olson et al. 1995) shows five general classes of soils:

Shallow to deep (<20" to >60") moderately coarse-textured soils (from eolian sand) on basalt plains with slope ranges from 0-20%. These soils include the subgroups Xerollic Calciorthids, Xerollic Haplargids and Xeric Torriorthents. Soils in this mapping unit are generally loams or fine sandy loams, are well drained and occur on basalt plains. Playa soils may also be associated with this mapping unit. These soils are silty clay loams, occur as bottomland in localized drainages and are affected by seasonal flooding. These soils occur on the INL Site as sand over basalt.

Shallow to deep (<20" to >60") medium to fine grained soils (from loess) on basalt plains with slopes ranging from 0-30%. These soils are all within the subgroup Xerollic Calciorthids. These soils are generally loams or silt loams. They occur on basalt plains and are well drained. These soils occur on the INL as loess over basalt. These first two classes predominate on the basalt plains of the southern two-thirds of the INL Site.

Shallow to deep (<20" to >60") medium to coarse textured soils over gravel: derived from alluvial deposits of the Big Lost River and Birch Creek. These soils include the subgroups Typic Calciorthids, Xerollic Calciorthids, Typic Cambiorthids, Typic Torrefluvents, Aridic Calcic Argixerolls, Calciorthidic Haploxerolls, Cumulic Haploxerolls, Fluvaquent Haploxerolls and Aquic Calcixerolls. These soils are generally loams or sands. They range in drainage class from somewhat poorly drained to well drained and somewhat excessively well drained. These soils occur on the INL Site in alluvial deposits on flood plains, stream terraces and fan terraces.

Deep, alkaline, fine grained lacustrine sediments from the ancestral Lake Terreton, overlain in some areas with sand dunes. These soils include the subgroups Typic Torriorthents, Xeric Torriorthents and Typic Calciorthids. These soils range in texture from silty clay loam to loamy sand and fine sand, but all are well drained to somewhat excessively well drained. This mapping unit is present in the vicinity of Lake Terreton and the associated sand dunes.

Shallow to very deep gravelly soils (<20" to >60") from residuum colluvium, and slope alluvium with slopes to 40%. These soils include the subgroups Typic Calciorthids, Xerollic Calciorthids, Lithic Calcixerolls and Lithic Cryoborolls. These soils are generally coarse textured and well drained. They form on ridgetops and sideslopes of foothills and mountains. On the INL Site they occur primarily on the Lemhi Mountains and the toe of the Lost River Range.

1.5 Climate

The climate of the INL Site is greatly affected by its altitude, latitude and intermountain setting. Air masses that reach the ESRP have crossed a mountain barrier and much of the moisture has been precipitated out of these air masses before reaching the ESRP, leaving it arid or semi-arid. Low humidity associated with air masses reaching the ESRP leads to minimal cloud cover and high solar heating during the day and rapid cooling by radiation at night. This results in large diurnal temperature fluctuations (Clawson et al. 1989).

The Pacific Ocean provides a moderating affect compared to other more continental regions at this latitude. This leads to a climate that is generally warmer in winter and cooler in the summer than would be expected. The mountains to the north of the INL Site also limit the movement of the severe cold air masses from pushing south into the ESRP. Occasionally fronts do spill over these mountains from the north and lead to periods of below normal temperatures (Clawson et al. 1989).

The mountains bordering the ESRP also affect wind patterns. The prevailing west winds are funneled to come from the southwest. The second most frequent winds are from the north-northeast and are generally drainage winds associated with rapid cooling at night initiating down-slope winds (Clawson et al. 1989).

For the period 1950 through 2005, mean annual air temperature for the INL Site was 5.6 °C (42.1 °F) (Figure 1-3). Mean daily maximum temperature of the warmest month is 30.8 °C (87.4 °F) and mean daily minimum temperature of the coldest month is -14.8 °C (5.3 °F) for the period 1950 through 2007 (NOAA 2010).

The average annual frost free period (1950 through 2005) is 88 days long (NOAA 2010). The average last spring day with a low temperature below 0 °C (32 °F) is June 12. The average first fall day with a low temperature below 0 °C (32 °F) is September 8. The annual average number of days that have a maximum temperature below 0 °C (32 °F) is 16 percent, and the annual average number of days that have a maximum temperature above 32 °C (90 °F) is 8 percent.

Soil temperature at 0.5 to 1.0 inches below surface was studied between 1955 and 1961 (Clawson et al. 1989). Onset of prolonged soil freezing begins in late November and lasts until late February or early March. Subsurface temperatures drop below 0 °C (32 °F) at depths exceeding 90 cm (3 ft.).

Annual average precipitation is 215 mm (8.46 in.) (Figure 1-3) and precipitation type is dependent on season. Summer has rain showers and thundershowers, spring and fall have periods of rain or snow, and winter precipitation is primarily snow. Although most precipitation annually comes as snow, monthly precipitation totals peak in May and June as rain showers (Figure 1-3). Average annual snow fall is 66.0 cm (26.0 in.) with December and January having the highest monthly averages (15.7 cm [6.2 in.] and 15.2 cm [6.0 in.] respectively) (Clawson et al 1989). An average of 18 percent of days per year have more than 0.25 mm (0.01 in.) of precipitation (1950 -2005) and only 0.8 percent of days have more than 12.7 mm (0.50 in.) of precipitation (Clawson et al. 1989).

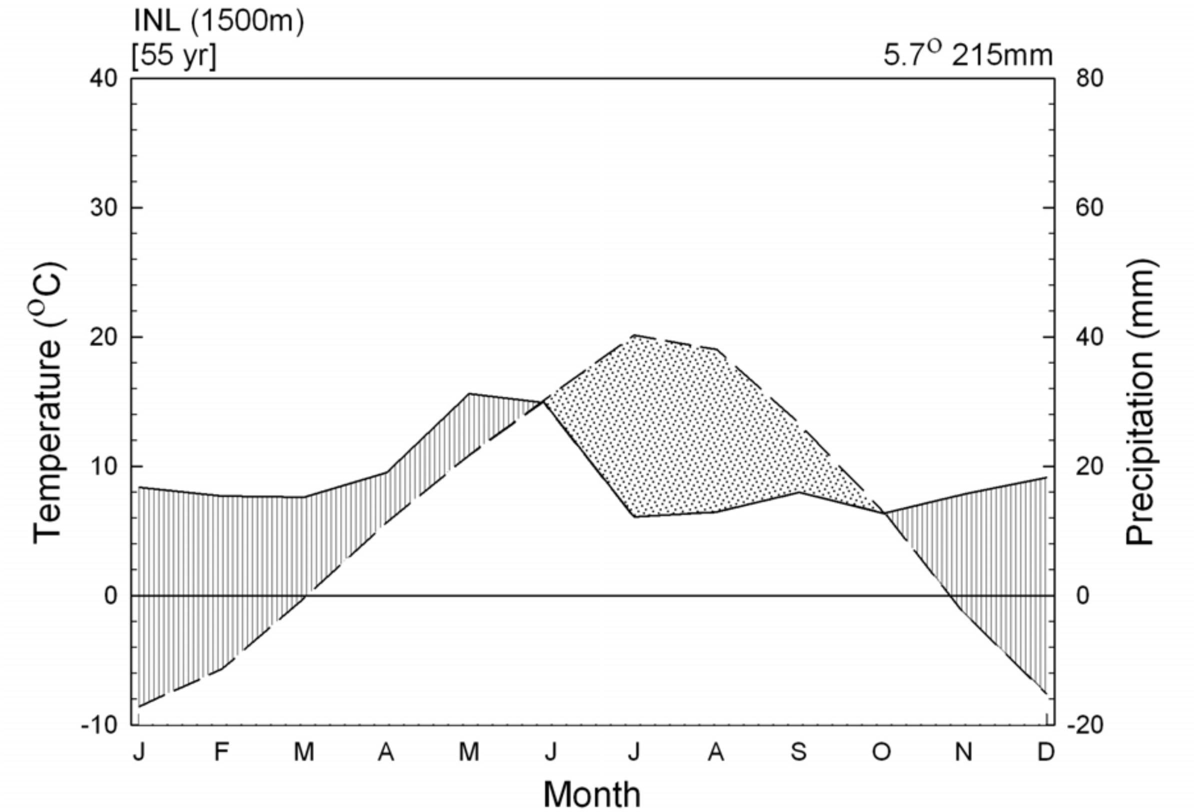


Figure 1-3. Climate diagram (sensu Walter et al. 1975) for the Idaho National Laboratory Site based on data from 55 years from the Central Facilities Area (NOAA 2010). Solid line depicts mean monthly precipitation; dashed line shows mean monthly temperatures. Vertical hatching indicates periods when precipitation generally exceeds potential evapotranspiration. Stippled area indicates the period when potential evapotranspiration exceeds precipitation. Numbers at top of graph are elevation (1500 m), number of years of record mean annual temperature (5.7 °C) and average annual precipitation (215 mm).

1.6 Principal Lineament and Fire History

Anderson et al. (1996) describe a distinct linear feature known as the Principal Lineament. Its origin is near East Butte and it extends northward for 27.8 km (17 mi.). Morin-Jansen (1987) characterized this feature as an accumulation of sand on the surface. The feature is not associated with other topographic features, but rather cuts across depressions and lava ridges. The feature varies in width from 20 m to 125 m (66 to 410 ft.).

Anderson et al. (1996) hypothesized that this feature represents sands accumulated in a dune on the downwind edge of a large burned area. Anderson et al. (1996) suggested this fire likely burned in the 1800s prior to settlement. This was because no charcoal had been found on either side of the lineament, the sagebrush on either side is of the same age and no written record of it could be found. In 1998, Anderson led a field investigation to look for charcoal beneath the sand accumulation. Anderson found charcoal and had the material radiocarbon dated. The results suggest the most likely date of fire to be in the early 1800s (Anderson 1999). Anderson (1999) concluded that the effects of disturbance due to wildland fire will persist for a very long time in cold-desert communities.

Historically, wildland fire was a natural disturbance in the sagebrush-steppe ecosystem with average fire rotation intervals of 200 to 350 years (Baker 2011). An examination of aerial photographs from the INL Site reveals that fire scars 50, 100, and even approaching 200 years old are still identifiable, often within a matrix of larger and older sagebrush stands. This suggests that wildland fires were probably an infrequent event. However, increased human activity on roadways and in the remote portions of the INL Site may have caused an increase in the risk of fire ignition. From 1994 through 2009, the INL Site had 79 human caused fires and 24 lightning caused fires. Most of these fires were small in extent.

The effects of fire and the patterns of post-fire vegetation recovery have been investigated on the INL Site. Colket and Bunting (2003) indicated that the time required for sagebrush to re-establish to pre-burn abundance levels varied greatly from one stand to another and that recruitment events are highly episodic. Blew and Forman (2010) also documented sagebrush recruitment patterns in unplanted burns. They found that seed availability may not necessarily be as prohibitive to re-establishment as previously thought, and that most burn scars have at least some sagebrush establishment in the first handful of years post-fire, although a return to pre-burn big sagebrush cover takes decades. Additionally, studies from the INL Site and other southeast Idaho locations demonstrate that native plant communities in good pre-burn ecological condition generally return to diverse, native plant communities within a few growing seasons post-burn (Ratzlaff and Anderson 1995, Buckwalter 2002, Blew and Forman 2010).

Research on the INL Site has found that the plant community present after a fire will reflect the one that was present before the fire, minus sagebrush. Conversion to annual grasses following fire has not been documented on the INL Site except where pre-fire disturbance or firefighting efforts have resulted in the loss of herbaceous perennial cover. Because of this, the Upper Snake River Plain, and specifically the INL Site, is one of the few remaining places where natural fire regimes may still be operating in sagebrush steppe.

1.7 Wildlife

Many wildlife species occupy the INL Site, and several of these animals can influence vegetation and ecosystem processes. The most prominent of these species include large herbivores, such as elk (*Cervus elaphus*), pronghorn antelope (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*). Additionally, various species of carnivores occur on the INL Site and are represented by coyotes (*Canis latrans*), badgers (*Taxidea taxus*), bobcats (*Lynx rufus*), and occasionally mountain lions (*Puma concolor*). Pygmy rabbits (*Brachylagus idahoensis*) are present on the INL Site. These small leporids are sagebrush obligates, and several petitions have been filed to list this species under the Endangered Species Act (ESA), with the most recent finding indicating that these mammals do not warrant listing under the ESA. Finally, the INL Site provides habitat for at least 14 bat species, including an Idaho State Species of Greatest Conservation Need, the Townsend's big-eared bat (*Corynorhinus townsendii*).

Numerous bird species occupy INL Site. One of these, the greater sage-grouse (*Centrocercus urophasianus*) is a candidate species under the ESA, because of its reliance on sagebrush habitat.

Three additional sagebrush obligates that commonly occur on the INL Site are Brewer's sparrows (*Spizella breweri*), sage thrashers (*Oreoscoptes montanus*), and sage sparrows (*Amphispiza belli*). Other avian species occurring on the INL Site include the following: bald eagles (*Haliaeetus leucocephalus*), ferruginous hawks (*Buteo regalis*), golden eagles (*Aquila chrysaetos*), northern harriers (*Circus cyaneus*), prairie falcons (*Falco mexicanus*), ravens (*Corvus corax*), red-tailed hawks (*Buteo jamaicensis*), rough-legged hawks (*Buteo lagopus*), and Swainson's hawks (*Buteo swainsoni*).

1.8 Vegetation

The natural vegetation of the INL Site consists of an overstory of shrubs and an understory of grasses and forbs. Nearly five hundred vascular species have been documented occurring on and adjacent to the Site (Anderson et al. 1996). Big sagebrush (*Artemisia tridentata)* and green rabbitbrush (*Chrysothamnus viscidiflorus*) are the most common shrubs (Forman et al. 2010), but there are over 40 species of shrubs on the INL and adjacent buttes and/or mountain toe slopes (Big Southern and East Buttes as well as the Lost River and Lemhi Mountain Ranges) (Anderson et at. 1996). Perennial grasses are generally the most abundant understory species and forbs are quite diverse in most plant communities.

Although vegetation types characterized by the dominance of big sagebrush are the most prevalent across the INL Site, several other communities are common across the landscape. Green-rabbitbrush dominated communities occur in wildland fire scars, on stabilized dunes, and in stands where big sagebrush cover has declined. Communities dominated or co-dominated by low sagebrush (*Artemisia arbuscula*), black sagebrush (*Artemisia nova*), and three-tip sagebrush (*Artemisia tripartita*) are frequently distributed around the periphery but within the boundary of the INL Site. Salt desert shrub communities, which are dominated by shadscale saltbush (*Atriplex confertifolia*), sickle saltbush (*Atriplex falcata*), and spiny hopsage (*Grayia spinosa*) are associated with playas and floodplains. Grasslands may be dominated by rhizomatous species like streambank wheatgrass (*Elymus lanceolatus*) and western wheatgrass (*Pascopyrum smithii*) or by bunchgrasses like bluebunch wheatgrass (*Pseudoroegneria spicata*), needle and thread (*Hesperostipa comata*), or Indian ricegrass (*Achnatherum hymenoides*) and are common in wildland fire scars and associated with temporarily flooded landforms. Junipers (*Juniperus* spp.) are common at higher elevations and dominate communities associated with the buttes and foothills on the INL Site.

A few communities are dominated by non-native species. They are often limited in spatial extend, but occur Site-wide. Some have been planted and continue to spread, like those dominated by crested wheatgrasses (*Agropyron* spp.). Others are the results of invasions which are facilitated and spread by a combination of disturbances such as altered hydrologic regime, overgrazing by domestic livestock, mechanical removal of soil, and wildland fire. These communities are often dominated by annuals like cheatgrass (*Bromus tectorum*), tall tumblemustard (*Sisymbrium altissimum*), and desert alyssum (*Alyssum desertorum*).

1.9 Previous INL Vegetation Maps

Norman French and Ray McBride are credited with the first vegetation map of the INL Site, produced in 1958. No documentation exists except as referenced in McBride et al. (1978). Vegetation classes were based on the two most prominent species. This classification provided good resolution in the more complex northern part of the INL Site. Much of the rest of the site was classified as *Artemisia tridentata* and *Chrysothamnus viscidiflorus*. Based on information from McBride et al. (1978), delineations were thought to be based on aerial photos from 1949.

In 1965, McBride produced a revised map to overcome limitations of the 1958 map. Vegetation classes were based on the three most prominent species. Delineations were based on aerial photos from 1949, 1953 and 1954. This map was not documented with a companion report in 1965, but was reproduced in Harniss (1968).

Harniss and West (1973) produced a vegetation map based on plant community changes noted in the 1965 survey of the Long-term Vegetation (LTV) plots (aka "Goodwin transects"). Vegetation classes were based on the dominant overstory species and the dominant understory species. The composition of each class was tabulated by cover, frequency, and presence, based on the 1965 LTV data. However, the categorization of the plots into vegetation classes does not appear to be driven by a statistical classification. Each class was also described in narrative form and included general information on locations and typical soils on which the communities exist. No basis for the delineations was provided by Harniss and West (1973). It is not apparent that aerial photos or other geographic references were used to delineate the map units.

A map titled "Idaho National Environmental Research Park Vegetation Map" was also produced, but no associated report or other documentation has been located for this map. Because it is labeled "Idaho National Environmental Research Park," it was likely developed after designation of the Idaho National Environmental Research Park in 1975. This map may have been produced after 1978, as it is not mentioned in McBride et al. (1978). Based on the information provided on the map it appears that the approach to classification and mapping was somewhat different from others in that the map units are based on overlays of prominent species. The basis for the geographical delineations is not known.

McBride et al. (1978) provided documentation for the 1965 McBride map. The 1965 map was "revised and redrawn," but no indication is given of the changes made. The report contains detailed descriptions of the vegetation community classes. The descriptions include general locations for each of the classes. This report also provided the first soils map for the INL Site.

Kramber et al. (1992) developed a vegetation map based on Landsat Thematic Mapper scenes. The satellite image data were classified using an unsupervised approach and initially generated 200 spectral classes. These classes were refined to 27 preliminary vegetation classes according to known or inferred vegetation patterns based on field experience of the ecologists and botanist on the team. Aerial photography was used as an ancillary information source to identify patterns in some areas. Field surveys were conducted to determine vegetation composition in 66 plots stratified by the 27 classes. The vegetation data was used to create an error matrix that was used to determine discrepancies between the draft vegetation classes derived from the satellite imagery and actual vegetation from the field plots. The field data were also used to identify assemblages of species, using ordination and cluster analysis, which were then correlated to the cover classes on the map.

Forman et al. (2003) developed a vegetation classification and map for the Sagebrush Steppe Ecosystem Reserve on the northern portion of the INL Site. This map preserved the delineations of McBride et al. (1978) and the vegetation classifications were taken from Anderson et al.

(1996). Two new classes not described by Anderson et al. (1996) were generated based on the results of field data collection. The field data was used to assign vegetation classes to the pre-existing map polygons.

1.10 Rationale for Updating the INL Site Vegetation Map

Accurate classification and mapping of vegetation communities have become increasingly important tools for conservation management. By understanding the distribution and condition of plant communities on a landscape, a number of conservation goals can more easily be met including:

- Determining which community types are intrinsically rare or have been severely degraded,
- Identifying the best remaining occurrences of natural communities across their geographic ranges,
- Assessing the impacts of various land-use scenarios on areas supporting different vegetation types,
- Developing habitat suitability models for predicting species occurrences, and
- Ranking vegetation classes with respect to their importance in conservation management planning.

Previous vegetation maps of the INL Site are inadequate to serve these conservation management planning goals, in part, because they are outdated. The most recent effort was almost twenty years ago and does not capture important habitat changes that have occurred since that time including fires, sagebrush die-off and invasion by non-native plants. Prior mapping efforts also lack assessments of accuracy, making it difficult to quantify uncertainty associated with habitat models derived from data contained in those maps. Furthermore, methodologies for vegetation classification and mapping have been refined and standardized since earlier vegetation maps of the INL Site allowing for continuity between classifications and mapping on the INL Site and on neighboring lands managed by other agencies.

Understanding the distribution of plant communities on the INL Site will support the Conservation Management Plan (CMP) through habitat mapping, development of Habitat Suitability Indices and will help to focus surveys for sensitive species. The purpose of the CMP is to assist the Department of Energy, Idaho Operations Office (DOE-ID) federal staff in understanding the ecosystem on the INL Site in order to enhance federal decision-making and to more properly direct future work performed by the INL Site contractors. The CMP is intended to minimize disruption to routine site operations and INL Completion Project activities as well as better position the DOE to offer the INL Site as an attractive site for new projects through considered and deliberate management of sensitive, threatened, and endangered species and associated habitat.

Additional benefits of understanding of plant community distribution to land management at the INL Site include guiding revegetation and weed management efforts, increasing the efficiency of assessing environmental impacts and siting plots for inventory and monitoring activities. It will also serve as an important background database for research on the Idaho National Environmental Research Park.

1.11 INL Site Vegetation Classification and Mapping Project Overview

The goal of the vegetation community classification and mapping project was to develop an updated vegetation map detailing the distribution of plant communities on the INL Site. Our specific objectives were to:

- Characterize the vegetation community types present on the INL Site (see Chapter 2)
- Define the spatial distribution of those community types (see Chapter 3), and
- Conduct a quantitative accuracy assessment of the resulting map (see Chapter 4).

Our approach is based on a process developed by the National Park Service (NPS) Vegetation Inventory Program (formerly known as U.S. Geological Survey-NPS Vegetation Mapping Program) for use in land management planning (USDI, NPS 2009). This approach can be divided into two major project components: the plant community classification and the image delineation and mapping. Plant community classification entails multivariate analysis of applicable vegetation data sets, resulting in a statistically definable list of vegetation classes which can be reconciled with the National Vegetation Classification Standard (NVCS)-defined vegetation associations (FGDC 2008). The image delineation and mapping process consists of digitizing patch boundaries using current digital color-infrared aerial imagery, several ancillary data layers, and image processing techniques to define areas of vegetation similarity. Products from each component are then reconciled by assigning vegetation community classes to delineated polygons resulting in a comprehensive vegetation map.

Our classification and mapping methods deviated slightly from the NPS Vegetation Inventory protocols, although the overall process was similar and the resulting data products are comparable with the vegetation classification and map recently completed at the neighboring Craters of the Moon National Monument and Preserve (Bell et al. 2009). Figure 1-4 provides a conceptual overview of our classification and mapping process including major tasks and a general timeline. Many of the primary processing steps do not differ from the NPS Vegetation Inventory Program approach, however; the specific analysis methods we followed for some tasks were modified. Because we were not constrained to defined protocols, we were able to explore novel statistical methods and improve upon the standard mapping approaches. The following chapters provide rationale and detailed descriptions of our classification analysis, mapping methods, and quantitative map accuracy assessment.

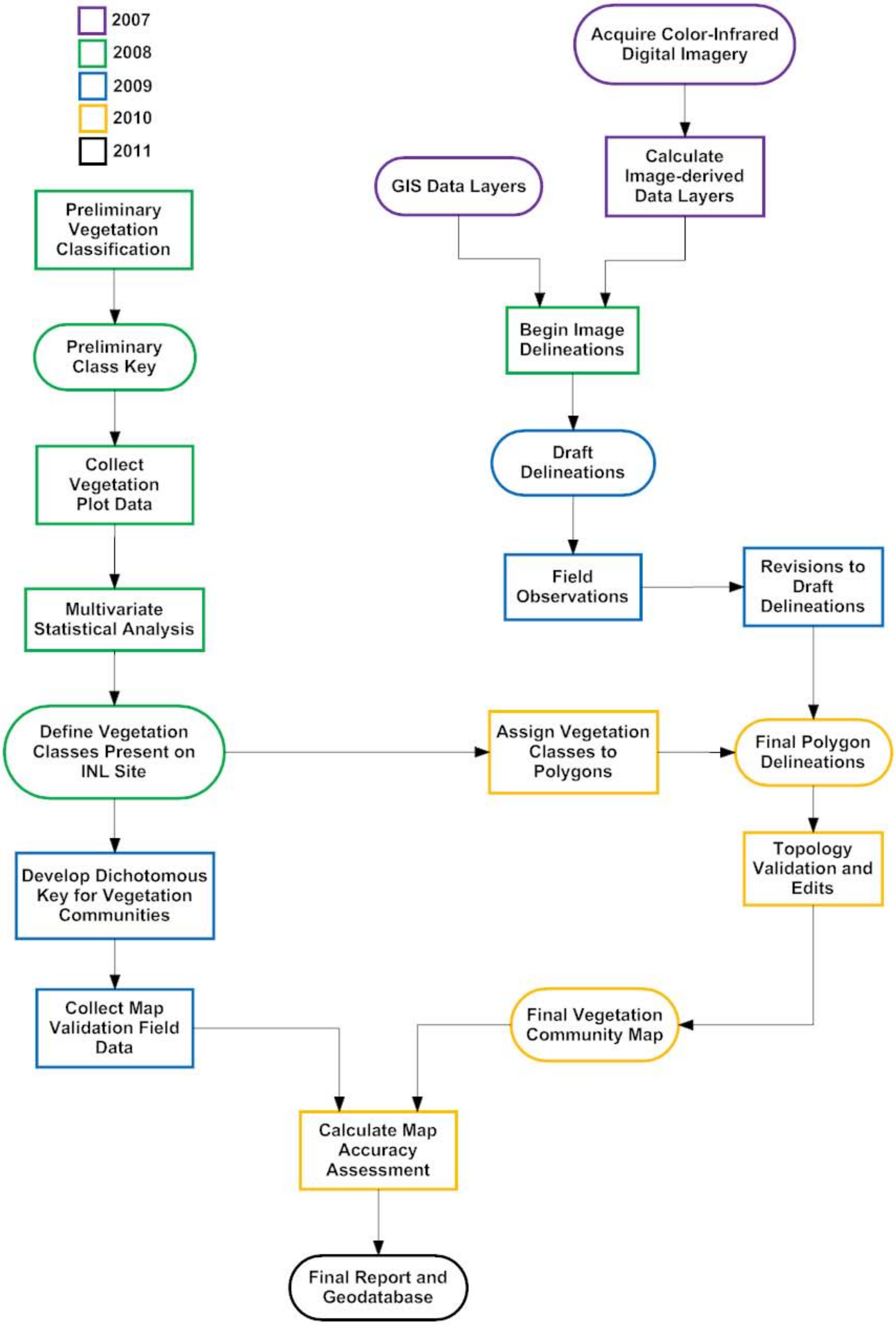


Figure 1-4. Idaho National Laboratory Site vegetation community classification and mapping project overview. The box colors denote the timeframe when these tasks were completed.

2.0 Plant Community Classification

2.1 Introduction

A primary objective of this classification and mapping project was to define and characterize plant communities across the Idaho National Laboratory (INL) Site. Plant community classification was also an important step in developing vegetation classes which could be assigned to delineated polygons. Vegetation classification is a process used to identify plant communities and/or vegetation classes by either designating communities in the field based on subjective interpretation of vegetation physiognomy and species composition, or by sorting field-sampled vegetation plots into groups based on compositional similarities. There are both non-quantitative and quantitative approaches to sorting and grouping vegetation plot data. Non-quantitative techniques, which include methods like relevé table-sorting (Braun-Blanquet 1964), are not unlike field-based interpretations in that they are inherently subjective and results can be difficult to reproduce. Quantitative categorization (i.e., cluster analysis) encompasses a large number of mathematical methods which allow for a more objective classification of vegetation data. Quantitative methods aren't entirely objective as the process is iterative and clustering results reflect the models, assumptions, and importance values chosen by the investigators. Quantitative approaches are, however, generally more objective, defensible, and repeatable than non-quantitative techniques.

Plant communities have been classified for the entire INL Site on at least two previous occasions, both of which were associated with a vegetation mapping project (see Chapter 1). The first classification effort was completed by McBride et al. (1978) and resulted in identification of 20 vegetation types. Vegetation sampling and classification methods for this effort were primarily qualitative and often included simple field-based interpretations of plant communities, which were defined by the three most visually abundant species. Visual estimates and classifications were referenced against quantitative plot data from other projects when those data were available.

Anderson (1991) completed a second classification of INL Site plant communities in 1991. That classification effort was based on quantitative and semi-quantitative plot data using ordination procedures and cluster analyses. Twenty-two vegetation classes were identified as a result of the classification process. Each of the 22 vegetation classes was later assigned to one of ten mapping classes for use in the associated vegetation map. Upon completing the classification, Anderson (1991) emphasized that INL Site plant communities occur as a "continuously varying phenomenon, a consequence of the distribution and proportional abundances of individual species, rather than a mosaic of discrete 'types.'" He further noted that the gradual, continuous changes in species compositions, across the landscape and within the plot cover data, resulted in plant communities and map units which were defined somewhat arbitrarily.

Several years after the second INL classification was completed, the Federal Geographic Data Committee (FGDC) published a Vegetation Classification Standard (NVCS; FGDC 1997, 2008). The standard represents an effort to improve coordination among federal agencies on programs and/or projects involving vegetation classifications and resulting vegetation type descriptions. It provides guidance for classification methodologies to be applied at a local scale and facilitates the successive refinement of a National Vegetation Classification (NVC). The NVC is a hierarchical framework under which standardized vegetation classes, or species associations, are organized. The upper levels of the hierarchy are defined by the general physiognomy and growth form of the dominant plant species, while the lower levels are defined by species compositions (Table 2-1). Ecological units which comprise several levels of the NVC hierarchy are cataloged and electronically available through the NatureServe (2010) database.

Table 2-1. Hierarchical levels of the National Vegetation Classification (reproduced from FGDC 2008).

Hierarchy Level	Criteria
	Upper: Physiognomy plays a predominant role.
L1 – Formation Class	Broad combinations of general dominant growth forms that are adapted to basic temperature (energy budget), moisture, and/or substrate or aquatic conditions.
L2 - Formation Subclass	Combinations of general dominant and diagnostic growth forms that reflect global macroclimatic factors driven primarily by latitude and continental position, or that reflect overriding substrate or aquatic conditions.
L3 – Formation	Combinations of dominant and diagnostic growth forms that reflect global macroclimatic factors as modified by altitude, seasonality of precipitation, substrates, and hydrologic conditions.
	Middle: Both floristics and physiognomy play a significant role.
L4 – Division	Combinations of dominant and diagnostic growth forms and a broad set of diagnostic plant taxa that reflect biogeographic differences in composition and continental differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.
L5 – Macrogroup	Combinations of moderate sets of diagnostic plant species and diagnostic growth forms that reflect biogeographic differences in composition and subcontinental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.
L6 – Group	Combinations of relatively narrow sets of diagnostic plant species (including dominants and co-dominants), broadly similar composition, and diagnostic growth forms that reflect biogeographic differences in composition and sub-continental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.
	Lower: Floristics plays a predominant role.
L7 – Alliance	Diagnostic species, including some from the dominant growth form or layer, and moderately similar composition that reflect regional to subregional climate substrates, hydrology, moisture/nutrient factors, and disturbance regimes.
L8 – Association	Diagnostic species, usually from multiple growth forms or layers, and more narrowly similar composition that reflect topo-edaphic climate, substrates, hydrology, and disturbance regimes.

The NVC and the content available through NatureServe are subject to frequent updates and revision. Though the upper levels of the NVC hierarchy are relatively complete and are only periodically revisited, the lower levels of the NVC hierarchy are largely unfinished and many Association-level plant communities have not yet been identified, described, and/or thoroughly evaluated. Nonetheless, we chose to utilize the FGDC (2008) guidance for sampling and statistical classification approaches, as well as the NVC framework to describe resulting plant communities, because combined they represent the most comprehensive and standardized classification process and organizational scheme available. This approach is also currently being utilized to support other local vegetation classification and mapping efforts conducted by neighboring federal agencies (e.g., National Park Service; NPS), which will allow the results of this classification to be directly comparable to results of other local classifications.

2.2 Methods

We completed two separate classification efforts to support this project. The purpose of the preliminary classification was to identify the range of vegetation types potentially occurring on the INL Site and to reconcile those types with the NVC (NatureServe 2010). Results of the preliminary classification were to be used to generate a working list of plant communities and a key for field identification of those communities. We intended to further utilize the preliminary plant community list and key to direct sampling efforts for subsequent vegetation data collection to support a final classification. In 2008, we collected vegetation data for the final vegetation classification effort. Upon completion of the final classification, we used the resulting plant community class list to identify polygons delineated through the mapping process. We also developed a dichotomous key based on the final classification to facilitate data collection and support an accuracy assessment of the final vegetation map.

2.2.1 Preliminary Classification

We compiled vegetation cover data from three previous research efforts on the INL Site for use in the preliminary classification. We utilized control plot data from two fire recovery studies, the Tin Cup Fire Recovery Study (Blew and Forman 2010) and a survey of vegetation recovery associated with wildland fire containment lines (Blew et al. 2002). Control plots from these studies were located in burn scars which had not otherwise been disturbed and plots were sampled from one to seven years post-fire. We also used data from the Long-term Vegetation Transects (LTV; Forman et al. 2010) to support the preliminary classification. Most of the LTV data used for the preliminary classification were from the 2006 sample effort. Several ancillary LTV plots were established and sampled in 1957 and 1965 with the objective of targeting plant communities less common across the INL Site, and we included these ancillary plots in our analysis as well.

The vegetation data compiled for the preliminary classification were sampled according to protocols specific to each project. Therefore, the data collection efforts often differed in sampling methodology, plot size, and species and/or intended communities sampled. The details of the experimental and sampling design for each research project can be found in associated project-specific reports (Forman et al. 2010, Blew et al. 2002, and Blew and Forman 2010). All data used to support the preliminary classification were collected using either line interception techniques (Canfield 1941) or point interception techniques (Floyd and Anderson 1982). Cover values estimated using point interception frames have been demonstrated to be statistically indistinguishable from those estimated using line interception techniques (Floyd and Anderson 1987). Also, plot scales were not highly disparate among the projects from which data were obtained. Plot sizes and shapes ranged from single 50-m transects which were sampled in their entirety, to 20 m x 50 m plots which were sub-sampled using point interception frames. We assessed sampling effort per plot on all three projects from which data were compiled and determined it was adequate to characterize cover within reasonable ranges of variation for the intended plot size and shape. All vascular species were sampled in all plots except the ancillary LTV plots, which were only sampled for perennial grasses and shrubs. Because the preliminary classification was intended to be used as an exploratory exercise with the intention of identifying as many potentially occurring communities as possible, and because data from all three projects were reasonably similar and were generally adequate for the intended purpose, we pooled a total of 149 plots from the three previous research efforts for the classification analysis.

We subcontracted the Idaho Conservation Data Center (ICDC) to complete the preliminary classification and to provide a key for the field identification of plant communities identified by the classification. Similar classifications had been completed by the ICDC for the National Park Service (NPS) at Craters of the Moon National Monument and Preserve (CRMO) and other Southern Idaho Parks during the same time period, which uniquely positioned them to facilitate consistency among classifications in multiple mapping projects. Multiple iterations of the analyses were completed for the INL Site, but the preliminary classification effort did not yield results useful to further guide the data collection and analytical process for the final classification.

Several details associated with the preliminary classification analyses precluded us from utilizing them in subsequent steps of the process. For example, the data were intensively pruned, both in the number of plots and in the number of species used to complete the analyses. Excessive noise in the dataset may have resulted from the use of plot data collected with several different sampling methodologies. Data pruning is an effective technique used to reduce noise and improve cluster recognition (McCune and Grace 2002), but in this case it likely resulted in the exclusion of unique plots and species that may have represented less common plant communities at the INL Site, especially since the data set was relatively small to begin with. Cluster analyses generally resulted in poor separation among clusters, and clusters were too broad to be cross-walked to NVC Alliance- or Association-level classes. The INL Site data were also analyzed with the assumption that the plant communities would be similar to many of those found at CRMO. Although both locations share a handful of similar communities and many of the same dominant species, they ultimately tended to be much more distinct than originally considered. Consequently, initial classification efforts resulted in a few very broadly-defined classes that were previously well-documented on the INL Site, rather than an extensive list of potentially occurring classes from which we could focus sampling efforts for the final classification. Due to the noisy nature of the data, relatively small sample size, and the resulting broadly-defined class types, we chose to pursue alternate methods for guiding data collection for the final classification.

Specifically, we generated an independent list of all NVC Associations potentially present on the INL Site, based on documented species occurrences, and organized them into a preliminary plant community key using species composition and cover values from NatureServe (2010). The preliminary list and key likely included many Associations that did not occur on the INL Site as many documented species don't necessarily dominate plant communities. The list also included communities which could be considered insignificant because of very limited distributions. However, the list and key were partially intended to ensure rarer plant communities were identified and sampled with enough effort to support a final statistical classification. Therefore we used an overly inclusive list, derived from all potential dominant species, to encourage field crews to identify and target less common communities for sampling. An equally important function of the preliminary key was to guarantee more common plant communities were sampled adequately.

2.2.2 Final Classification

The final classification effort was initiated in 2008. The specific objectives of the final classification were to collect suitable data, apply appropriate analytical methodologies, and use the resulting information to identify and characterize plant communities meaningful to the management of ecological resources on the INL Site. Ideally, we would have liked to distinguish all plant communities occurring across the study area at the Association level, as defined by the NVCS (FGDC 2008). We recognized however, that some plant communities occur in very limited distributions which would preclude us from collecting enough independent samples to properly classify and characterize them. Furthermore, we understood that we were unlikely to collect enough samples across the INL Site to classify every plant community at the Association level. Therefore, we focused our efforts on defining the most abundant, widespread, and ecologically meaningful vegetation classes, and we established a target of identifying classes to at least the Alliance level with very high certainty.

2.2.2.1 Study Design

Plot Sampling Methodology

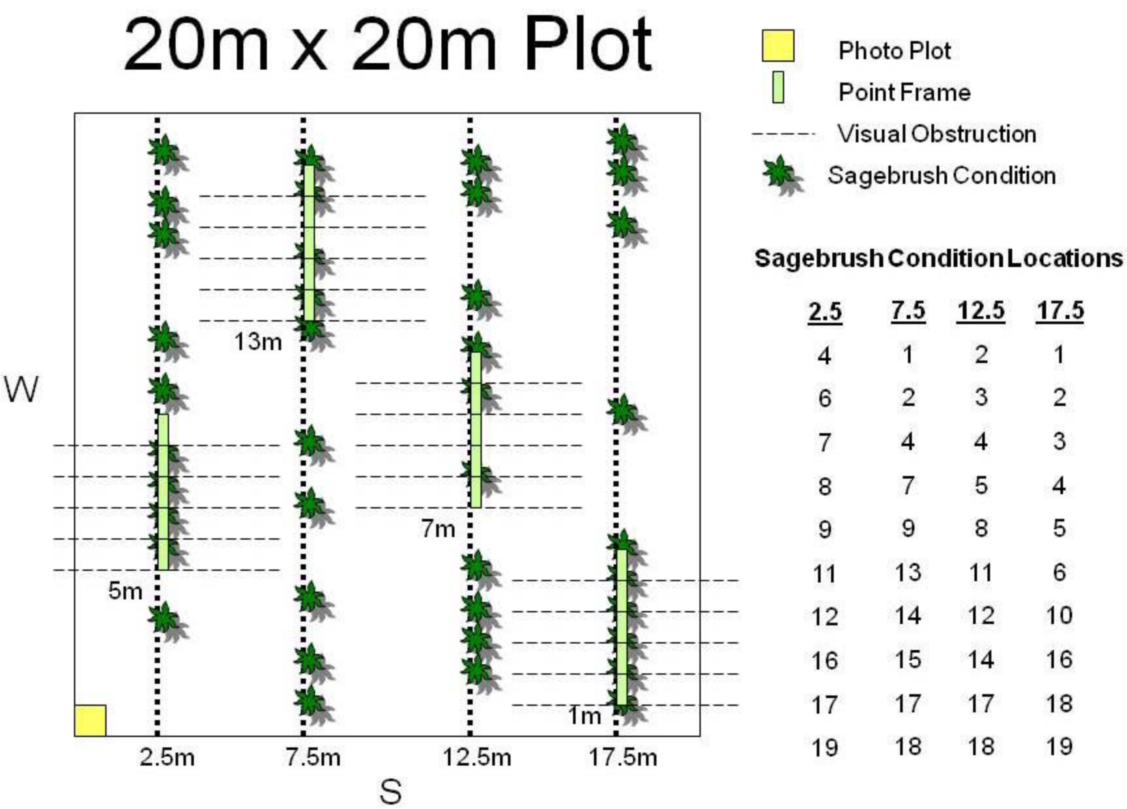
Sample scale and plot size were a key concern for the study design of the final classification. Our intended mapping scale had been established at 1:12,000, but sampling plant communities at scales that were directly compatible with the mapping scale would be logistically impossible and potentially unreasonable in terms of the scale at which plant communities occur or are customarily defined. Also of concern was the necessity of collecting statistically independent data which were sampled objectively, from as many plots as possible, while maintaining the ability to adequately characterize species composition and cover at each plot. We chose to use 20 m x 20 m plots as the fundamental sample unit. This plot size was within the range of sampling scales that had been used to characterize vegetation at the INL Site for several previous monitoring and research efforts and is not unreasonable for sampling plant communities in more general applications (Stohlgren 2007). The scale is also similar to that used by the NPS at other Southern Idaho Parks (e.g., Bell et al. 2009) and is at the upper end of plots sizes recommended for sampling shrub and shrub-steppe communities specifically for classifications to support mapping efforts (Environmental Systems Research Institute et al. 1994). Additionally, we were certain that we could sample plots of this size adequately and in a reasonable amount of time.

Rectangular plots are often favored over circular or square plots for general monitoring applications because they better capture the heterogeneity of the community being sampled (Elzinga et al. 1998). Sampling to support this classification effort, however, posed some unique challenges as one of our goals was to reduce the ambiguity in the classification results to the extent possible. In order to reduce variability within vegetation classes and increase differentiation among vegetation classes, we chose to sample square plots which were located in as homogenous a patch as possible. We also located plots that were as representative of the surrounding plant community as possible. We acknowledged that vegetation classes resulting from this sampling approach would likely be somewhat idealized and not particularly representative of the range of variability in species composition, but the approach would facilitate interpretation of cluster analyses and result in vegetation classes which were clearly distinguishable from one another.

In addition to the 20 m x 20 m plot layout, we developed two alternate plot layouts, which were designed for sampling plant communities that would not be adequately characterized otherwise. Some plant communities with unique species assemblages, such as those occurring on basalt outcroppings or around small playas, are often very limited in spatial extent. Others, such as those occurring along rivers, streams, or other drainage corridors exhibit a distinct spatial pattern. Therefore, one alternate plot layout was at a smaller spatial scale, 3 m x 3 m, and the other utilized a different plot shape, linear rather than square. The linear plot design was 20 m in length.

We sampled plots for absolute cover by species, abundance rank by species, visual obstruction, and sagebrush (*Artemisia tridentata*) condition. Additional data collected at each plot included; Global Positioning System (GPS) location, two photographs, a provisional vegetation community assignment, a brief description of the soil surface characteristics, assignment of a soil texture class, and notes on any sign from sensitive animal species. A diagram of the plot layout and general plot sample design for the standard 20 m x 20 m plot is shown in Figure 2-1. The diagrams for the alternate plot layouts and the detailed sampling protocol, including all sampling directions used during the field sampling effort are included in Appendix A.

Collection of cover data was the most important component of the entire sample design, as those data would be used as the input variables for the multivariate classification models. We chose a point-intercept sampling method described by Floyd and Anderson (1982), in which points are sighted using a 0.5 m x 1.0 m frame (henceforth referred to as “point sighting frame”). Thirty-six points are arranged on 10 cm centers and are sighted through two sets of crosshairs. Point sighting frames have been used on multiple vegetation monitoring and research projects over the past 25 years (e.g., Forman et al. 2010, Forman and Hafla 2010, Blew and Forman 2010, Anderson and Forman 2002) and are generally considered to be the most precise and cost-efficient quantitative sampling method commonly used at the INL Site (Blew and Forman 2010). Previous investigations on sampling effort and cover estimate precision using point sighting frames indicated that 20 to 30 frames were sufficient for characterizing all but the rarest species in a plot (Blew and Forman 2010). Since the objective guiding our data collection effort was to classify plant communities, which are most often defined by their dominant species, we determined that 20 frames per plot would be adequate, but we were aware that rare species may have been missed entirely.



2.5	7.5	12.5	17.5
4	1	2	1
6	2	3	2
7	4	4	3
8	7	5	4
9	9	8	5
11	13	11	6
12	14	12	10
16	15	14	16
17	17	17	18
19	18	18	19

Figure 2-1. Diagram (not to scale) of the standard 20 m x 20 m plot layout used to collect data during the 2008 field season to support a classification of plant communities.

Point sighting frames were located within each plot using a stratified random configuration. Four transects were systematically placed within each plot, and five point frames were located beginning at a random point along each transect. We used the same random start locations for all plots sampled. Point sighting frames were placed contiguously to address spatial autocorrelation issues. Halvorson et al. (1994) described a spatial pattern of about 2.0 m for sagebrush and associated resource islands in sagebrush steppe rangelands. Thus, individuals located within the range of spatial pattern of the community are likely to be sampled using a single point sighting frame. This potential autocorrelation issue is also of concern and has been addressed in line intercept sampling by ensuring the line is “long enough to include all phases of any mosaic pattern that may be present” (Greig-Smith 1983). Therefore, frames placed contiguously over 5 m should sufficiently overcome the spatial pattern described for sagebrush steppe.

Foliar cover rules were used for determining the number of “hits” by each species under the point sighting frame. There were two rationales for selecting foliar, rather that basal or aerial cover. First, we wanted our plot cover estimate to approximate the amount of “cover” detected by the sensor in the images used for polygon delineations. This would facilitate the use of the plot cover data as map “training data” to assist with the assignment of vegetation classes to delineated polygons. Second, while more stable and less sensitive to weather fluctuations, basal cover tends to underestimate the relative importance, or biomass, of grasses in a plant community (Bonham 1989). Our ability to characterize and describe the differences between grassland plant communities and shrubland plant communities was an essential component of our classification objective, which made accurately assessing the relative importance of grass and shrub species a critical factor for understanding the classification results.

We were not able to collect quantitative cover data for Utah Juniper (*Juniperus osteosperma*) in the field because tree heights prohibited the standard use of point sighting frames. Consequently, we were forced to find another method to estimate juniper cover from sample plots. We considered two alternate approaches, both of which utilized the 2007 imagery. One option was to manually digitize individual juniper crowns at a scale fine enough to capture the spatial detail of the crown edges. An alternative option was to utilize an automated image classification of juniper trees thereby reducing the time it would take to manually delineate tree crowns.

We had already experimented with the use of an object-oriented (rather than pixel-based) feature extraction and classification software extension, Feature Analyst. Feature Analyst is a third-party extension that functions within Environmental Systems Research Institute's (ESRI) ArcGIS Desktop® software and provides a suite of machine learning algorithms and hierarchical learning models for extracting features of interest from imagery. The automated feature extraction process begins by digitizing training polygons around the features of interest, selecting the feature input context representation and pattern width, and setting learning options (e.g., Find Rotated Instances of Features). Once the Learning Model completes the initial feature extraction step, the user performs a clutter removal step where correct and incorrect features are marked and missed features are digitized separately. This step allows the software to "learn" how to improve the feature extraction process which is then applied a second time. Further clutter removal iterations can be conducted if feature extraction results are not acceptable.

To test the software application for mapping vegetation communities, we selected juniper trees as the feature of interest because tree crowns are fairly obvious at 1 m resolution and the spectral response from juniper crowns is distinct from other species. We only needed to run the clutter removal step one time and the automated classification result mapped nearly every juniper tree in the study area. We investigated different areas of the INL Site where juniper are present and were confident the automated feature extraction produced highly accurate results that would be much more efficient than manual delineations.

We imported field plot GPS coordinates from the 20 m x 20 m plots and digitally recreated plot boundaries in a Geographic Information System (GIS). We used the digital plot boundary to clip the juniper automated classification results. Juniper areal cover was calculated by dividing the total plot area by area of classified juniper trees (i.e., the number of pixels).

In addition to cover data, we collected rank abundance data using a technique described by Anderson (1991). We created a complete, but not necessarily exhaustive, species list for each plot, and each species was ranked on a one to four scale based on its abundance at that plot. A rank of "1" indicated that the species was a dominant or co-dominant and a rank of "4" indicated that the species was rare. These data were collected to test the relationship between rapidly assessed rank abundance scores and the more time-consuming quantitative cover estimates described above. If the rank abundance data were useful for approximating patterns in relative species abundance, they may have also suitable for collecting accuracy assessment data, which requires larger sample sizes and limits the amount of time that can be spent collecting data at each plot.

We collected visual obstruction data to provide an estimate of vertical structure and related habitat characteristics of the plant community at each plot. Twenty points were sampled according to methods described by Robel et al. (1969). Sample points were located according to the same stratified random configuration established for the point sighting frames (Figure 2-1). Upon completion of the classification, each vegetation type could be assigned a range of associated visual obstruction values using these data. Assigning visual obstruction values to vegetation classes could facilitate the use of the resulting vegetation map for habitat suitability analyses to support the Conservation Management Plan (CMP; see Chapter 1).

We assessed sagebrush condition on all plots containing at least 10 big sagebrush individuals. Forty random locations were selected, ten along each of the four plot transects (Figure 2-1), and the nearest big sagebrush individual was scored according to its health status. If fewer than 40 individuals were present in a plot, all individuals were surveyed. An individual receiving a rank score of “1” was still rooted into the ground, but was entirely dead, whereas an individual receiving a rank score of “5” was entirely alive with no dead branches. The purpose of collecting these data was to provide a basis for evaluating the condition of big sagebrush stands across the INL Site. Coupled with the map resulting from this project, these data may be useful in describing spatial patterns of die-off and/or re-establishment.

We collected two qualitative variables describing soil texture and appearance at each plot. Surface characteristics were described in terms of the amount of bare soil, gravel, rock, cinder, etc., and the texture class of the soil was assigned using a texture class key (Foth et al. 1980). These data were intended to provide information for image interpretations where patterns apparent in the imagery may have resulted from surficial geology and related soil characteristics. Because some plant species are tightly constrained by soil texture, these data were also expected to be valuable for describing plant community distributions across the INL Site.

In order to guide sampling efforts, we assigned each plot to a provisional vegetation class using the preliminary plant community key discussed above. The number of each of the vegetation classes sampled was tracked throughout the sampling season and plot placement strategies were modified periodically. We targeted sample sizes at a minimum of five and a maximum of twenty plots for all vegetation classes provisionally identified using the preliminary plant community key. Twenty plots are generally considered sufficient to identify and characterize a plant community (McCune and Grace 2002). However, it would be unlikely to locate and sample twenty statistically independent plots for plant communities which are rare or occur at a limited spatial scale. For these uncommon plant communities, we determined that at least five plots would be necessary to adequately describe species composition and summarize meaningful ranges of cover values.

We generally referred to the PLANTS National Database (USDA, NRCS 2010) as the taxonomic standard for species nomenclature during the data collection and classification process. Occasional departures from this standard reflect naming conventions from long-term vegetation research efforts at the INL Site. Site-specific identification and nomenclature conventions are described in Forman and Hafla (2005) and Forman et al. (2010).

Plot Site Selection

Our site selection process utilized existing GIS datasets and spatial analyses to filter the landscape into a potential sampling area. Once the potential sampling area was defined, we selected plot locations using a stratified random sampling approach combined with the manual selection of discretionary plots to meet minimum sample size requirements and guarantee all important regions of the INL Site were adequately represented during the vegetation field sampling campaign. Some of the pertinent GIS datasets were outdated and did not reflect recent changes across the landscape including the alteration of vegetation communities caused by natural wildland fire and addition of new roads. Consequently these GIS layers needed to be updated prior to beginning the site selection process. Figure 2-2 provides a graphical overview of the GIS-based site selection methods performed, followed by a detailed description of the process.

Although our sampling effort targets were established using the preliminary vegetation class list, we had to use existing spatial data to stratify plot locations. The McBride vegetation community map was completed through traditional photographic interpretation conducted through the 1960's using a variety of aerial images collected at different scales (McBride et al. 1978). This community map represented the best available starting point to guide plot placement. In the time since the map was published, approximately 25% of the INL Site has been altered by wildland fire. To update the map, we merged the fire boundaries across the INL Site from 1994-2007. The merged wildland fire dataset was combined with the McBride vegetation map using the *Union* command in ArcGIS. The vector boundaries of each fire divided the original vegetation polygons into smaller polygons that maintained the vegetation community database attributes assigned to the original polygon.

We assumed that sagebrush shrubs and trees were lost within all wildfire boundaries, and the new community would not likely contain either as a dominant or co-dominant as represented in the name of the (McBride et al. 1978) vegetation class. We manually selected all polygons that were within a fire boundary and removed big sagebrush from the '*Name*' field within the McBride database. We also removed Utah juniper from all polygons where fire had occurred. The remaining dominant species assemblages resulted in several new vegetation classes not originally described by McBride et al. (1978).

There have been a considerable lengths of new roads established across the INL over the past decade. We obtained a copy of the most current INL roads GIS shapefile as a starting point for further editing. Using digital imagery collected in 2007, we manually digitized all new observed roads within the INL boundary at approximately a 1:4,000 mapping scale. Several of the new roads digitized appear to be associated with grazing operations evident by road loops and spurs in close proximity to watering tanks. Because we did not want to encourage the use of these roads or help facilitate their establishment, we did not consider them in the selection processes described below and only included new roads that appeared well traveled.

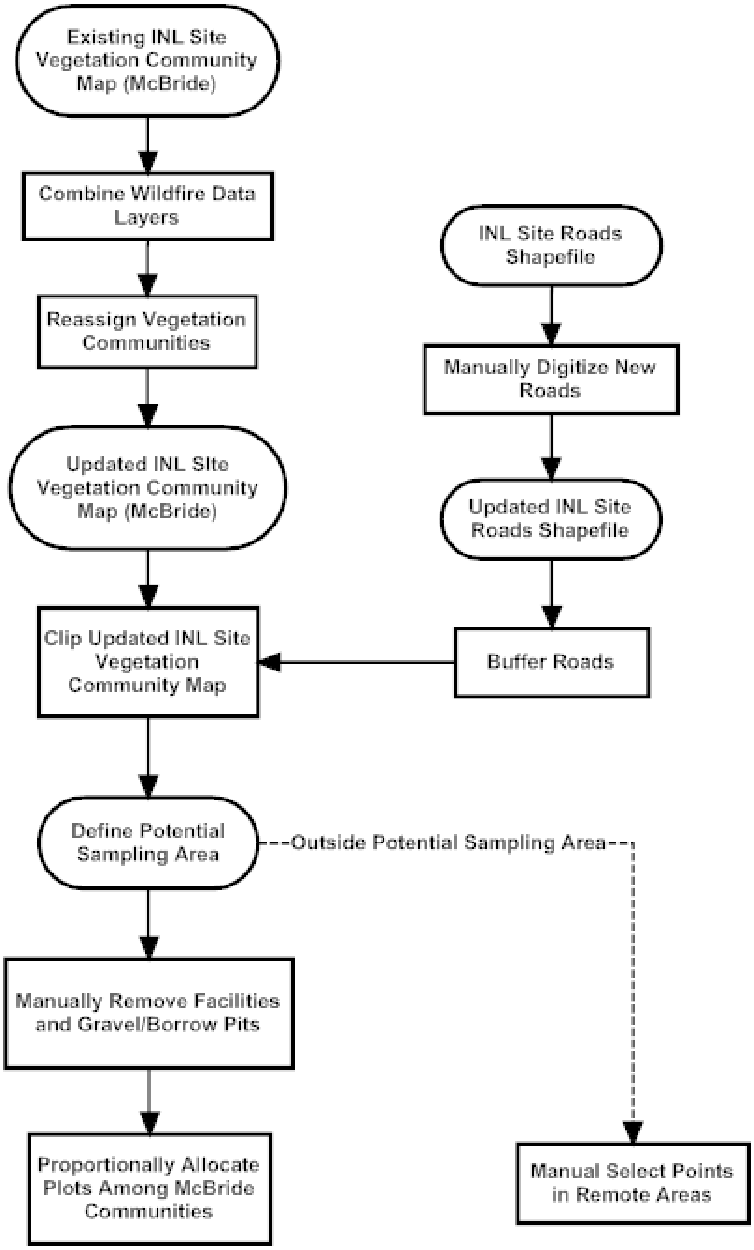


Figure 2-2. An overview diagram of the Idaho National Laboratory Site vegetation classification and mapping project 2008 field plot site selection methods.

For logistical considerations, we wanted to limit the potential field sampling area to a distance of 1 km from existing roads because the time it takes to drive to regions of the INL and hike to truly random locations limits the amount of field data a crew can collect. We also wanted to eliminate the influence of roads on vegetation communities by removing the area of the road and all ground within 100 m of the road. A multi-ring road buffer was calculated in ArcGIS with the inner distance designated at 100 m radius and a second at 1100 m radius. We selected the *Dissolve* and *All* options in the buffer window to combine all road segments that overlap. The inner 100 m buffered area was deleted resulting in 1 km of potential sampling area that begins 100 m from all roads.

In addition to roads, we wanted to be able to remove regions that experience human-disturbance from the potential sampling area. The entire potential sampling area identified from buffering the roads existed as a single feature with multiple polygons. We used the *Explode Multi-Point* option in the Advanced Editor toolbar to transform the single feature with multiple polygons into multiple features of single polygons. This provided the capability to edit and delete individual polygons from the larger comprehensive feature. We overlaid the potential sampling area onto the 2007 digital imagery and identified regions within that contained disturbed ground, such as gravel pits and borrow sources. We deleted all disturbed ground and area that fell within facility boundaries by editing the polygons in the sample area feature, resulting in the final potential sampling area (Figure 2-3).

Figure 2-3. The final Idaho National Laboratory Site potential sampling area identified after buffering roads and removing disturbed ground and facilities. White areas are the regions removed through the landscape filtering process.

The final step was to overlay the potential sampling area onto the updated McBride vegetation community map and select sampling plot locations using a stratified random process. We took the final potential sampling area polygon and used the *Clip* function in ArcGIS to subset the updated McBride vegetation community map. We calculated the total area (km^2) of each McBride vegetation community (Table 2-2). We set a sampling goal to collect at least 300 plots of field data in 2008. We withheld 60 plots from the stratified random sampling effort to serve as discretionary plots that were manually selected to ensure unique or rare communities were sampled and minimum sample sizes requirements were met for all communities.

We calculated the proportional area of each McBride community by dividing the total area of each community by the total area of the INL Site. The 240 plots set aside to be allocated through the stratified random process were also proportionally allocated based on the total potential sampling area of each community (Table 2-2). To avoid spatial autocorrelation issues between field sampling locations, we set the minimum distance between random points to 100 m. This resulted in a fairly uneven distribution of vegetation community samples, and some rare communities were assigned no plots. From the initial proportional plot allocation, we used our minimum sample size standards to further guide sample plot distribution. We limited the number of plots to a maximum of 20 and a minimum of five for each community type, resulting in the redistribution of 236 total plots selected through the stratified random process (Figure 2-4). Although plots were allocated and located using the McBride et al. (1978) plant community map, the McBride et al. (1978) class designations were removed from the sample plots and each plot was assigned an independent provisional vegetation class at the time it was sampled using the preliminary class key.

There were large tracts of land in remote regions of the INL that did not contain any vegetation plots, and we did not want to bias our sampling effort by ignoring these habitats. Therefore, we selected additional remote plots from regions excluded from the random selection that limited points to 1100 m from roads. We selected 20 additional plots from remote regions (Figure 2-4). Excluding the 236 plots which were located using the stratified random process and 20 plots which were placed in remote areas, the remaining sample plots were allocated as discretionary plots selected by the field crews to increase the sample size for uncommon or rare vegetation communities. Under-sampled communities were identified by tracking vegetation class assignments for all sampled plots using the preliminary field key.

2.2.2.2. Analytical Approach

The analytical approach to classifying the vegetation cover data collected in 2008 is best described as a multi-step process. First, we identified the best classification model for describing the structure and pattern of species abundance and composition using the plot cover data. Next, we determined the optimal number of clusters, or vegetation classes, within the dataset. We calculated summary statistical descriptions for the two classifications with the most optimal number of clusters and we described those clusters in terms of and mean species cover and constancy. Both classification solutions were evaluated with regard to the Association-level vegetation types described in the NVC, as well as plant communities described in previous classifications completed for the INL Site, and the most appropriate solution was selected. Upon selection of the most appropriate classification, we re-evaluated several clusters within that classification to determine whether they should be further split. Finally, the classification and cluster summaries were updated to reflect additional cluster divisions. The process will be summarized briefly here; however a detailed description of the classification process is included in Appendix B.

Table 2-2. The updated INL Site McBride vegetation community map area summary for each community within the final potential sampling area. The 'Sampling Plots' column shows the number of sampling plots assigned from the initial stratified random sampling scheme based on proportional area. The 'Adjusted Plots' column shows the final sampling plot numbers after the redistribution.

McBride Community (see McBride et al. 1978)	Total Area (km^2)	Percent of INL	Sampling Plots	Adjusted Plots
ARTTRI-CHRYSVISC-SITHYS	282.85	17.97%	43	20
ARTTRI-AGRSPIC-CHRYSVISC	194.26	12.34%	30	20
ARTTRI-ORYZHYMEN-STICOM	192.27	12.22%	29	20
ARTTRI-AGR DASY-STIPA COMATA	104.67	6.65%	16	16
AGRSPIC-CHRYSVISC	88.21	5.60%	13	13
CHRYSVISC-SITHYS	79.24	5.03%	12	12
ARTTRI-EURLAN-CHRYSVISC	74.32	4.72%	11	11
ORYZHYMEN-STICOM	72.29	4.59%	11	11
TETRACANES-CHRYSVISC-ARTTRI	59.78	3.80%	9	9
ARTARB-ARTTRI-ATRCONF	52.42	3.33%	8	8
ORYZHYMEN-CHRYSVISC-OPUNPOLY	51.10	3.25%	8	8
ATRNUT-EURLAN-ORYZHYM	47.14	2.99%	7	7
CHRYSVISC-GRASS	41.70	2.65%	6	6
CHRYSVISC-ARTTRI-GRASS	33.76	2.14%	5	5
JUNOST-ARTTRI-AGRSPI	32.23	2.05%	5	5
ARTTRI-ATRCONF-CHRYSVISC	31.10	1.98%	5	5
AGROPYRON CRISTAUM (Seeded)	25.39	1.61%	4	5
AGRSPI	21.24	1.35%	3	5
ARTTRI-EURLAN-ATRCONF	21.00	1.33%	3	5
AGRSPIC-ARTTRIP-CHRYSVISC	18.43	1.17%	3	5
AGR DASY-STIPA COMATA	13.29	0.84%	2	5
AGRSMI-IVAAXIL-JUNCUS SP.	11.47	0.73%	2	5
EURLAN-CHRYSVISC	10.37	0.66%	2	5
ARTARB-ATRCONF-SITHYS	5.39	0.34%	1	5
ELYMCIN-CHRYSVISC-ARTTRI	4.93	0.31%	1	5
MIXED SHRUBS	3.95	0.25%	1	5
ELYMCIN-CHRYSVISC	0.65	0.04%	0	5
SAND DUNES	0.44	0.03%	0	5
Total	1573.89		240	236

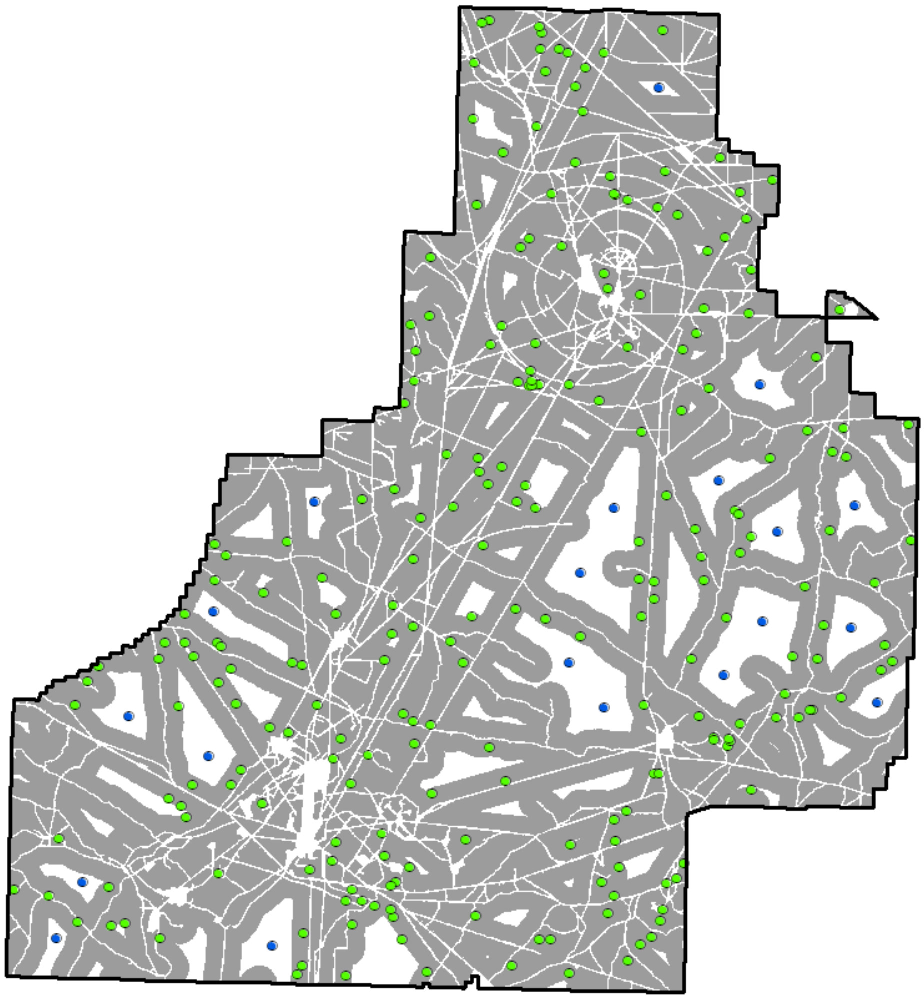


Figure 2-4. The 2008 vegetation sampling plot distribution in the Idaho National Laboratory Site. The gray area represents the filtered potential sampling. The stratified random sampling points are depicted by green circles, and the manually selected sampling points from remote areas are depicted by blue circles.

2.2.2.3 Supplemental Sampling

After completing the initial steps of the classification analysis with the data collected in 2008, we determined that juniper-dominated plots had not been sampled sufficiently for classification at the level of detail we had previously identified. Therefore, we sampled five additional plots in 2009. We selected juniper plot locations manually to ensure we sampled an adequate number of plots to characterize two Juniper classes, one with an open juniper canopy and one describing stands with greater juniper cover. Potential plot locations were selected from regions where the visual juniper cover in the imagery appeared greatest. The selected plot locations served as a guide and the field crew had the authority to shift the plot boundaries on the ground if actual juniper cover was lower than expected.

In order to identify the best possible classification method given the general cluster structure of the INL Site data , we compared eight classification methods: **(1)** average linkage (Sokal and Michener 1958), **(2)** centroid linkage (Sokal and Michener 1958), **(3)** complete linkage (McQuitty 1960), **(4)** flexible β = -0.25 (Lance and Williams 1967), **(5)** k-means analysis (MacQueen 1967), **(6)** partitioning around medoids, (i.e., PAM; Kauffman and Rousseeuw 1990), **(7)** single linkage (Sneath 1957), and **(8)** variance minimization linkage (i.e., Ward's method; Ward 1963). PAM and k-means analysis are non-hierarchical methods while the other six are hierarchical agglomerative methods. We compared the eight methods using six classification evaluators, four of which are geometric, and two of which are indicator species-based analyses. The classification evaluators we used for our analyses were: **(1)** indicator species analysis (ISA) number of significant indicators (Dufrêne and Legendre 1997; McCune and Grace 2002), **(2)** ISA average *p*-value (Dufrêne and Legendre 1997; McCune and Grace 2002), **(3)** C-index (Hubert and Levin 1976), **(4)** average silhouette width, (i.e., ASW; Rousseeuw 1987), **(5)** point biserial correlation, (i.e., PBC; Brogden 1949), and **(6)** partition analysis ratio; (i.e., PARTANA; Roberts 2005, Aho 2006a). We compared the eight classification methods with respect to their forty-nine simplest clustering solutions (i.e., 2 to 50 clusters), and we made comparisons of methods for each evaluator.

The six evaluators used to determine the most appropriate classification method were also used as criteria to assess the optimal number of clusters for that classification method. The geometric evaluators (ASW, C-index, PARTANA, and PBC) index classification effectiveness based on cluster compactness and distinctness in multivariate space (cf. Dale 1991). The non-geometric evaluators (ISA number of significant indicators, and ISA average *p*-value) measure classification effectiveness with respect to indicator species. For instance, a clustering solution in which a species occurs predominantly in one cluster while being absent from others indicates a "real" cluster structure from the perspective of that species (Aho et al. 2008). As with the initial model selection, we considered forty-nine possible classification solutions.

We selected the two "best" solutions with respect to the optimal number of clusters and generated classification descriptions for both. Descriptions consisted of conventional statistical summaries and relevé tables. Conventional statistical summaries included the following metrics for each component cluster; total number of plots, total cluster richness, mean plot richness, mean plot cover, mean Simpson's diversity (Simpson 1949), mean Shannon-Wein diversity (MacArthur and MacArthur 1961), and beta diversity (Whittaker 1960). Relevé tables were generated using the mean cover and constancy of each species within each cluster. Columns were sorted according to total mean vegetation cover and rows were sorted according to species' fidelity (Aho 2006b).

We compared the classification descriptions with plant communities previously described on the INL Site (McBride et al. 1978, Anderson 1991) and with plant communities characterized for other localities with some similar vegetation types (Bell et al. 2009). We also evaluated our results within the hierarchical framework of vegetation classification described by the NVCS (FGDC 2008) and to vegetation types currently described and archived in the NVC (NatureServe 2010) database. We chose to use the classification which was most readily interpreted within the context of the resources described above.

Once we selected a final classification, we analyzed several clusters to determine whether they could be further split. In particular, we focused on clusters with high beta diversity scores. We identified three clusters for further refinement. We re-analyzed all three clusters using the final classification method selected and the same six evaluator criteria. Final statistical classification descriptions (summary statistics and a relevé table) were updated to reflect clusters that had been further split.

In the final step of the classification process, we identified two clusters containing either black sagebrush or shrubs generally associated with remnant riparian corridors, which have often been considered to be indicative of particular INL Site plant communities. In both of these clusters, the species of interest generally had relatively high mean cover numbers, but moderate to low constancy values. We suspected that the communities were very localized in extent and restricted in distribution which resulted in low sample sizes and little power to differentiate them statistically. For each of these two clusters, we chose to manually split the plots into two sub-clusters based on the presence/absence of the target indicator species.

Upon finalizing the classification, we generated a vegetation class list. We named plant communities according to the conventions outlined by the FGDC (2008), using constancy and mean cover as criteria to determine nominal taxa for each cluster or class. Generally, the species with the highest constancy and mean cover values were coincident within each cluster and only species having 100% constancy and cover within the top three or four mean values were used in the class name. A handful of classes contained species having high mean cover values, but less than 100% constancy. When mean cover values of these species indicated they were likely co-dominants in the plant community, meaning cover values of these species approached or exceeded cover values of the next most dominant species having 100% constancy, we included these species in the class name.

We developed a finalized dichotomous key to INL Site plant communities, or vegetation classes, as they were defined by the final classification, using constancy and mean cover values for each class (Appendix C). Because specific ranges of cover values are difficult to estimate rapidly in the field, dichotomies in the key are driven by relative abundance concepts like; “dominant,” “co-dominant,” “abundant,” “common,” and “rare.” While these concepts facilitate efficient data collection, they necessarily oversimplify the range of variability present in most plant communities. These generalizations result in plant communities defined by plots which are typical of the center of a cluster, and plots near the cluster periphery may “key” differently than they clustered in the classification analysis, especially for clusters with substantial overlap. We used the finalized dichotomous key to assign plant communities observed in the field to previously delineated polygons (see Chapter 3) and to assign vegetation classes to plots sampled during independent map validation data collection (see Chapter 4).

2.3 Results and Discussion

2.3.1 Classification Results

In 2008 we sampled 314 plots (stratified random, remote, and discretionary) across the INL Site. Of those, 304 plots were the standard 20 m x 20 m plots, seven were 3 m x 3 m plots, and three were linear plots. Five additional 20 m x 20 m plots were sampled in dense juniper stands in

2009. We designed a Microsoft Access database utilizing ESER vegetation data management standards (described in Forman et al. 2010) and it was populated with the plot data from both sample efforts. We used the cover values from all 314 plots sampled in 2008 for the classification analyses, and only used the cover data from the plots sampled in 2009 to describe a juniper community not adequately sampled in 2008.

In general, classification methods which created spherical clusters (i.e., average linkage, flexible β = -0.25, complete linkage, PAM, and Ward) were favored by the evaluators. This was true for both geometric evaluators, which are predisposed to favoring spherical clusters, and non-geometric evaluators (i.e., the indicator species analysis methods) which do not favor a particular type of cluster geometry. As a result, spherical cluster interpretation of the INL Site data (as opposed to a linear cluster interpretation) is the most valid one. Classifications of the eight methods differed significantly from the perspective of all six evaluators ($df = 7$, $131.4 \leq \chi^2 \leq 249.5$, $p < 2.2\times10^{-16}$; Appendix B). Flexible β = -0.25 created the strongest classifications as it had the highest evaluator score for all six evaluators (Appendix B). Thus, we proceeded classifying INL Site plant communities using flexible β = -0.25.

All six evaluators found solutions with only two or three clusters to be the worst possible solutions. The non-geometric ISA evaluators found 8 and 12 cluster solutions to be optimal, while the geometric evaluators found a higher number of clusters (i.e., 17-22) to be optimal. Averaging the scores of all six evaluators, the best solution was 12 clusters, although solutions around twenty clusters were also favored. Classifications with fewer than 8 clusters and more than 30 clusters were found to be particularly poor. Because plant communities across the INL Site tend to occur as assemblages of the same species with differing compositional abundances, we had hypothesized that the geometric evaluators would provide the best cluster solution. However, we compared the 12 and 22 cluster solutions in the event that the solution favored by indicator species analyses was more compatible with the method of defining plant communities as described by the NVCS (FGDC 2008).

Vegetation classes resulting from the 22 cluster classification were actually more readily interpreted within the NVCS framework than classes resulting from the 12 cluster classification. We were able to crosswalk the classes resulting from the 22 cluster classification to classes represented in the NVC, often at the Association level, in a very straightforward manner. All plant communities represented by clusters in the 22 cluster solution were unique, and only a handful of communities that we had anticipated detecting were absent. The 12 cluster classification would require substantial refinement to yield Alliance and/or Association-level classes. Because each of the classes resulting from the 22 cluster classification represented unique vegetation types, we chose to proceed with the 22 cluster classification results.

Plant communities resulting from the 22 cluster solution ranged from being relatively broad and inclusive to being fairly narrow and specific. This range is illustrated nicely by the range in beta diversity values, which vary by nearly an order of magnitude (Appendix B). Several clusters also had substantial overlap in species occurrence, and to some extent in species composition. This is especially true for plant communities defined by dominant species which are common across the INL Site and range widely in abundance depending on the plant communities in which they occur. For example, cluster 12 is characterized by the dominance of Indian ricegrass

(*Achnatherum hymenoides*). Indian ricegrass also occurs at lower cover values, but with high constancy in most of the other plant communities. In one of these other plant communities, represented by cluster 3, needle and thread is the dominant species; however, Indian ricegrass ranges from moderately abundant to nearly co-dominant. Thus, classes represented by clusters 12 and 3 had substantial overlap. Some of the greatest cluster overlap occurred in communities with considerable cover of big sagebrush, green rabbitbrush (*Chrysothamnus viscidiflorus*), and streambank wheatgrass (*Elymus lanceolatus*).

We considered statistically refining a few of the 22 clusters to ensure that all unique vegetation classes were identified and represented to the extent possible with the given dataset. Specifically, we selected cluster 4, dominated by green rabbitbrush; cluster 7 dominated by Wyoming big sagebrush; and cluster 11, co-dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg bluegrass (*Poa secunda*) and characterized by substantial Utah Juniper cover, for further evaluation. Clusters 4, 7, and 11 had three of the four highest beta diversity scores of all identified communities. In addition, cluster 4 was by far the largest group identified (53 plots; Appendix B). The reclassification of these clusters resulted in splitting cluster 4 into two sub-clusters, one with a bluebunch wheatgrass-dominated understory and one with a relatively sparse herbaceous component. Sub-clusters resulting from the reclassification of cluster 7 did not yield unique plant communities with differing co-dominant species, so cluster 7 was not split. The reclassification of cluster 11 yielded three sub-clusters; one which contained most of the plots with junipers, and two which had the same two dominant species with differing mean cover values. Cluster 11 was ultimately split into two vegetation classes; the sub-cluster containing juniper was identified as a unique plant community, while the other two sub-clusters were recombined since they likely represented variation within one plant community co-dominated by bluebunch wheatgrass and Sandberg bluegrass. In our attempt to reclassify cluster 11 we also found that plant communities characterized by dense juniper stands were not represented, so a vegetation class characterized by dense juniper was provisionally added until additional data could be collected the following growing season.

We also identified clusters 16 and 17 as possible candidates for reclassification because they contained species which have often been considered indicative of particular INL Site plant communities. Cluster 16 was generally dominated by Sandberg bluegrass, but some of the plots within the cluster had substantial cover from black sagebrush. Cluster 17 was generally dominated by tall tumblemustard (*Sisymbrium altissimum*), but a few of the plots within the cluster had at least some cover from shrubs associated with remnant riparian plant communities. Neither of these clusters contained enough plots to support statistical reclassification, so we manually split them based on whether or not they contained black sagebrush in cluster 16 or riparian shrubs in cluster 17.

After the 2008 field data had been collected and the classification completed, it became apparent there had been some issues identifying species of rhizomatous grasses; in particular it was unclear whether streambank wheatgrass and western wheatgrass (*Pascopyrum smithii*) had been differentiated properly. In fact, the identification of those species, as they were labeled in the INL Site reference herbarium, was called into question about one year after the 2008 sampling effort was completed. It was also noted that slender wheatgrass (*Elymus trachycaulus*) had likely been misidentified (based on herbarium reference specimens) as western wheatgrass in some areas of the INL Site during this and past data collection efforts. Since the classifications had been completed and revisiting all plots containing rhizomatous grass was impractical, we combined the classes characterized by the dominance of rhizomatous grasses, represented by clusters 1 and 9.

2.3.2 Plant Community Descriptions

The final classification combined with the subsequent iterations of classification refinement resulted in 26 plant communities or vegetation classes for the INL Site. The final class list, with class names assigned according to NVCS (FGDC 2008) conventions, is presented in Table 2-3.

Of the 26 vegetation classes identified for the INL Site, two are wooded or woodland types, seven are shrubland types, four are shrub herbaceous types, five are dwarf shrubland or dwarf-shrub herbaceous types, five are herbaceous types, and three are semi-natural herbaceous types. Semi-natural types are generally defined as being dominated by non-native species. We classified 14 of the 26 classes at a hierarchical level comparable to an Association within the NVC (NatureServe 2010), while the remaining 12 classes were classified at a level comparable to an Alliance. Alliance-level classes were often the result of shrubland or dwarf shrub plant communities with understories which were either sparse, or had species compositions characterized by high species richness and for which cover values for each species varied along a continuum. The continuously varying understory of several shrub- or dwarf-shrub-dominated communities made the identification of sub-clusters arbitrary and statistically indefensible. More information on the crosswalk between the vegetation classes described here and those presented in the NVC (NatureServe 2010) can be found in the comprehensive community descriptions contained in Appendix D.

Utah juniper was the dominant tree species in the wooded and woodland classes. Many of the shrubland and shrub herbaceous classes were dominated by big sagebrush and/or green rabbitbrush. Three-tip sagebrush (*Artemisia tripartita*) and spiny hopsage (*Grayia spinosa*) each dominated a shrubland class, but the sample sizes were relatively small for each of the clusters representing those classes, indicating that they were likely somewhat restricted in size and spatial extent. The dwarf shrubland classes were dominated by little sagebrush species (*Artemisia arbuscula, Artemisia nova*), salt desert shrub species (*Atriplex* spp.), or by dwarf goldenbush (*Ericameria nana*). Dominant species characterizing the herbaceous plant communities included; needle and thread (*Hesperostipa comata*), bluebunch wheatgrass, Indian ricegrass, Great Basin wildrye (*Leymus cinerus*), and Sandberg bluegrass. Crested wheatgrass (*Agropyron cristatum*), cheatgrass, and introduced mustard species (*Sisymbrium altissimum, Descurainia sophia*) dominated the three semi-natural vegetation types.

Big sagebrush plant communities are represented by three vegetation classes. One class is characterized by the dominance of Wyoming big sagebrush (*Artemisia tridentata* ssp. *Wyomingensis*), another is characterized by the dominance of basin big sagebrush (*Artemisia tridentata* ssp. *tridentata*), and the third class is characterized by the dominance of a combination of both big sagebrush subspecies. Cluster 2 was generally defined by an abundance of big sagebrush which could not be readily identified to one specific subspecies in the field. West et al. (1978) discuss the difficulties in identifying subspecies based on morphological characteristics alone; they concluded that phenotypic variability is so great that even the most experienced range scientists would not be able to identify specimens correctly to the subspecies level for nearly two thirds of specimens they encountered. The authors also argue that hybridization occurs between several combinations of *Artemisia* species and subspecies resulting in morphological intermediates, which further complicates correct subspecies identifications. Others have actually described the occurrence of Wyoming and basin big sagebrush hybrids on the INL Site (Colket 2003). Although the debate is ongoing as to the correct approach for taxonomic classification of the sagebrush subspecies, there are distinct and intermediate morphological characteristics associated with the "hybrid" as it is encountered at the INL Site.

Table 2-3. Twenty-six plant communities, or vegetation classes, identified for the Idaho National Laboratory Site using cluster analyses and subsequent cluster refinement. Classes are based on cover data from 314 plots sampled in 2008 and five plots sampled in 2009.

Cluster #	Scientific Class Name	Colloquial Class Name	# of Plots
1/9	*Chrysothamnus viscidiflorus*/*Elymus lanceolatus* (*Pascopyrum smithii*) Shrub Herbaceous Vegetation	Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	27
2	*Artemisia tridentata* Shrubland	Big Sagebrush Shrubland	9
3	*Hesperostipa comata* Herbaceous Vegetation	Needle and Thread Herbaceous Vegetation	26
4a	*Chrysothamnus viscidiflorus* Shrubland	Green Rabbitbrush Shrubland	34
4b	*Chrysothamnus viscidiflorus*/*Pseudoroegneria spicata* Shrub Herbaceous Vegetation	Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation	19
5	*Chrysothamnus viscidiflorus* – *Krascheninnikovia lanata* Shrubland	Green Rabbitbrush - Winterfat Shrubland	22
6	*Artemisia tridentata* ssp. *tridentata* Shrubland	Basin Big Sagebrush Shrubland	10
7	*Artemisia tridentata* ssp. *wyomingensis* Shrubland	Wyoming Big Sagebrush Shrubland	30
8	*Chrysothamnus viscidiflorus*/*Alyssum desertorum* Herbaceous Vegetation	Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation	16
10	*Agropyron cristatum* (*Agropyron desertorum*) Semi-natural Herbaceous Vegetation	Crested Wheatgrass Semi-natural Herbaceous Vegetation	13
11ab	*Pseudoroegneria spicata* – *Poa secunda* Herbaceous Vegetation	Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	18
11c	*Juniperus osteosperma* Wooded Shrub and Herbaceous Vegetation	Utah Juniper Wooded Shrub and Herbaceous Vegetation	3
11d	*Juniperus osteosperma* Woodland	Utah Juniper Woodland	5
12	*Achnatherum hymenoides* Herbaceous Vegetation	Indian Ricegrass Herbaceous Vegetation	16
13	*Bromus tectorum* Semi-natural Herbaceous Vegetation	Cheatgrass Semi-natural Herbaceous Vegetation	11
14	*Leymus cinereus* Herbaceous Vegetation	Great Basin Wildrye Herbaceous Vegetation	7
15	*Atriplex falcata* Dwarf Shrubland	Sickle Saltbush Dwarf Shrubland	7
16a	*Poa secunda* Herbaceous Vegetation	Sandberg Bluegrass Herbaceous Vegetation	6
16b	*Artemisia nova*/*Poa secunda* Dwarf-shrub Herbaceous Vegetation	Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	8

Table 2-3. Continued

Cluster #	Scientific Class Name	Colloquial Class Name	# of Plots
17a	*Sisymbrium altissimum – Bromus tectorum* Semi-natural Herbaceous Vegetation	Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	7
17b	Remnant Riparian Shrub Herbaceous Vegetation	Remnant Riparian Shrub Herbaceous Vegetation	3
18	*Artemisia tripartita* Shrubland	Three-tip Sagebrush Shrubland	5
19	*Artemisia arbuscula* Dwarf Shrubland	Low Sagebrush Dwarf Shrubland	7
20	*Grayia spinosa* Shrubland	Spiny Hopsage Shrubland	3
21	*Ericameria nana* Dwarf Shrubland	Dwarf Goldenbush Dwarf Shrubland	4
22	*Atriplex confertifolia* Dwarf Shrubland	Shadscale Dwarf Shrubland	3

Regardless of whether these morphological characteristic are a consequence of true genotypic hybridization or of phenotypic expressions of one subspecies or the other in response to different edaphic factors, the individuals exhibiting intermediate morphological characteristics often form stands which are unique in structure when compared to stands of either of the typical subspecies.

In addition to stands typified by big sagebrush individuals expressing intermediate morphological characteristics, we also encountered stands in the field and in our plot data that contained relatively even mixtures of both big sagebrush subspecies. Plots dominated by these mixtures often classified into cluster 2. Shumar and Anderson (1986) described large expanses of the INL Site, which contain stands of both subspecies mixed at a very fine spatial scale. The vertical structure of theses stands is also intermediate between stands dominated by one subspecies or the other. Therefore, cluster 2 was ultimately described as a plant community, or vegetation class, characterized by the dominance of big sagebrush for which the subspecies were mixed and/or hybridized. Thorough descriptions of the big sagebrush plant communities and each of the other 23 plant communities can be found in Appendix D.

Overall, the results of this classification are not highly disparate from those reported for previous classifications. In fact, the most abundant plant communities are very similar when evaluated against comparable classes described by either McBride et al. (1978) or Anderson (1991). The most notable deviations are in the current treatment of the big sagebrush classes as McBride et al. (1978) did not differentiate between subspecies and Anderson (1991) did not address mixes or hybridizations between the subspecies. The current classification also describes a greater variety of green rabbitbrush-dominated shrublands and native grasslands than were described in either of the previous classifications. This result is not unexpected as wildland fire has removed sagebrush from nearly 25% of INL Site area in the time since the previous classifications were completed. Loss of sagebrush due to wildland fire on the INL Site often results in grassland communities and/or communities with a substantial green rabbitbrush component.

A few of the less common plant communities described in previous classifications such as the spiny horsebrush (*Tetradymia canescens*) community described by McBride et al. (1978) and the summer cypress (*Iva axillaris*) community described by Anderson (1991) were not identified in the current classification effort. Those communities likely still exist in distributions somewhat similar to those reported by previous authors; however, we were unable to locate and sample enough distinct and independent stands to be able to classify and adequately characterize them as part of this classification effort. During the field sampling campaign, we also encountered several additional unique and spatially limited plant communities that were not previously described nor were they sampled in conjunction with this classification. We did not characterize these communities because they were often spatially insignificant when compared to the communities which were classified. The uncharacterized communities were dominated by species like gray rabbitbrush, bud sagebrush, greasewood, and antelope bitterbrush.

Finally, crested wheatgrass-dominated plant communities were the only consequential non-native communities described in both previous classifications (McBride et al. 1978, Anderson 1991). The current classification resulted in several additional communities either dominated or co-dominated by non-natives. The additional non-native communities may have been a result of an increased focus on properly classifying non-native communities, and non-native distributions have also likely increased in since the previous classifications were completed. Many of the deviations between this classification and previous classifications, in both native and non-native plant communities, resulted from specific goals related to using the final classification and map to support the CMP.

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3.0 Vegetation Class Mapping

3.1 Introduction

Remote sensing technology has played an integral role mapping the environment, specifically land cover, across various spatial and temporal scales (Townshend 1992). Results from early vegetation mapping studies were visually attractive and generally assumed to be correct because the maps depicted reasonable patterns and distribution of land cover classes (Dicks and Lo 1990). Even though map classification accuracy was only qualitatively evaluated; the ability to map large extents without the logistical constraints of sending field crews to collect data and map regions of comparable area was quickly embraced by many scientists and land managers.

As mapping accuracy assessments shifted from qualitative assessments to quantitative methods it became apparent that most land cover maps did not achieve the mapping accuracies expected, and in many cases were below acceptable levels for management applications (Foody 2002). Even as technology continued to progress and sensors began collecting more spectral bands (i.e., hyperspectral imagery), it was recognized that certain vegetation types or land cover classes can be difficult to map accurately because of spectral similarities (Okin et al. 2001). Image classification of vegetation classes can be challenging in many environments, but arid and semi-arid regions are particularly difficult and pose additional mapping problems (Huete 1988).

Vegetation communities in arid environments tend to have low absolute vegetative cover values, commonly less than 50 percent. Because the area of exposed bare ground can exceed the total vegetative cover, the sensor actually records more spectral information from the ground rather than the plants growing on the surface. In these environments, the image data more likely depict patterns of surface characteristics and soil types rather than vegetation communities. Low vegetative cover values questions the suitability of automated classification algorithms to accurately map vegetation communities distributed across similar soil types.

Automated classification and mapping has become the standard for most image analysis projects and this approach has a number of advantages over traditional photointerpretation techniques. Automated classifications are unbiased and not as significantly influenced by the experience of the image analyst. Automated image classifications are repeatable given similar types of imagery, and do not depend on the same analyst to conducting repeat mapping for temporal comparisons. Automated classifications can also be applied to very large image datasets, whereas comparable manual delineations would be time consuming and correspondingly expensive. One of the underlying assumptions behind automated classification algorithms is each intended map class is spectrally determinate, meaning it has a unique reflectance pattern that does not match or substantially overlap other classes. This assumption is generally not realistic for most environments and particularly sagebrush steppe semi-arid landscapes where different species can appear spectrally similar (Okin et al. 2001).

The potential shortcomings of automated classification algorithms in a sagebrush steppe environment suggested an alternative approach was needed to produce accurate vegetation class boundaries. Long before digital image datasets were available and automated classification algorithms were developed, image analysts relied on traditional aerial photograph interpretation to map the environment. An image analyst intuitively considers a number of variables other than pixel value including; location, size, shape, shadow, tone/color, texture, and pattern (Jensen 2000). More recent advances in automated classification algorithms are now focused on object-oriented classifications that intend to utilize these spatial and contextual variables in an automated strategy. Nonetheless, computer software cannot currently reproduce complex human reasoning and the intuitive interpretation process an analyst utilizes when delineating features in an image.

Long before sophisticated image classifications were developed, landscapes were mapped using manual photointepretation of aerial photography. The traditional photointerpretation mapping process required multiple production steps prior to creating a digital map product. A photo interpreter generally hand drew line boundaries on translucent Mylar overlays fastened to hard-copy photograph prints. Interpretation was aided by the use of a stereoscope and stereo-pair images to view the landscape from a three-dimensional perspective. Stereoscopic interpretation can be extremely valuable across landscapes where communities are distributed along topographic gradients, but does not significantly influence the interpretation of vegetation communities in a relatively flat landscape. Once the delineations were completed, the Mylar sheets were scanned into a digital format, converted from raster to vector format, and georeferenced using control points. Lastly, the vector lines were edited to remove errors (e.g., dangles), edge-matched to adjacent delineations, and the polygon attributes were entered into the database. Current Geographic Information System (GIS) technology provides an avenue to streamline the traditional mapping process by eliminating the interim processing steps described above, and allowing for map production to take place within a georeferenced digital environment.

We understood the possible limitations of automated classification methods and conducted manual photointerpretation of the digital imagery directly within a GIS framework. This approach provides numerous advantages over traditional methods, such as the capability to overlay additional image datasets and ancillary GIS data layers to help identify vegetation class boundaries, and map delineations are automatically georeferenced to a coordinate system while digitizing boundaries. A GIS provides a suite of vector editing tools that allow for quick spatial adjustments to delineations, and we can implement polygon topology rule sets to perform Quality Assurance/Quality Control (QA/QC) of the delineations to ensure spatial accuracy.

3.2 Methods

3.2.1 Digital Imagery

We contracted Horizons, Inc. (now Fugro-Horizons) of Rapid City, SD, to collect high resolution digital imagery across the Idaho National Laboratory (INL) Site. Initial plans for the aerial image collection were postponed due to an extremely dry spring and very little vegetation growth or ‘green-up.’ Following a week of substantial precipitation, we visited the field to investigate the conditions of a variety of vegetation communities. The vegetation responded with some new growth and we anticipated there was enough differential green up among species in various community types that the types would be distinguishable with high resolution aerial imagery. The data collection was immediately rescheduled and imagery was successfully collected on June 15, 2007.

Horizons, Inc. collected digital imagery from an airborne platform operated at a flight altitude of 8839 m (29,000 ft) above the mean terrain elevation producing a ground sample distance (i.e., pixel size) of 1 m. The imagery was collected using a Leica ADS40/SH52 pushbroom sensor. The Leica ADS40 collects four spectral bands in the visible and near-infrared wavelengths with each spectral band precisely coregistered to eliminate color separation (Table 3-1). The image data were delivered in 16-bit format georeferenced to the North American Datum 1983 and Universal Transverse Mercator Zone 12N.

Table 3-1. The spectral band wavelength ranges for the Leica ADS40 pushbroom sensor used to collect digital imagery across the Idaho National Laboratory Site.

Spectral Band	Wavelength (nm)
Blue	430-490
Green	535-585
Red	610-660
Near Infrared	835-885

A total of 88 individual images were collected corresponding to U.S. Geological Survey (USGS) 7.5 minute series quarter-quadrangle boundaries with 30% sidelap and endlap between adjacent image tiles (Figure 3-1). The imagery was orthorectified using existing 10 m USGS National Elevation Dataset (NED) grid data that were modified through the proprietary ISTAR autocorrelation process of point densification to produce a Digital Elevation Model (DEM) with 5 m spatial resolution. The data vendor processed a radiometrically ‘corrected’ mosaic dataset that attempted to smooth the abrupt illumination differences evident between flightlines across the image mosaic. A raw, calibrated radiance mosaic dataset was also produced (Figure 3-2).

There were a few regions of cloud cover and cloud shadows present in the imagery, which prevented the identification of appropriate vegetation class boundaries in these areas. The U.S. Department of Agriculture (USDA) sponsors the National Agricultural Imaging Program (NAIP) which strives to collect high resolution digital imagery across each state on a 3-5 year return interval. These datasets are made publically available and can be downloaded for free as orthorectified compressed county mosaics or as uncompressed quadrangles. In 2004, Idaho NAIP imagery was acquired at 1 m spatial resolution as color imagery without a near-infrared spectral band. A second NAIP image dataset was collected across the State of Idaho in 2009 at 1 m spatial resolution and included a near-infrared band in addition to the three visible bands. We utilized each of these datasets to define class boundaries in the areas where clouds and cloud shadows obscured the ground. The 2009 NAIP imagery also provided updated information in the regions that experienced wildfires after the 2007 project-specific imagery was collected. Some fires do not completely burn the entire area within the perimeter, and imagery after a fire can be used to identify unburned or partially burned patches of intact vegetation.

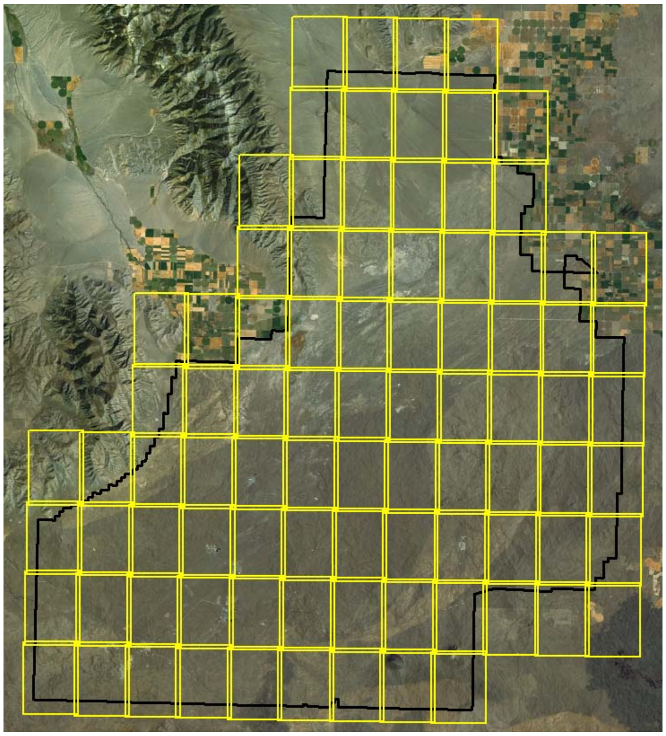


Figure 3-1. The 88 digital image tile boundaries collected at the Idaho National Laboratory Site on June 15, 2007.

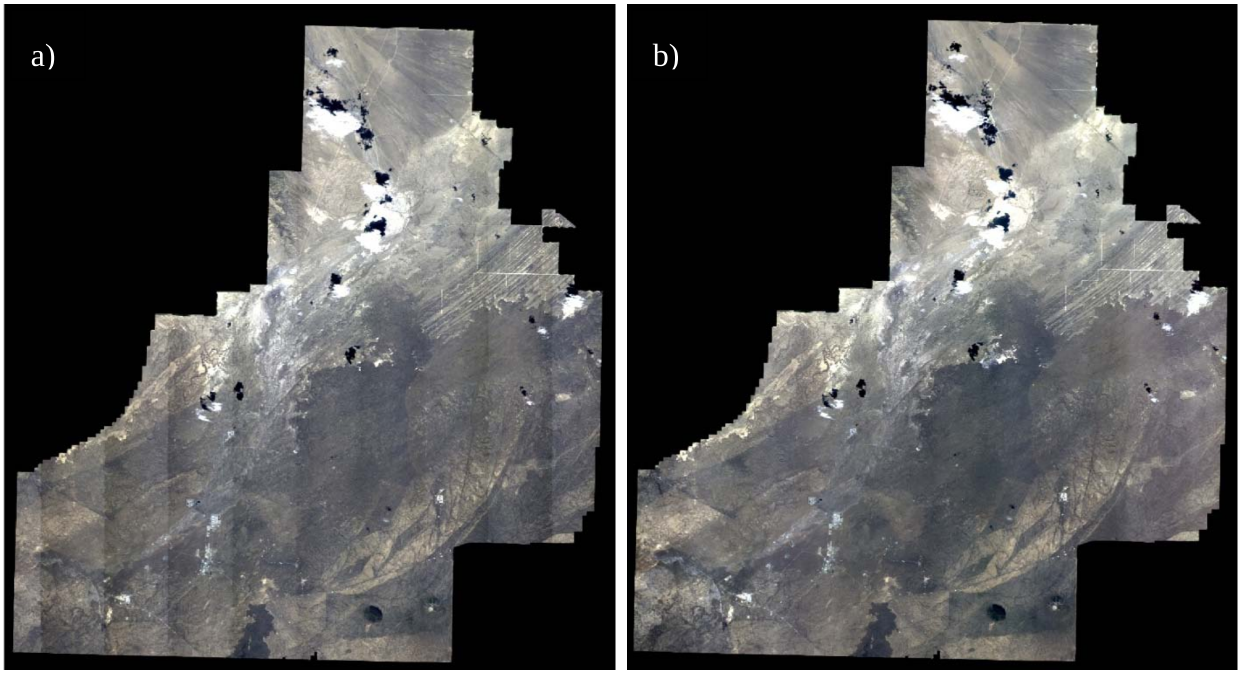


Figure 3-2. a) The original calibrated image mosaic of the Idaho National Laboratory Site collected on June 15, 2007. b) The radiometrically smoothed image mosaic prepared by the data vendor.

3.2.2 Image-Derived Data Layers

There has been a number of vegetation indices developed for identifying vegetation distributions from remotely sensed data (Jensen 2000). We calculated two common vegetation indices to help highlight and interpret vegetation class boundaries in the imagery. The most common vegetation index used today is probably the Normalized Difference Vegetation Index (NDVI) (Rouse et al. 1974). A second commonly used vegetation index is the Soil-adjusted Vegetation Index (SAVI) (Huete 1988). The SAVI is designed to improve NDVI results in regions with large proportions of exposed bare ground, and attempts to remove soil-plant interactions by including a soil calibration factor. The suggested soil adjustment factor of 0.5 was used for this calculation (Heute and Lui 1994).

We also used the raw imagery to calculate spatial texture data layers in Environmental Systems Research Institute (ESRI) ArcGIS®. The texture layers were calculated using a square moving window, and initially we evaluated a number of different statistical measures and window sizes. We compared test results from the Mean, Range, and Standard Deviation block statistics, and also compared 3x3, 5x5, and 7x7 pixel window sizes (Figure 3-3). The Mean statistic was sensitive to the changes in illumination between flightlines present in the raw imagery. The Standard Deviation statistic created results very similar to the Range statistic. As the moving window sizes were increased, abrupt edges became larger and larger. Although this helps highlight edges in the imagery, it blurred the more distinct boundaries created with the 3x3 pixel window. Following our initial review, the 3x3 Range statistic highlighted features of interest that were less evident in the raw imagery, while minimizing the influence from illumination changes across the image. Brighter pixel values represent higher statistic values and can be interpreted as greater pixel heterogeneity. Darker pixel values represent lower statistic values and can be interpreted as more homogenous areas. Figures 3-3b and c both show a dark triangular patch in the bottom center of the screen that is a seeded crested wheatgrass monoculture; the patch is not distinctly visible in the Mean statistic calculation (Figure 3-3a) or the raw imagery. This example is illustrative of how the statistical texture layer helped with the delineation process by accentuating edges that were otherwise more obscure.

3.2.3 Ancillary GIS Data Layers

We used available INL Site GIS data layers during the image delineation process, but many of these datasets are outdated and/or the accuracy and was unknown or questionable. These data layers were referenced by toggling overlapping layers on and off within a GIS to help identify vegetation class boundaries across the imagery or when assigning class attributes to polygons. But when discrepancies were evident between GIS data layers (e.g., a wildfire polygon edges is shifted from the burn edge evident in the imagery), the imagery was considered the most accurate spatial dataset.

Vegetation patterns across a landscape tend to follow the distribution of appropriate soils types. We have a GIS soils data layer for the INL Site, but these data were not specifically produced for the INL based on field studies (refer to Chapter 1 for more details). Consequently, these data layers were of little use helping define vegetation class boundaries.

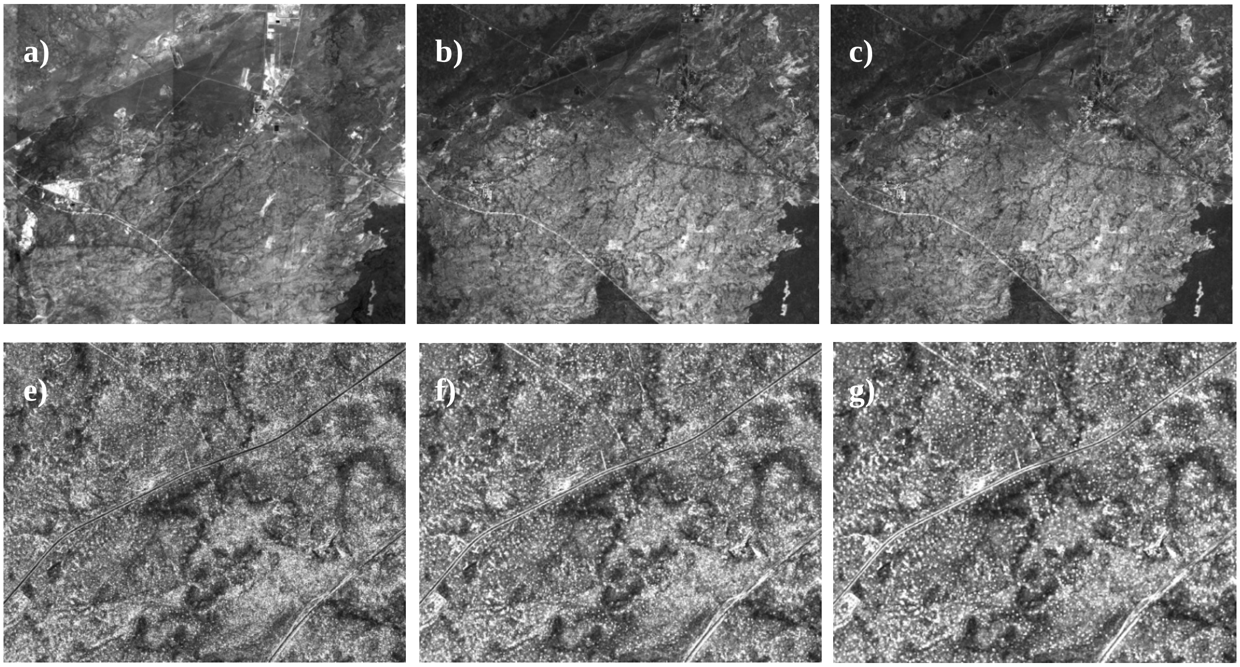


Figure 3-3. Statistical texture results from an image subset of the Idaho National Laboratory Site. a) 3x3 Mean; b) 3x3 Range; and c) 3x3 Standard Deviation. The second row of images represents results from varying the moving window sizes on a different Range texture image subset. e) 3x3 window; f) 5x5 window; and g) 7x7 window.

Topography can also influence patterns of vegetation distribution because aspect affects the amount of incoming solar radiation a community receives and can serve as a surrogate for soil moisture. We mosaicked a 10 m resolution DEM of USGS NED quadrangles for the entire INL Site. We calculated raster layers for Slope, Aspect, and Hillshade (i.e., artificial topographic shading) using the ArcGIS Spatial Analyst® extension's topographic modeling tools. The INL Site does not contain very complex topography and consists primarily of rolling relief caused by surface lava flows. There were some instances where broad topographic relief corresponded to vegetation class boundaries, and where possible we used topographic contours as boundaries between similar classes when the image data where too similar to identify the boundary.

Other than the image-derived data layers, the vector GIS data most useful during the digitizing process were the previous McBride vegetation community map (McBride et al. 1978) and wildfire boundaries. Even though the McBride et al. (1978) map accuracy was never quantified and the map has not been updated for recent wildfires and other landscape changes, it still provided a general basis for identifying spatial patterns for potential vegetation communities present across the INL Site. The most obvious landscape changes have been caused by wildfires and the fire boundary data layers provide distinct edges that were used to help define burned community boundaries.

The INL Site experienced five major wildfires during the course of this project. Two wildfires burned in 2007 after the imagery was collected, but before we started classification or delineation work. Another fire burned in 2008, after we had begun the digitizing process.

Boundaries of the 2007 and 2008 fires were mapped by the INL using satellite imagery or through Global Positioning System (GPS) data collected while walking the containment line perimeter. The fire boundary data was provided to us in GIS shapefile format, and we used the boundary to directly map those patches. Two additional fires burned in 2010 after we completed the vegetation map and collected the field validation data. These fires did not impact the mapping process described here, but considerations for updating the vegetation map based on these vegetation changes are discussed at the end of this chapter (refer to Figure 3-6).

3.2.4 Image Delineations

The vegetation class boundaries were initially delineated using the true-color image and false-color composites, and the goal was to roughly identify the boundaries of broad landscape patterns. The initial draft delineations were produced through manual interpretation and digitizing at a 1:12,000 mapping scale. We used this scale to maintain consistency with the National Park Service (NPS) Vegetation Inventory Program under which the nearby Craters of the Moon National Monument and Preserve (CRMO) was being mapped. One goal was to produce a vegetation map similar to that being produced at CRMO, so classes can be compared and cross-walked within the Eastern Snake River Plain (ESRP) region.

The manual interpretation process resembles traditional photointerpretation mapping methods, but we digitized polygon boundaries directly within a GIS. Working in a GIS eliminates unnecessary mapping steps and enables vector polygons to be managed within a topological environment. We created all vegetation class polygons using tools from the ArcGIS Editor Toolbar. We manually digitized vegetation patch boundaries using the *Sketch Tool* to create new features. When two features shared an adjacent edge, we used the *Trace Tool* with snapping enabled to maintain topology between polygons and then continued to manually draw the remaining outer boundary using the *Sketch Tool*.

We used the digital imagery as the primary data source and many times compared draft boundaries between image data layers (e.g., 2007 INL Site digital imagery and 2004 NAIP imagery) throughout the vegetation mapping process. We initially developed visual associations between known vegetation classes on the ground and their corresponding spectral signatures in the imagery using the 2008 field plot data. Field observations helped verify and refine some draft delineation boundaries. In some areas the distinct class boundary was not obvious and we manually adjusted the display stretch in local regions to accentuate edges. Occasionally, we adjusted the GIS display zoom to coarser scales (e.g., 1:24,000) where broad landscape patterns were more evident. We also considered DEM topographic contours which sometimes helped delineate class boundaries. Once we digitized coarser boundaries, we zoomed back to the original 1:12,000 mapping scale to refine polygon edges where appropriate.

The (21) Dwarf Goldenbush Dwarf Shrubland class was the only class statistically defined but not mapped. Originally, this class was identified using a smaller 3 m x 3 m plot rather than the standard 20 m x 20 m field plot sampled in 2008. This class occurs at spatial scales well below our mapping capabilities, and exposed basalt where this class occurs is black or very dark in the imagery making it nearly impossible to detect vegetation on the surface. Although it was not mapped, the Dwarf Goldenbush Dwarf Shrubland class can commonly be found in small patches (i.e., less than 10 m x 10m) on exposed basalt outcrops throughout much of the INL Site.

There was one special feature we wanted to map with finer detail because the features are obvious in the imagery but the 1:12,000 mapping scale was too coarse to depict the edges accurately. We find basin big sagebrush growing in ephemeral or intermittent stream channels across the INL Site. Basin big sagebrush communities are declining range-wide and are limited in distribution on the INL Site. We have also found pygmy rabbit burrows within these drainage features, and we suspect rabbits may utilize these pathways for movements or migration corridors. A petition to protect pygmy rabbits under the Endangered Species Act (ESA) was recently found to be unwarranted, but they remain a management concern on the INL Site. Mapping this feature will improve the development of predictive habitat models for pygmy rabbits and may assist with the management of this species on the INL Site.

There are five non-vegetation classes and one agricultural class we digitized at a 1:2,000 scale and included in the final map. Anthropogenic features (e.g., paved roads and facilities) and disturbances characterized by little vegetative cover (e.g., gravel and borrow pits) are widespread throughout the INL Site, and although these features encompass a small total area, they bisect vegetation classes and can contribute to habitat fragmentation. The vegetation map data will contribute to a number of ongoing and future studies on the INL Site, and we wanted to make sure anthropogenic features are not included in the actual vegetation polygons where they could negatively impact other studies (e.g., site selection). Here is a summary of the special feature classes which were mapped but not identified as part of the classification effort:

Agriculture - The INL Site is bordered by agricultural fields near the northeast edge of the Site and also along the west-central boundary. In a number of locations it appears adjacent agricultural field have expanded and now overlap the INL Site boundary slightly. Even though the *Agriculture* class is actually vegetation, it does not represent a natural community present on the INL Site and is denoted with a special feature class code.

Industrial Facility - This map class represents the major active Site facilities that contain large buildings, warehouses, cooling towers, etc. Examples of *Industrial Facilities* are the Materials and Fuels Complex (MFC) and the Central Facilities Area (CFA).

Other Facility - This map class includes other facilities that are not considered Industrial Facilities and may have been decommissioned. These features tend to lack a large number of buildings and structures compared to the *Industrial Facility* class. Examples of *Other Facilities* include the EBR-1 historical site and the CFA main gun range.

Borrow/Gravel Pits - This map class represents the INL Site active and inactive borrow pits and gravel pits. We identified these locations from the most recent GIS data layer. The location boundaries were digitized and edited using the imagery to define the actual extent. There are a number of smaller borrow sources roadside along the State and Federal Highways that are visible in the imagery but are not included in this map class.

Big Lost River Channel - The Big Lost River (BLR) enters the INL Site from the southwest and flows north past CFA and Idaho Nuclear Technology & Engineering Center (INTEC) ending at an ephemeral wetland known as the BLR Sinks. The BLR channel is small in width (approximately 10-20 m wide) and proved difficult to delineate at a 1:12,000 scale. The BLR channel is an important feature on the INL Site, and although it doesn’t contain water annually, it contains some small patches of remnant riparian vegetation.

Paved Roads - This map class represents all of the major paved roads across the INL Site. These include paved roads within the secure area of the INL Site as well as State and Federal Highway system that crosses the INL Site. This map layer does not include any gravel or two-track T-roads present throughout the INL Site.

3.2.5 Assigning Mapped Polygons to Vegetation Communities

After we completed the draft delineations for the entire INL Site, we made numerous visits to the field to investigate the classes present on the ground. Typically ground data are used to help train automated algorithms or assist with assigning vegetation classes to mapped polygons. The field data collected to support the statistical community classification were limited because the goal was to collect fine scale quantitative cover data and not to provide widespread training data to assist with the mapping portion of the project. Our field observations were made mostly from roads and were independent of the accuracy assessment plot locations. In most cases hundreds of meters separated the closest accuracy plot from our observation points. We had to generalize our field observations to the entire extent of the polygon even though we were limited in the amount of area we could see from the ground.

The first important observation we made in the field was the initial draft delineations captured too much detail and many times the same vegetation community extended across multiple map polygons that appeared different in the imagery (Figure 3-4). Based on field observations, we were able to better understand how the subtle changes in imagery corresponded to changes in patterns of vegetation communities on the ground. We reviewed all delineations and combined adjacent polygons using the information we observed on the ground to guide the decision making process.

Another important observation we made was that the majority of mapped polygons contained multiple vegetation communities present on the ground forming multi-class complexes. We defined the community classes based on analysis of data collected from 20 m x 20 m plots which was substantially smaller area than the minimum mapping unit. The mapped polygons were generally at least an order of magnitude larger and it was common to find polygons that would include more than one vegetation community within the boundary. We generally found mapped polygon boundaries matched observable boundaries in the field and multi-class complexes either intermixed evenly or formed a patchwork mosaic within the mapped polygon area. In some cases, primarily in wildfire burn scars, there were nearly even mixtures of more than two vegetation community classes. We limited map polygons to only two-class complexes in an attempt to minimize the number of unique map classes. We identified the two most common communities as we drove through individual large polygons, and assigned those to the map polygon although additional communities were occasionally observed on the ground.

Even though assigning map polygons to two-class complexes complicated the accuracy assessment, we wanted to provide potential map users with as much information as possible. In areas where mapped polygons were assigned to a two-class complex, both classes could be observed on the ground and these mixed classes are visibly different than either single vegetation class. The two-class complexes provide some insight to map users about the possible vegetation species and composition variability expected in map polygons.

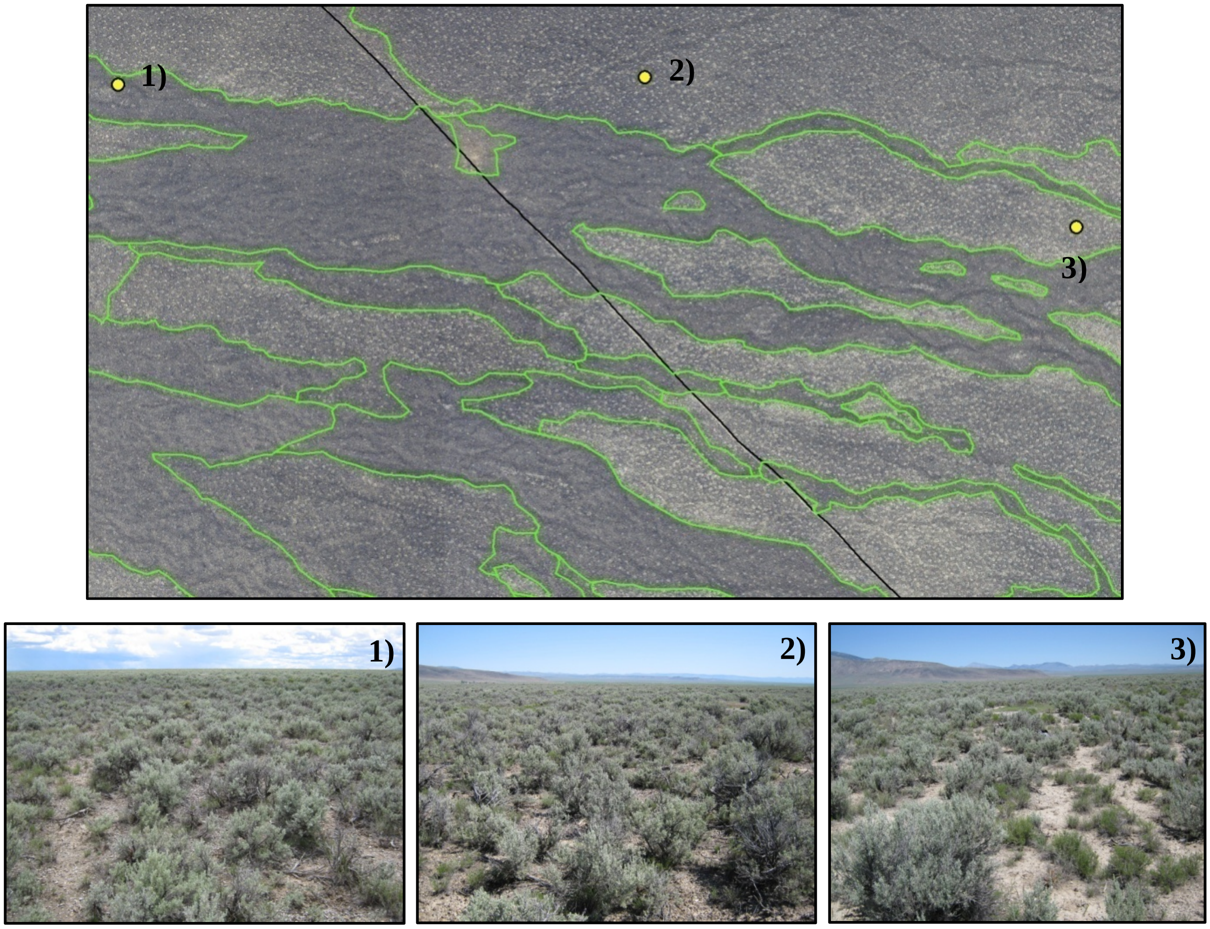


Figure 3-4. Draft image delineations (green polygons) on the Idaho National Laboratory Site plotted on a true-color image composite. The locations labeled 1-3 represent field investigation sites where we took representative photographs. The photographs that correspond to each of the field locations are numbered below the imagery. Although the three locations appear to have different tones and texture in the imagery, and were initially delineated as separate communities, each site was the same (7) Wyoming Big Sagebrush Shrubland class on the ground. All polygons shown in the first image were consequently collapsed into a single large polygon for this region.

3.2.6 Final Map Polygons

Once we completed the final edits and revisions to the draft polygons, we implemented topology to perform the final QA/QC of the map polygons. GIS topology refers to a set of rules that defines the spatial relationships among and between point, line, and polygon geometry. The ESRI File Geodatabase offers a suite of topology rules that can be selected to validate the spatial accuracy of GIS data. We selected two topology rules, *Must Not Have Gaps* and *Must Not Overlap*, and ran topology validation on the final map polygons. These topology rules test whether polygons erroneously overlap one another or have small gaps between adjacent polygons that should share a common edge. The validation report is summarized in a database table that allows each individual error to be viewed and corrected. We manually edited all vector errors using the ArcGIS Editor Toolbar, and topology validation was rerun to verify all geometric errors were fixed.

During the imagery flight planning process in 2007, we buffered the INL Site GIS boundary by 100 m to ensure we confidently imaged the entire site. Map polygons were originally delineated across the entire image mosaic extent which included the additional area around the boundary. We clipped the final polygons to the INL Site GIS boundary at the end of the mapping process.

3.3 Results and Discussion

The final vegetation map contains a total of 2038 polygons, of which 1964 (96.4%) represent vegetation communities (Appendix E & F). The remaining 74 polygons (3.6%) represent non-vegetation or agriculture classes we included in the map. The non-vegetation map classes represented a total area of 21.9 km^2 (5405 acres) with the Paved Roads and Industrial Facilities being the most common non-vegetation map class. We generally maintained a minimum mapping unit of 0.0020 km^2 (0.5 acres), but we ended up with some small polygons right near the INL Site boundary and also smaller patches of vegetation that were the basin big sagebrush special features digitized at a 1:2,000 scale. The smallest mapped polygon, not part of a special feature or the edge of the INL Site, is 0.0021 km^2 (0.52 acres). The largest polygon we mapped is 236.3 km^2 (58,399.6 acres) located in the undisturbed interior portion of the INL Site. The mean area for all vegetation map polygons is 1.1 km^2 (286.8 acres).

A total of 127 vegetation map classes were produced when including all two-class community complexes (Table 3-2). Of the 127 total map classes, 30 classes (23.6 %) contain only a single polygon and these classes encompass 87.6 km^2 (21,637 acres) or 3.8% of the map area. Seventy-six map classes (59.8%) contain five or fewer polygons representing 261.7 km^2 (64,661 acres) or 11.4% of the map area. Even though there were a large number of vegetation classes and complexes mapped, the majority of those classes are limited in frequency and distribution. The remaining 51 map classes contain the majority of mapped area on the INL Site (about 85%) (Appendix E & F).

Twenty-two map classes were stand-alone communities as originally defined through statistical analysis and were not mapped in a complex with another class. The stand-alone map classes represented 45.7% of the INL Site area comprised of 1135 polygons (55.8% of the total). Nearly half the INL Site area was mapped as single community classes and the most common stand-alone community was the (2) Big Sagebrush Shrubland class.

Table 3-2. Vegetation map class summary for the Idaho National Laboratory Site.

Map Class	Total Area (acres)	Total Area (km²)	# of Polygons	Mean Polygon Area (acres)
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	3672	20.8	16	229
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(3)** Needle and Thread Herbaceous Vegetation	7682	31.1	7	1097
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	13	0.1	3	4
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(12)** Indian Ricegrass Herbaceous Vegetation	1836	7.4	7	262
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	894	3.6	4	224
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(14)** Great Basin Wildrye Herbaceous Vegetation	46	0.2	1	46
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(16a)** Sandberg Bluegrass Herbaceous Vegetation	1374	5.6	4	343
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(16b)** Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	56	0.2	1	56
(1/9) Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	3165	12.8	9	352
(2) Big Sagebrush Shrubland	117365	475.0	297	395
(2) Big Sagebrush Shrubland and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub	6981	28.3	63	111
(2) Big Sagebrush Shrubland and **(3)** Needle and Thread Herbaceous Vegetation	1591	6.4	13	122
(2) Big Sagebrush Shrubland and **(4a)** Green Rabbitbrush Shrubland	13129	53.1	12	1094
(2) Big Sagebrush Shrubland and **(4b)** Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation	26721	108.1	9	2969
(2) Big Sagebrush Shrubland and **(5)** Green Rabbitbrush - Winterfat Shrubland	2223	9.0	14	159
(2) Big Sagebrush Shrubland and **(8)** Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation	764	3.1	4	191
(2) Big Sagebrush Shrubland and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	6685	27.1	26	257
(2) Big Sagebrush Shrubland and **(11ab)** Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	411	1.7	3	137
(2) Big Sagebrush Shrubland and **(12)** Indian Ricegrass Herbaceous Vegetation	2567	10.4	10	257
(2) Big Sagebrush Shrubland and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	3735	15.1	5	747
(2) Big Sagebrush Shrubland and **(15)** Sickle Saltbush Dwarf Shrubland	727	2.9	5	145
(2) Big Sagebrush Shrubland and **(16b)** Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	959	3.9	7	137
(2) Big Sagebrush Shrubland and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	1833	7.4	5	367
(2) Big Sagebrush Shrubland and **(18)** Three-tip Sagebrush Shrubland	7390	29.9	11	672
(2) Big Sagebrush Shrubland and **(20)** Spiny Hopsage Shrubland	47	0.2	1	47
(2) Big Sagebrush Shrubland and **(22)** Shadscale Dwarf Shrubland	28	0.1	1	28
(3) Needle and Thread Herbaceous Vegetation	1130	4.6	4	283
(3) Needle and Thread Herbaceous Vegetation and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	59	0.2	4	15
(3) Needle and Thread Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	413	1.7	2	206
(4a) Green Rabbitbrush Shrubland	10401	42.1	26	400
(4a) Green Rabbitbrush Shrubland and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	10394	42.1	24	433

Table 3-2. Continued.

Map Class	Total Area (acres)	Total Area (km²)	# of Polygons	Mean Polygon Area (acres)
(4a) Green Rabbitbrush Shrubland and **(3)** Needle and Thread Herbaceous Vegetation	7076	28.6	23	308
(4a) Green Rabbitbrush Shrubland and **(4b)** Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation	11138	45.1	5	2228
(4a) Green Rabbitbrush Shrubland and **(5)** Green Rabbitbrush - Winterfat Shrubland	309	1.3	2	155
(4a) Green Rabbitbrush Shrubland and **(8)** Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation	4422	17.9	16	276
(4a) Green Rabbitbrush Shrubland and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	1077	4.4	3	359
(4a) Green Rabbitbrush Shrubland and **(11ab)** Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	370	1.5	1	370
(4a) Green Rabbitbrush Shrubland and **(12)** Indian Ricegrass Herbaceous Vegetation	14366	58.1	9	1596
(4a) Green Rabbitbrush Shrubland and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	9	0.0	2	4
(4a) Green Rabbitbrush Shrubland and **(14)** Great Basin Wildrye Herbaceous Vegetation	64	0.3	2	32
(4a) Green Rabbitbrush Shrubland and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	1550	6.3	4	387
(4b) Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation	1114	4.5	5	223
(4b) Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	2939	11.9	18	163
(4b) Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation and **(8)** Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation	3589	14.5	5	718
(4b) Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	241	1.0	1	241
(4b) Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation and **(11ab)** Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	17345	70.2	11	1577
(5) Green Rabbitbrush - Winterfat Shrubland	1727	7.0	30	58
(5) Green Rabbitbrush - Winterfat Shrubland and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	4756	19.2	22	216
(5) Green Rabbitbrush - Winterfat Shrubland and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	727	2.9	1	727
(5) Green Rabbitbrush - Winterfat Shrubland and **(12)** Indian Ricegrass Herbaceous Vegetation	5892	23.8	10	589
(5) Green Rabbitbrush - Winterfat Shrubland and **(15)** Sickle Saltbush Dwarf Shrubland	3488	14.1	36	97
(5) Green Rabbitbrush - Winterfat Shrubland and **(16b)** Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	141	0.6	1	141
(5) Green Rabbitbrush - Winterfat Shrubland and **(22)** Shadscale Dwarf Shrubland	1916	7.8	10	192
(6) Basin Big Sagebrush Shrubland	7782	31.5	262	30
(6) Basin Big Sagebrush Shrubland and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	1362	5.5	2	681
(6) Basin Big Sagebrush Shrubland and **(3)** Needle and Thread Herbaceous Vegetation	1079	4.4	1	1079
(6) Basin Big Sagebrush Shrubland and **(5)** Green Rabbitbrush - Winterfat Shrubland	232	0.9	1	232
(6) Basin Big Sagebrush Shrubland and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	301	1.2	1	301
(6) Basin Big Sagebrush Shrubland and **(14)** Great Basin Wildrye Herbaceous Vegetation	277	1.1	3	92
(6) Basin Big Sagebrush Shrubland and **(17b)** Remnant Riparian Shrub Herbaceous Vegetation	29	0.1	1	29
(7) Wyoming Big Sagebrush Shrubland	91564	370.5	223	411
(7) Wyoming Big Sagebrush Shrubland and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	9147	37.0	34	269
(7) Wyoming Big Sagebrush Shrubland and **(3)** Needle and Thread Herbaceous Vegetation	911	3.7	4	228

Table 3-2. Continued.

Map Class	Total Area (acres)	Total Area (km²)	# of Polygons	Mean Polygon Area (acres)
(7) Wyoming Big Sagebrush Shrubland and **(4a)** Green Rabbitbrush Shrubland	10990	44.5	34	323
(7) Wyoming Big Sagebrush Shrubland and **(4b)** Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation	408	1.7	1	408
(7) Wyoming Big Sagebrush Shrubland and **(5)** Green Rabbitbrush - Winterfat Shrubland	20812	84.2	59	353
(7) Wyoming Big Sagebrush Shrubland and **(8)** Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation	177	0.7	3	59
(7) Wyoming Big Sagebrush Shrubland and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	6073	24.6	49	124
(7) Wyoming Big Sagebrush Shrubland and **(12)** Indian Ricegrass Herbaceous Vegetation	964	3.9	16	60
(7) Wyoming Big Sagebrush Shrubland and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	560	2.3	1	560
(7) Wyoming Big Sagebrush Shrubland and **(14)** Great Basin Wildrye Herbaceous Vegetation	57	0.2	1	57
(7) Wyoming Big Sagebrush Shrubland and **(15)** Sickle Saltbush Dwarf Shrubland	1590	6.4	10	159
(7) Wyoming Big Sagebrush Shrubland and **(16b)** Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	901	3.6	6	150
(7) Wyoming Big Sagebrush Shrubland and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	398	1.6	4	99
(7) Wyoming Big Sagebrush Shrubland and **(18)** Three-tip Sagebrush Shrubland	13083	52.9	1	13083
(7) Wyoming Big Sagebrush Shrubland and **(19)** Low Sagebrush Dwarf Shrubland	981	4.0	2	491
(7) Wyoming Big Sagebrush Shrubland and **(20)** Spiny Hopsage Shrubland	1231	5.0	8	154
(7) Wyoming Big Sagebrush Shrubland and **(22)** Shadscale Dwarf Shrubland	469	1.9	5	94
(8) Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation	216	0.9	4	54
(8) Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	9880	40.0	13	760
(8) Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation and **(3)** Needle and Thread Herbaceous Vegetation	7597	30.7	10	760
(8) Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	1442	5.8	1	1442
(8) Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	1194	4.8	7	171
(8) Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	274	1.1	2	137
(10) Crested Wheatgrass Semi-natural Herbaceous Vegetation	16382	66.3	107	153
(10) Crested Wheatgrass Semi-natural Herbaceous Vegetation and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	6	0.0	2	3
(10) Crested Wheatgrass Semi-natural Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	51	0.2	1	51
(11ab) Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	216	0.9	3	72
(11ab) Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	438	1.8	1	438
(11c) Utah Juniper Wooded Shrub and Herbaceous Vegetation	1229	5.0	33	37
(11c) Utah Juniper Wooded Shrub and Herbaceous Vegetation and **(2)** Big Sagebrush Shrubland	940	3.8	8	118
(11c) Utah Juniper Wooded Shrub and Herbaceous Vegetation and **(11ab)** Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	56	0.2	5	11
(11c) Utah Juniper Wooded Shrub and Herbaceous Vegetation and **(16b)** Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	3443	13.9	7	492

Table 3-2. Continued.

Map Class	Total Area (acres)	Total Area (km²)	# of Polygons	Mean Polygon Area (acres)
(11c) Utah Juniper Wooded Shrub and Herbaceous Vegetation and **(18)** Three-tip Sagebrush Shrubland	1002	4.1	4	251
(11d) Utah Juniper Woodland	909	3.7	48	19
(11d) Utah Juniper Woodland and **(2)** Big Sagebrush Shrubland	82	0.3	1	82
(11d) Utah Juniper Woodland and **(11ab)** Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	28	0.1	1	28
(11d) Utah Juniper Woodland and **(11c)** Utah Juniper Wooded Shrub and Herbaceous Vegetation	681	2.8	1	681
(11d) Utah Juniper Woodland and **(16b)** Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	942	3.8	4	236
(12) Indian Ricegrass Herbaceous Vegetation	159	0.6	4	40
(12) Indian Ricegrass Herbaceous Vegetation and **(3)** Needle and Thread Herbaceous Vegetation	17224	69.7	26	662
(12) Indian Ricegrass Herbaceous Vegetation and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	43	0.2	2	22
(12) Indian Ricegrass Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	447	1.8	4	112
(13) Cheatgrass Semi-natural Herbaceous Vegetation	397	1.6	28	14
(13) Cheatgrass Semi-natural Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	226	0.9	5	45
(14) Great Basin Wildrye Herbaceous Vegetation	153	0.6	6	26
(14) Great Basin Wildrye Herbaceous Vegetation and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	516	2.1	1	516
(14) Great Basin Wildrye Herbaceous Vegetation and **(13)** Cheatgrass Semi-natural Herbaceous Vegetation	1029	4.2	5	206
(14) Great Basin Wildrye Herbaceous Vegetation and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	531	2.1	13	41
(15) Sickle Saltbush Dwarf Shrubland	257	1.0	9	29
(15) Sickle Saltbush Dwarf Shrubland and **(1/9)** Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	209	0.8	2	104
(15) Sickle Saltbush Dwarf Shrubland and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	69	0.3	1	69
(15) Sickle Saltbush Dwarf Shrubland and **(16a)** Sandberg Bluegrass Herbaceous Vegetation	84	0.3	1	84
(16a) Sandberg Bluegrass Herbaceous Vegetation	33	0.1	1	33
(16b) Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	940	3.8	13	72
(16b) Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation and **(11ab)** Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	93	0.4	1	93
(16b) Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation and **(12)** Indian Ricegrass Herbaceous Vegetation	114	0.5	6	19
(17a) Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	101	0.4	5	20
(18) Three-tip Sagebrush Shrubland and **(17a)** Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	212	0.9	2	106
(19) Low Sagebrush Dwarf Shrubland	1624	6.6	4	406
(19) Low Sagebrush Dwarf Shrubland and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	105	0.4	1	105
(19) Low Sagebrush Dwarf Shrubland and **(11ab)** Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	49	0.2	1	49
(20) Spiny Hopsage Shrubland	67	0.3	2	33
(20) Spiny Hopsage Shrubland and **(16b)** Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	140	0.6	2	70
(22) Shadscale Dwarf Shrubland	962	3.9	5	192
(22) Shadscale Dwarf Shrubland and **(10)** Crested Wheatgrass Semi-natural Herbaceous Vegetation	269	1.1	3	90
(22) Shadscale Dwarf Shrubland and **(15)** Sickle Saltbush Dwarf Shrubland	563	2.3	1	563

The (2) Big Sagebrush Shrubland class contains the greatest amount of area on the INL Site with 475 km^2 representing 20.6% of the map area. The second largest map class is the (7) Wyoming Big Sagebrush Shrubland with 370.6 km^2 mapped representing 16.1 % of the map area. Some other map classes may have a greater number of polygons, but these two stand-alone sagebrush classes are by far the largest on the map and combined represent 36.7% of the total mapped area. The largest map class that does not contain a sagebrush component is the Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation (4b) and Bluebunch Wheatgrass-Sandberg Bluegrass Herbaceous Vegetation (11ab) class complex which covers 70.2 km^2 representing 3% of the map area.

The big sagebrush classes were found to most often complex with other vegetation classes. The (7) Wyoming Big Sagebrush Shrubland class had the greatest number of different map complexes with 17, and the (2) Big Sagebrush Shrubland class was a close second with 16 different map complexes. The third and fourth largest map classes contain Class 2 and Class 7 as a complex, respectively. The (2) Big Sagebrush Shrubland class and (4b) Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation class covers 108.1 km^2 (4.7%), and the (7) Wyoming Big Sagebrush Shrubland and (5) Green Rabbitbrush-Winterfat Shrubland covers 84.2 km^2 (3.7%).

Two vegetation classes defined through statistical analyses were only mapped in one polygon and one class was not mapped at all. The (16a) Sandberg Bluegrass Herbaceous Vegetation class was only mapped one time as a stand-alone class covering 33 acres (0.1 km^2). The (17b) Remnant Riparian Shrub Herbaceous Vegetation class was only mapped a single time and was in a complex with the (6) Basin Big Sagebrush class in the vicinity of the Birch Creek historical channel covering 29 acres (0.1 km^2). The (17b) Remnant Riparian Shrub Herbaceous Vegetation class also occurs sporadically along the BLR channel, but is rarely large enough to be identified in imagery or form communities that would key to this class in the field. The (21) Dwarf Goldenbush Dwarf Shrubland class was not mapped at all due to the small scale at which patches occur, as discussed above. Several classes that were only represented by one or a few small polygons likely occur as small patches elsewhere, but tend to occur at a scale smaller than was detectable for this project.

3.3.1 INL Site Vegetation Map Comparisons

The new INL Site vegetation community map provides greater detail than previous vegetation mapping efforts (Figure 3-5). The McBride et al. (1978) map contained a total of 103 polygons across the INL Site, and by comparison the new INL Site vegetation map now contains 2038 polygons. The McBride map included 21 classes, while some classes did not actually represent vegetation communities (e.g., lake and dunes). The new INL Site map has 22 stand-alone map classes, but the contribution from two-class complexes resulted in a total of 127 vegetation map classes. The majority of two-class complexes are limited in size and distribution; however, they provide the map user with more information than if we had forced each map polygon into a single map class. Both of these maps are comprised of polygons that cover contiguous patches across the landscape, however, the McBride map polygons were very broad and encompass large diverse expanses of the INL Site that are generalized to a single map class.

A more recent INL Site vegetation map was produced through automated classifications of Landsat satellite imagery with 30 m pixel sizes (Kramber et al. 1992). The Landsat-based map contained 23 classes and a number of these were not vegetation classes (e.g., mountains, old lava, new lava, shadow, unknown, etc.). Pixel-based classifications tend to result in a 'salt-and-pepper' appearance where pixel level variability results in map classes that do not form contiguous areas. Manual delineations can ignore fine scale variability and accept that specific locations within polygons may differ slightly than the defined polygon class.

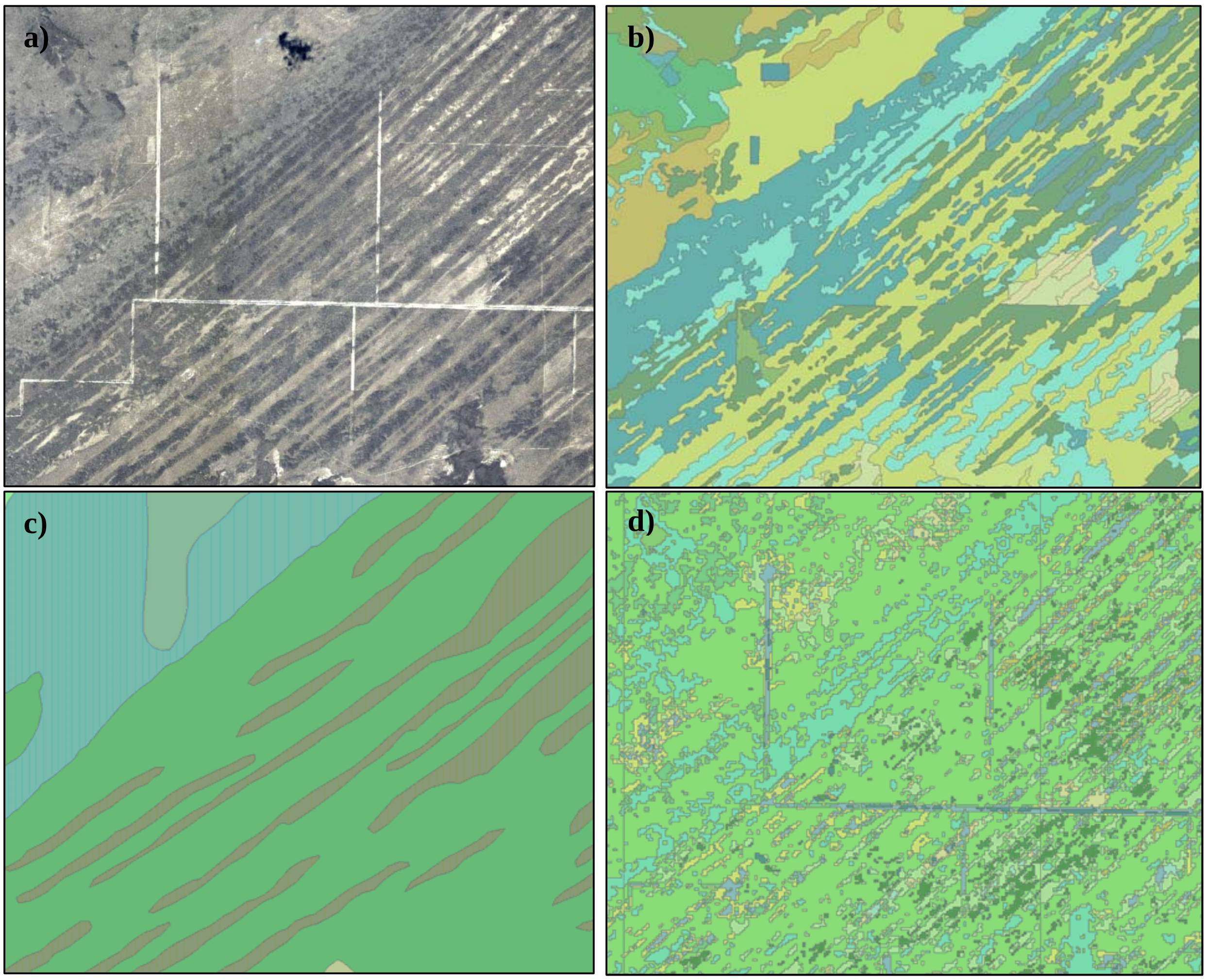


Figure 3-5. An example map subset of an area of the Idaho National Laboratory (INL) Site where there is a lot of spatial variability in vegetation communities. Each map example represents the same scale and extent. a) The raw true-color display of the subset area from the 2007 digital imagery. b) The new 2010 INL Site vegetation map. c) The McBride et al. (1978) vegetation map. d) The Landsat-based INL Site vegetation map described in Kramber et al. (1992). Note: the colors displayed in each tile are default colors assigned in the Geographic Information System, and differences between class colors are not intended to be interpreted as different communities between maps.

3.3.2 Pending Updates to the Vegetation Map

The vegetation class map should be considered a dynamic dataset that requires consistent updating when changes occur across the INL Site. Anthropogenic disturbances and development in addition to natural disturbances can cause significant changes to the landscape and vegetation communities. The INL Site vegetation map was finished, the field validation data were collected, and map accuracy statistics were calculated when the Jefferson Fire burned about 326.7 km^2 (80,729 acres) of the INL Site on July 13, 2010. About a month later on August 28, 2010, the Middle Butte Fire burned approximately 56 km^2 (14,058 acres) across the southern region of the INL Site. Satellite image analysis has not been completed for the Middle Butte fire, but the general perimeter was mapped with a helicopter collecting GPS perimeter data. The Jefferson Fire intersected some portion of 147 map polygons and we estimate the Middle Butte Fire intersected 67 map polygons (Figure 3-6). Because of the fires, the vegetation information associated with those polygons is now outdated. We suggest waiting until the first growing season post-fire before assigning any vegetation classes to new mapped boundaries.

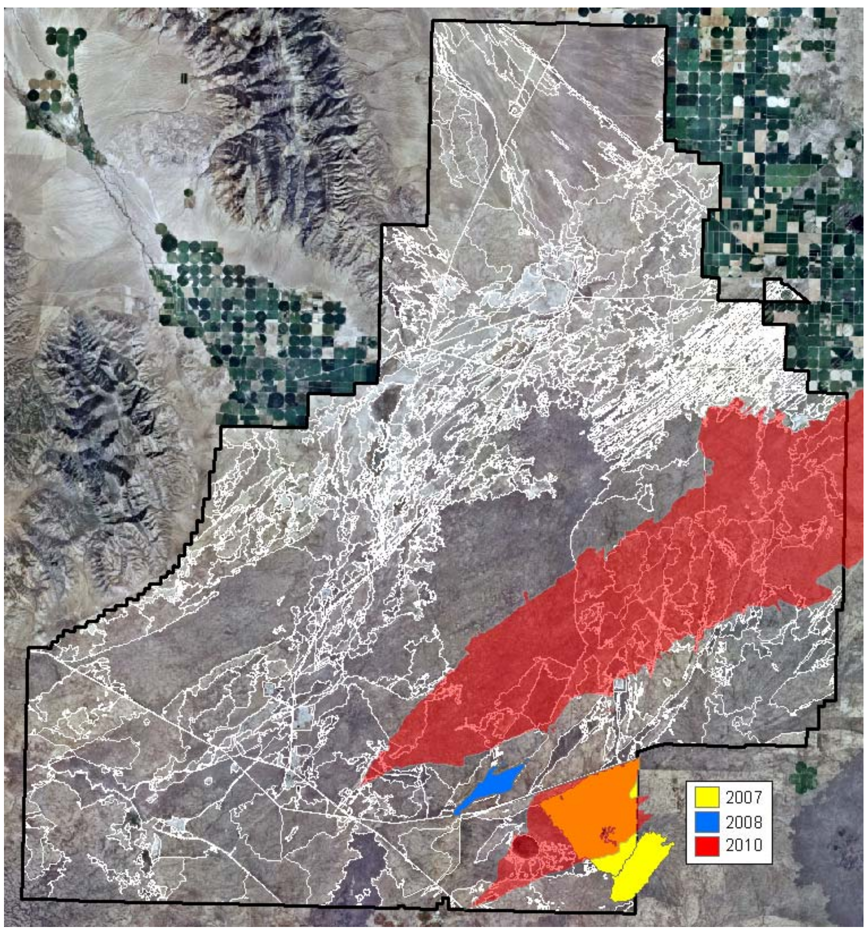


Figure 3-6. Major wildland fire boundaries that occurred on the Idaho National Laboratory Site during the vegetation mapping project. The vegetation classes are delineated in white. The 2010 fires burned after the map was completed and those areas are now outdated.

4.0 Map Accuracy Assessment

4.1 Introduction

Early remote sensing applications produced visually attractive map products, but quantitative accuracy assessment of the mapping results was typically an afterthought (Jensen 1996). Classifying or mapping imagery can be challenging, however the collection of quality ground validation data and the corresponding accuracy assessment may be the most difficult step in the image classification process (Congalton and Green 1999). The goal of any accuracy assessment is to provide the map user with all of the information needed to interpret map errors and assess what implication those errors may have on intended applications. It is important that the appropriate measures of accuracy are selected, as some metrics may have insignificant bearing on project goals (Stehman 1997). We provide a brief discussion of accuracy assessment topics below, including a general overview of the error matrix and conceptual examples of accuracy metrics, fuzzy set theory, and statistical considerations for designing accuracy assessment surveys.

4.1.1 The Error Matrix

One of the fundamental elements of a mapping project is an independent accuracy assessment which adds validity to the project and provides a basis for evaluating the utility of the map for potential applications. There have been a number of proposed statistical methods for validating image classification accuracy, but the error matrix remains the most commonly used method to calculate map accuracies and serves as the basis for most descriptive and analytical statistics (Congalton 1991, Congalton and Green 1999). The error matrix, also known as a confusion matrix or contingency table, is a square array organized in rows and columns where predicted data is compared to measured data through cross-tabulation. The columns in an error matrix represent the reference data collected on the ground, and the rows in an error matrix represent the classified (or map) data.

The error matrix supports the calculation of numerous measures of map and class accuracy. The most commonly reported measures of classification accuracy are the user’s accuracy, producer’s accuracy, and overall accuracy. User’s accuracy represents the probability that a classified image pixel or map polygon is actually that category on the ground (Story and Congalton 1986). The complement of user’s accuracy represents a measure of the commission error rate. For example, if the user’s accuracy for the (19) Low Sagebrush Dwarf Shrubland is 80%, the commission error rate for this class is 20%. Producer’s accuracy represents the probability that a true positive location on the ground is correctly classified (Congalton and Green 1999). The complement of producer’s accuracy can be interpreted as an omission error rate. Conceptually, we can consider a scenario where the (7) Wyoming Big Sagebrush map class has a calculated user’s accuracy of 60% and a producer’s accuracy of 85%. This means a person using the map would only find the Wyoming Big Sagebrush community to be present 60% of the time map polygons are visited in the field. From the map producer’s perspective, 85% of the time Wyoming Big Sagebrush is present, it is mapped correctly. In other words, 85% of the Wyoming Big Sagebrush communities on the ground have been correctly mapped as Wyoming Big Sagebrush, but only 60% of polygons mapped as Wyoming Big Sagebrush are actually Wyoming Big Sagebrush. Overall accuracy provides a measure of the agreement among all map classes and reference data and serves as a single metric that collectively represents the entire classified map (Congalton and Green 1999). One critique of the overall accuracy metric is that it does not account for agreement between map and reference data that can occur by chance alone.

Cohen (1960) introduced a discrete multivariate technique called the Kappa coefficient as a novel method to evaluate overall map accuracy which allows for compensation due to chance agreement. Calculation of the Kappa coefficient results in a KHAT statistic which measures the agreement between predicted and reference data with values ranging from -1 to +1. KHAT values are generally expected to be positive since a positive correlation between the map and reference data is assumed. Landis and Koch (1977) described three general ranges for KHAT: a value greater than 0.80 indicates strong agreement; a value between 0.40 and 0.80 indicates moderate agreement; and a value below 0.40 represents poor agreement. The Kappa coefficient can also be used to test for statistical significance and comparisons between different classifications and corresponding matrices (Rosenfield and Fitzpatrick-Lins 1986).

4.1.2 Fuzzy Set Theory

Thematic maps typically consist of “hard” classifications where every image pixel or map polygon is assigned to a single class. Hard classification refers to the idea that each image pixel or map polygon is assigned to a single map class regardless of the variability present within the pixel. The downfall of this approach is the majority of image pixels are actually mixed pixels of multiple surface features (e.g., vegetation communities), and rarely does a pixel represent a perfect match to the class it is assigned to. Thematic maps generally fail to capture the inherent fine-scale mixtures within a pixel, and fuzzy sets enable these mixtures to be embraced and maintained in the map.

Zadeh (1965) first introduced the original fuzzy set concept for mathematical sets that allow degrees of memberships rather than traditional binary membership (belongs or does not belong). Gopal and Woodcock (1994) introduced the concept of using fuzzy set theory as an improvement for evaluating thematic map accuracy. As an alternative to hard classification of single-class membership for each pixel or polygon, fuzzy set theory has been used to allow multi-class membership when there are degrees of ‘correctness’ rather than strict right or wrong comparison between map and validation data.

Gopal and Woodcock (1994) compared and analyzed the qualitative responses from numerous experts during map accuracy assessments, and recognized that not only were “absolutely right” and “absolutely wrong” consistently distinguished, but three intermediate descriptive categories were identified as well. This resulted in the development of a five-point linguistic scale to encompass the range of qualitative categories that map accuracy experts collectively consider:

1) **Absolutely Wrong:** This answer is absolutely unacceptable. Very wrong.
2) **Understandable but Wrong:** Not a good answer. There is something about the site that makes the answer understandable but there is clearly a better answer. This answer would pose a problem for the users of the map. Not Right.
3) **Reasonable or Acceptable Answer:** Maybe not the best possible answer but it is acceptable. This answer does not pose a problem to the user if it is seen on the map. Right.
4) **Good Answer:** Would be happy to find this answer given on the map. Very right.
5) **Absolutely Right:** No doubt about the match. Perfect.

Fuzzy set theory contributes to more meaningful accuracy assessments by providing a method to adjust error matrix calculations and account for map errors that are less significant or "less wrong". For example, the (2) Big Sagebrush Shrubland class and (7) Wyoming Big Sagebrush Shrubland class overlap considerably in community composition and cover values, and Class 7 can be locally present in Class 2. So, if a map polygon is labeled Big Sagebrush Shrubland, but the ground validation data identified the plot as Wyoming Big Sagebrush Shrubland, technically that is a map error. However, this is not necessarily wrong because Class 7 can be a component of Class 2 as a mixed big sagebrush community. Fuzzy assessment allows the acceptance of this type of mapping error in accuracy calculations because it has potentially important implications for the map user.

4.1.3 Accuracy Assessment Surveys

The use of an error matrix requires the consideration of underlying statistical assumptions when designing an accuracy assessment study. Specific considerations include: selecting the appropriate sampling scheme, collecting adequate sample size, maintaining sample independence, and accounting for spatial autocorrelation issues (Congalton 1991, Stehman and Czaplewski 1998, Foody 2002).

There are various options for the sampling scheme such as simple random sampling, stratified random sampling, and systematic sampling. Each sampling method has inherent advantages and disadvantages and many times the selection of a sampling scheme is driven by project funding and the logistics of accessing remote locations and/or sampling across the range of variability. Random sampling is an attractive method because it conforms to underlying statistical assumptions. More commonly, stratified random sampling is generally undertaken where some practical limits are placed upon the truly random site selection (e.g., proportionally allocated sample sizes among predicted classes).

Collecting adequate sample sizes of reference data is important and requires thoughtful consideration so the resulting accuracy assessment is meaningful and representative of the entire map area from which the sample was drawn (Hay 1979). The goal is similar to traditional field surveys where the intent is to collect cost-effective, representative, and statistically rigorous data across the entire study area, however, in practice compromises may be needed. General sample size guidelines have been proposed which suggest a minimum of 50 samples per land cover class, and if the study area is large (i.e., more than a million acres) the minimum number of samples should be increased to 75-100 samples per class (Congalton 1991). This guideline is a theoretical construct based on early mapping studies, however, these guidelines can be considered quite ambitious when the logistical and financial considerations of collecting large amount of reference data are factored into a study design. This strict standardized sample size requirement may not be realistic when there may be rare or unique classes limited in distribution within a study area, and forcing more samples into these map classes begins to compromise the sampling independence of reference data.

Sample independence is a concern when all field data for both image classification and validation are collected at the same time. It is important that any field data used during the classification mapping effort is kept separate from the data used to validate the final map. A related sampling independence principle is that of spatial autocorrelation among reference data points. Spatial autocorrelation is a concept statistic which describes the relationship of a variable according to the spatial arrangement of data values where the strength of correlation depends on the distance and direction separating the locations. The underlying premise is that data values in close proximity to one another are more likely to be similar. If two plots are sampled in close proximity they may violate the sample independence consideration because they effectively represent the same location.

Validation or reference data are commonly referred to as ground-truth data and any disagreement between the map and ground data is assumed to be a map error. However, the ground data are also subject to errors and in some cases, especially where qualitative visual estimates are made by an observer, the reference data may contain more errors than the map (Congalton and Green 1999, Lunetta et al. 2001). Reference data errors may arise from a number of scenarios including assigning the wrong thematic class labels in the field or misregistration of field plots and classified data. These problems and others have been recognized by researchers and the use of the term ground "truth" to describe validation data is now discouraged (Khorram 1999).

4.2 Methods

4.2.1 Field Validation Site Selection

Ideally, the mapping process is completed prior to initiating the accuracy assessment phase of a mapping project. Knowing where rare communities have been mapped in advance, ensures adequate sampling locations can be allocated to maintain minimum sample size requirements. Another advantage of selecting validation sites after the delineations are complete is that it allows the polygon boundaries to be buffered to avoid selecting locations where a plot will overlap map class boundaries. We were in the process of completing the delineations while the validation field sampling campaign began, which precluded us from stratifying the sample design and buffering boundaries.

Instead, we used the filtered landscape sampling area described in Chapter 2 site selection methods and randomly selected the initial 500 plot locations. Each randomly selected plot was reviewed to determine whether the location overlapped existing polygon boundaries (where mapping was completed), fell on distinct edges that were not yet mapped (e.g., wildfire boundaries), or was located in areas that were inaccessible for field crews (e.g., restricted access sites). If the plot was near an obvious edge but fell within a fairly homogenous area, the point was manually shifted further into the patch away from the edge. Some of the randomly selected locations were omitted for the reasons listed above, which resulted in 482 randomly selected plot locations.

We selected 20 locations from the remote areas of the Idaho National Laboratory (INL) Site outside of the filtered sampling area to ensure remote areas were represented. During the field season we kept tallies of vegetation class sample sizes, and added plots in under sampled and/or rare classes by selecting additional locations based on knowledge and familiarity with the INL Site. Some of the initial 482 randomly selected points were dropped later in the field season to focus efforts on rare classes and remote plot locations.

4.2.2 Field Sampling Protocol

The ground validation data were collected in 2009 using a sampling plot array design where five subplots collectively represented a single accuracy assessment location (Appendix G). The rationale for multiple subplots was an attempt to capture community variability across an extent that bridged the gap between the 1:12,000 mapping scale and the original vegetation classification 20 m x 20 m plot scale.

The sampling plot array consisted of five circular plots with an 8 m radius (~200 m^2) spaced 50 m apart in the four cardinal directions (Figure 4-1). Field crews navigated to plot location waypoints using a Trimble GeoXH Global Positioning System (GPS) receiver. Once the field crew located the sampling plot array location, the center focal plot was established by hammering a rebar stake into the center and attaching an 8 m length of rope. One crew member pulled the rope taught and walked the outer edge of the plot, while the second crew member created a comprehensive vegetation species list. Both crew members reviewed the list and cooperatively assigned each species a categorical abundance ranking. The categorical abundance rankings are described further in Chapter 2. Lastly, the crew used the dichotomous key developed from the 2008 field data to assign the subplot to an appropriate vegetation class. After the data were collected at the focal subplot, the crew navigated to the north subplot, repeated the data collection, and then proceeded to the east, south, and west peripheral subplots until the entire plot array was sampled. We recorded all field data digitally using data dictionaries and Excel data templates uploaded to the Trimble GeoXH GPS receivers.

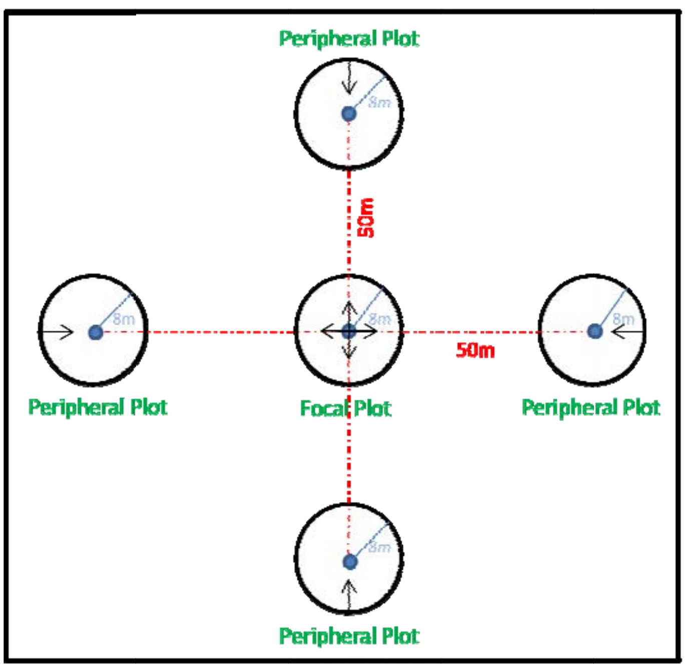
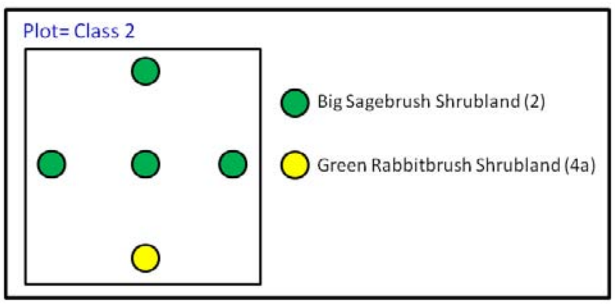


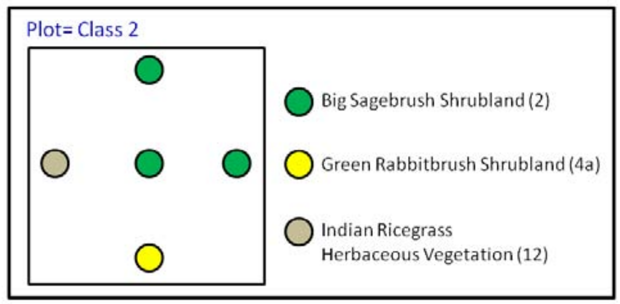
Figure 4-1. The validation sampling plot array design used to collect vegetation class field data in 2009 on the Idaho National Laboratory Site. The area of each subplot was approximately 200 m^2 and subplots were spaced 50 m away in the four cardinal directions around the focal plot. The black arrows denote the direction of the eight field photos (four from the focal plot and one from each subplot) collected at each plot array.

At the focal plot, we took field photographs from the plot center looking towards the outer peripheral subplots in the four cardinal directions. We took a single photograph from the outer edge of each peripheral subplot facing back towards the interior focal plot. The intent was to image as much of the landscape area the plot array encompassed as possible.

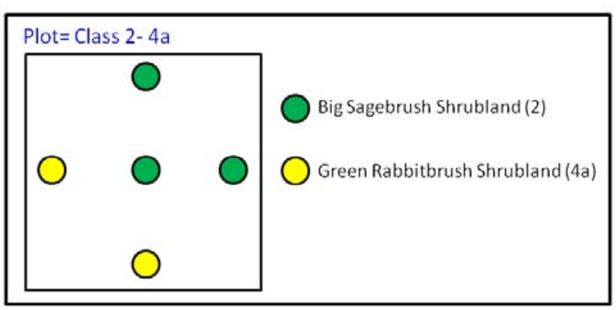
4.2.3 Assigning Validation Plots to Community Classes

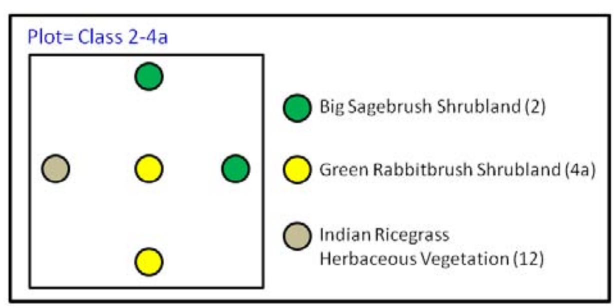
Each validation plot array was treated as a single validation point, but because we implemented a multiple subplot design, assigning validation plots to a vegetation class required the development of a rule set. The recorded vegetation class variability within a plot presented a number of different scenarios that needed to be considered prior to designating the plot to a final class or in many cases to a two-class complex. The rule sets described below include example plot schematics to illustrate how we assigned validation plots to a single class or two-class complex, and also how we determined which plots were assigned to the mixed (2) Big Sagebrush Shrubland class.



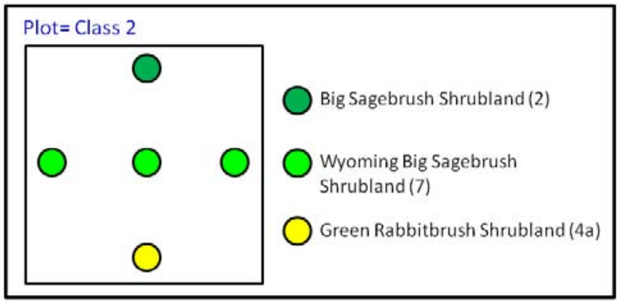


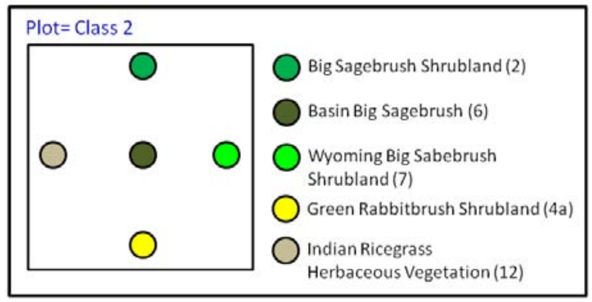
Majority Rule: In the simplest scenario, where all five subplots keyed to same vegetation class, we assigned the validation plot array to that vegetation class. A more common scenario was to have some variability among the subplots where only three or four subplots keyed to the same vegetation class. When there was more than one vegetation class present among the subplots, the class with the majority among subplots was assigned to the entire plot. A minimum of three subplots was needed to form a majority (i.e., two subplots cannot form a majority even if the other three subplots are each a different class). When only three subplots form the majority, the communities present in the remaining two subplots do not contribute to the plot class unless they are the same and are described in the two-class complex rule below.

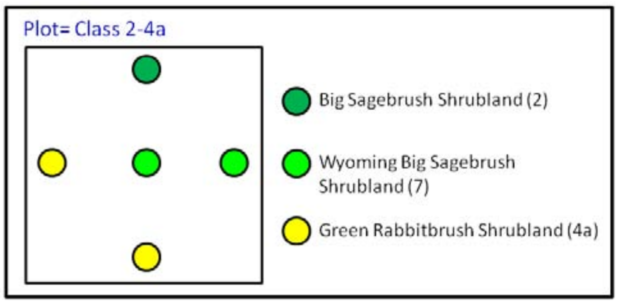




Two-Class Complex Rule: When there was a single class majority and the remaining two subplots were both the same class, the validation plot was assigned to a two-class complex. For example, if three of the subplots keyed to the (2) Big Sagebrush Shrubland class and the remaining two subplots keyed to the (4a) Green Rabbitbrush Shrubland class, then the validation plot would be assigned as Class 2-4a complex. Another scenario where we assigned a two-class complex was when two of the subplots were the same class, and two other subplots were a different class. The resulting plot became a two-class complex even if the last subplot was different from the two classes in the complex.







Big Sagebrush Rule: The (2) Big Sagebrush Shrubland class encompasses a range of variability in sagebrush communities. This class includes communities where the hybridized big sagebrush subspecies is dominant, as well as communities where both the (7) Wyoming Big Sagebrush Shrubland class and the (6) Basin Big Sagebrush Shrubland class were mixed across the landscape. We incorporated these considerations into the process of assigning validation plots to the (2) Big Sagebrush Shrubland class. Any time Classes 2, 6, or 7 occurred together within the same plot array, we assigned the plot to the (2) Big Sagebrush Shrubland class because this scenario fits the Class 2 description. Our rationale is if there is a mixture of big sagebrush classes occurring on the spatial scale of our validation plot, it is likely mixed across the extent of the larger map polygon and Class 2 is the most appropriate designation.

4.2.3.1 Split Plots

Map polygons are normally buffered by a fixed distance prior to the validation site selection process to avoid plot overlap with polygon boundaries. Buffering also eliminates issues with ecotones in transitions between vegetation communities which can be problematic for field crews to key properly. Once the field data were plotted over the final map polygons, we had some plots that did overlap polygon boundaries. Some of the overlap plots were informative, as they provided some confirmation of the spatial accuracy of the mapped vegetation class boundaries (i.e., subplots that fell in the adjacent polygon differed from the other subplots but matched the map polygon vegetation class assignment). We wanted to preserve all of the field data possible for the accuracy assessment, so we developed a rule set for split plots to determine if they could be used or should be removed from the dataset.

The focal plot location in each plot array determined which map polygon the validation plot would be compared against. We developed additional rules to assign split plots to a vegetation class or two-class complex. Figure 4-2 shows some examples from our validation data and the rules applied to each scenario are discussed below.

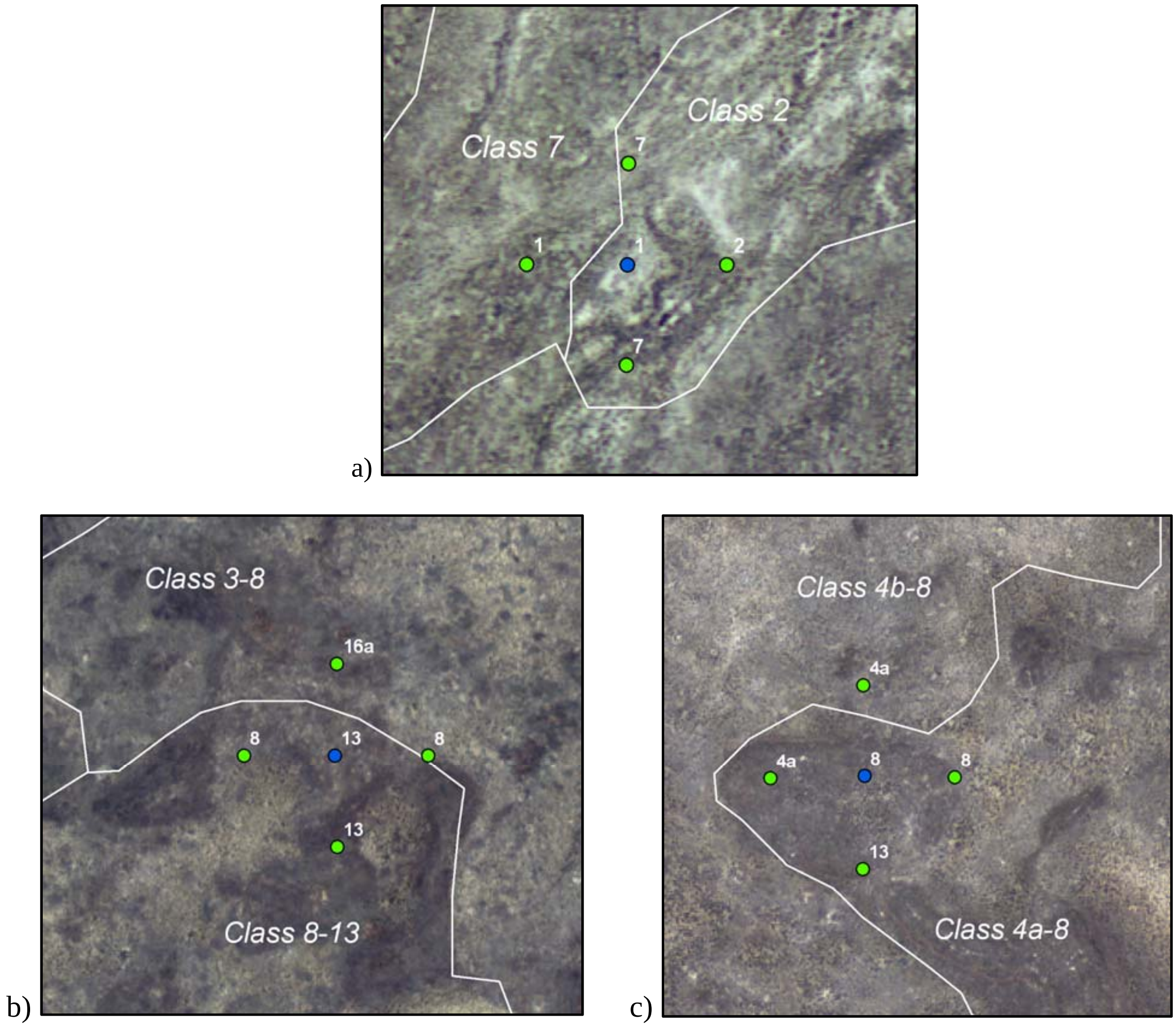


Figure 4-2. Examples of validation plots split between two map polygons. The polygon map class labels are displayed in large white letters and each green subplot (focal plot is blue) within the plot array is labeled as the class it keyed to during the field sampling.

The focal plot (blue point) in Figure 4-2a fell within a map polygon assigned to the (2) Big Sagebrush Shrubland class. Without the map polygons splitting the plot, we would have originally assigned this plot as a two-class complex (2-1) using the rules previously described. In this example, we considered all the subplots that fell within the focal map polygon (a total of four) and adjusted the validation plot class designation to omit the western subplot that was located in the adjacent map polygon. Now that we were only considering four subplots, the same rule sets described above concerning majority and Big Sagebrush Shrubland apply. We assigned this validation plot as a stand-alone Class 2, which matches the map polygon. Note that if the adjacent map polygon would have included Class 1 in a two-class complex, then a different rule would have been applied and is described for Figure 4-2b.

We employed different rules when polygon boundaries split plots resulting in scenarios where the subplots did not form a majority or majorities could only be assigned if subplots across the boundary were considered. Figure 4-2b shows an example validation plot where the focal plot and two other subplots all fall within a map polygon assigned to Class 8-13. Considering these three subplots, there is no majority (a minimum of three plots for majority) or two-class complex even though all three plots agree with the map polygon. We allowed the inclusion of subplots if they fell in the adjacent polygon and the class assigned to that subplot was common to both map polygons. In this example, both map polygons are in a complex with Class 8 and the east subplot also keyed to Class 8. By considering the east subplot, this validation plot becomes a two-class complex (Class 8-13).

Figure 4-2c shows a similar scenario where the subplots contained within the map polygon do not form a majority even though three subplots match the map complex exactly. If we included the north subplot, we could assign the validation plot to a two-class complex (Class 4a-8). But because Class 4a is not part of the adjacent map polygon complex (Class 4b-8), we did not consider this subplot. Consequently, this plot was omitted from the accuracy assessment because it did not meet the criteria we developed to assign it to a vegetation class even though three of the subplots matched the map polygon.

4.2.4 Error Matrix Calculations

Typically, error matrices are populated using a binary coding where a single map class is being compared directly to a single class reference point. For each comparison a “0” or “1” is populated into the appropriate cell to denote the agreement between the validation data and the mapped class. We needed to modify the standard approach to account for class complexes that commonly occurred during this mapping project. The vegetation classes were statistically defined from plot data collected at a finer scale than the 1:12,000 mapping scale. We discovered that in the field, vegetation classes commonly mixed or formed complexes across the large areas map polygons encompassed. This scenario presents a situation where making direct class-to-class comparisons is impossible because sometimes the map polygons are assigned to two-class complexes and other times validation plot data are assigned to two-class complexes.

Given that we had to accommodate two-class complexes in both the map polygons and the validation plot data, we devised alternative methods for populating the error matrix. We took two different approaches for entering data into the error matrix. The first method was a direct comparison where if a single map class within a complex matched the ground data it was marked correct. In other words, if the map polygon is assigned a two-class complex or the validation plot data are comprised of a two-class complex, only one class needs to match to mark that validation plot correct. This evaluation approach assumes that multi-class map labels represent mosaics across the landscape where either class may be locally abundant and both classes tend to intermix patchily across the mapped polygon. The second method requires both classes in a two-class complex from the map to be present in the validation plot data. This evaluation approach assumes that multi-class map labels represent continuous mixtures of the two vegetation classes across the landscape where both classes are expected to be uniformly present across the mapped polygon.

We wanted to avoid including all two-class complexes as unique classes in the matrix, because with that many map classes (127) samples size becomes limiting and would require thousands of validation plots to adequately assess the map. We created the error matrix with the original classes and developed a tally method to account for the two-class complexes. Our strategy was intended to account for all class complex comparisons by allowing fractional (0.5) tallies in the error matrix to reflect partial right and wrong answers (i.e., both the polygon and validation data share only one common class in a complex).

Error Matrix Method 1: When a single class is being compared to a two-class complex and there is at least one class correct, the correct tally goes into the corresponding correct class. For example, if the validation data report Class 18 and the map data predict Class 7-18 complex, the correct tally (1) will go under the Class 18 matrix cell. If the validation data and map both predict the same two-class complex, then a fractional correct tally (0.5) was entered into each class' corresponding cell. For example, if the validation data report a Class 7-18 complex and the map polygon is labeled as Class 7-18, then a fractional tally (0.5) is entered into both the Class 7 and Class 18 matrix cells.

Errors are tallied normally in the matrix for single class comparisons. When an error occurs between a single class and a two-class complex, fractional tallies (0.5) are entered into the appropriate matrix cell. For example, if the validation data report a Class 7-18 complex and the map polygon is labeled as Class 2, then fractional tallies (0.5) are entered into Class7/Class2 (class column/class row, respectively) and Class 18/Class2 matrix cells. If both ground validation data and the map polygon data are different two-class complexes with no shared classes, fractional tallies (0.5) were entered into the appropriate matrix cell.

When there is no agreement between two-class complexes, we attempted to populate the error matrix with meaningful groupings of errors by selecting classes that share dominant species or physiognomic structure. For example, if the ground validation data report a Class 4a-12 complex and the map polygon was labeled as a Class 8-3 complex, we developed criteria to decide which two sets of class errors would be grouped. In this situation, we would group classes 4a and 8 together because they are both types of green rabbitbrush shrublands, and classes 12 and 3 together because they are both herbaceous classes. The fractional error tallies are then entered using standard error matrix methods.

Error Matrix Method 2: When a single class is being compared to a two-class complex, the fractional tally (0.5) is placed in the correct corresponding matrix cell, and if there are errors, the remaining error fraction (0.5) is placed in the appropriate error cell. This approach differs from Method 1 by penalizing for any discrepancy between the map and validation data regardless if one class was mapped correct. For example, if the validation plot data report a Class 7-18 complex and the map polygon is labeled as Class 7, then the correct fractional tally (0.5) is entered into the Class 7 matrix cell, but an error fraction (0.5) is entered into the Class 18/7 matrix cell (class column/class row, respectively). Using Method 1, this scenario would have resulted in a full tally (1) placed in the Class 7 matrix cell. If the validation plot and map data both correctly predict a two-class complex, then a fractional correct tally (0.5) is entered into each class' corresponding cell. If the validation plot two-class complex and map polygon two-class complex differ, then fractional tallies (0.5) are entered into the corresponding cells for partially right or partially wrong comparisons using the grouping strategy discussed in Method 1.

Once the error matrix was fully populated, we calculated the most common map accuracy metrics, and those reported by the National Park Service (NPS) Vegetation Inventory Program (Lea and Curtis 2010). Specifically, we calculated the user's and producer's accuracy, overall accuracy, and the kappa coefficient. Following the equations for the accuracy metrics, we provide a sample error matrix showing example calculations from generic data (Table 4-1).

User's accuracy is calculated as:

$$\frac{n_{ii}}{n_{i+}}$$

where i is the vegetation class, n_{ii} is the number of matches between the map and reference data (major diagonal), and n_{i+} is the total number of samples of i in the map data (row total). User's accuracy is calculated by dividing the number of true positive (correct) samples by the total samples in the error matrix row.

Producer's accuracy is calculated as:

$$\frac{n_{ii}}{n_{+i}}$$

where n_{+i} is the total number of samples of i in the reference data (column total). Producer's accuracy is calculated by dividing the number of true positive (correct) samples by the total samples in the error matrix column.

Overall accuracy is calculated as:

$$\frac{\sum_{i=1}^{k} n_{ii}}{n}$$

where k is the number of vegetation classes and n is the total number of validation plots. Conceptually this metric is calculated by dividing the sum of all class true positives (correct) by the total samples in the error matrix.

Estimates of map accuracy are produced though sampling inference drawn from map sites, and it has been suggested that map accuracy estimates should be accompanied by confidence intervals (Thomas and Allcock 1984). We calculated the 90% confidence interval for each map class as:

$$\hat{p}\left\{z_{\alpha}\sqrt{\frac{\hat{p}(1-\hat{p})}{n}}+\frac{1}{2n}\right\}$$

where $\hat{p}$ is the sample (class) accuracy probability, z_{α} is the z-score (1.645) for the two-tailed significance level (Zar 1996), and n is the number of sites sampled. We chose the 90% confidence interval to match the NPS Vegetation Inventory Program and make our results comparable.

The **Kappa coefficient** is calculated as:

$$\widehat{K}=\frac{N\sum_{i=1}^{r}x_{ii}-\sum_{i=1}^{r}(x_{i+}\bullet x_{+i})}{N^2-\sum_{i=1}^{r}(x_{i+}\bullet x_{+i})}$$

where N is the total number of validation plots (samples in the error matrix), r is the number of rows in the error matrix, x_{ii} is the number of correct observations of row i and column i (major diagonal), x_{i+} is the total observations in row i, and x_{+i} is the total number of observations in column i.

Table 4-1. A sample error matrix depicting four generic map classes and the corresponding accuracy metric calculations. The yellow diagonal cells represent true positive class agreement, while all off-diagonal errors inform the map user about class-to-class mapping errors.

Classified (Map) Data	Reference (Validation) Data: Class 1	Class 2	Class 3	Class 4	Row ∑
Class 1	**16**	1	3	1	*21*
Class 2	0	**18**	0	1	*19*
Class 3	1	1	**19**	0	*21*
Class 4	0	1	2	**21**	*24*
Column ∑	*17*	*21*	*24*	*23*	*85*

	Producer's Accuracy	User's Accuracy
Class 1	16/17 = 94.1%	16/21 = 76.2%
Class 2	18/21 = 85.7%	18/19 = 94.7%
Class 3	19/24 = 79.2%	19/21 = 90.5%
Class 4	21/23 = 91.3%	21/24 = 87.5%

Overall Accuracy = (16+18+19+21)/85 = **87.1%**

4.2.5 Fuzzy Accuracy Assessment

Vegetation communities can gradually transition and intermix across the INL Site landscape, and species composition and abundance fluctuate spatially, especially in ecotones near community boundaries. Our observations from the field support the notion that many locations on the ground can resemble more than one vegetation class. Fuzzy set theory provides an avenue to embrace multiple class membership at a single location and allows for more meaningful interpretations of the map accuracies and errors. Conducting fuzzy assessments is meaningful when several map classes are very similar. For this project, we report classes that overlap and can be locally present in other classes (e.g., [17a] Tall Tumblemustard- Cheatgrass Semi-natural Herbaceous Vegetation class and the [13] Cheatgrass Semi-natural Herbaceous Vegetation class).

Most studies rely on expert opinion to assign the level of fuzzy similarity between pair-wise community comparisons. We wanted to minimize the subjective decision making process where expert opinion alone is responsible for the designation of fuzzy membership. Townsend (2000) introduced a quantitative fuzzy assessment approach that follows established methods used by plant ecologists where a fuzzy similarity index is developed from community similarity indices of species lists and cover values.

In 2008, we collected vegetation cover data using both point sighting frames and visual estimates of categorical ranks of species abundance. In an effort to expedite the validation data collection process in 2009, and because the dichotomous class key did not depend on quantitative cover values, we did not collect point sighting frame data and only recorded categorical abundance ranks. We tested the strength of linear and monotonic associations between the 2008 absolute cover and rank cover data. If a strong predictive relationship was found, we could be confident that the abundance rank data collected in 2009 could be used as a quantitative surrogate to proceed with the fuzzy methods proposed by Townsend (2000).

We transformed the rank abundance data using:

$$\eta_i = \text{abs}(\nu_i - 4),$$

where ν_i is the rank of the *i*th observation. This allowed the ranks to increase with increasing cover, and vice versa, on the original scale. We calculated the correlation between the quantitative cover data and the categorical rank abundance data. The analysis resulted in low Pearson correlation coefficients among classes ranging from 0.160 to 0.729 with a mean of 0.566, and a Kendall tau rank coefficient mean of 0.573.

We then made a log base 2 transformation to the rank abundance data using:

$$\alpha_i = \log_2(\eta_i + 1)$$

This assumes an abundance rank represents a doubling of cover from the rank immediately below it and it better represents species abundance patterns within plant communities (Anderson 1991). We found that the log base 2 transformation did not improve the linear or even monotonic correlation (measured by Kendall's tau).

Once we learned that we could not pursue the quantitative methods proposed by Townsend (2000), we decided to use an alternative method to more objectively assign classes to fuzzy memberships based on community similarity. We chose to use the complement of the Bray-Curtis measure of dissimilarity as our similarity metric (Bray and Curtis 1957). The Bray-Curtis metric calculates similarity by comparing absolute cover values on a species by species basis for comparisons between each pair of communities and returns a proportional value between 0 and 1. A value of 0 indicates that the two communities have no species in common and a value of 1 indicates that the two communities are identical, containing the same species at the same absolute cover values for each species. It is important to note that the Bray-Curtis measure is particularly sensitive to fluctuations in absolute cover values which results in low expected maximum similarity values (Krebs 1999). For example, two plots having similar species compositions with similar relative cover values may receive a low similarity score if total vegetation cover between the two plots varies in response to local stochastic factors. Consequently, the range of similarity values represented for all pair-wise combinations will often be concentrated toward the middle- to lower-end of the 0 to 1 similarity scale, even when several pair-wise combinations of communities are similar in terms of proportional species composition.

The Gopal and Woodcock (1994) linguistic scale defines five levels of fuzzy membership. Fuzzy Level 5 (Absolutely Right) is a direct class-to-class comparison and is essentially redundant with the original error matrix calculations where no fuzzy memberships are assigned. We determined that we would only consider Fuzzy Level 4 (Good Answer) during the fuzzy assessment, rather than accepting correct alternative classes assigned to Fuzzy Level 3 (Reasonable or Acceptable Answer). Fuzzy Level 3 has been used on previous NPS mapping projects in an effort to achieve programmatic accuracy goals (Hansen et al. 2004a, b, c, Salas et al. 2005). Limiting our assessment to Fuzzy Level 4 also prevents the need to select additional Bray-Curtis thresholds to define the split between Fuzzy Levels 3 and 4.

The Bray-Curtis similarity index resulted in a range of continuous values, and we needed to select a threshold value to divide the classes considered for fuzzy level designation and those not considered. We chose a Bray-Curtis similarity index threshold of 0.35 to group classes expected or known to be similar (e.g., [4a] Green Rabbitbrush Shrubland class and [4b] Green Rabbitbrush/Bluebunch Wheatgrass Herbaceous Vegetation class) (Table 4-2). Once all pair-wise classes above the selected threshold were selected, we compared the groupings and recognized some classes within each grouping were inherently more similar than others.

To be conservative in the number of pair-wise classes assigned to Fuzzy Level 4, we limited the number of classes above the selected threshold by excluding those without similar physiognomic structure or dominant species (Table 4-2). For example, when considering all pair-wise comparisons for the (4a) Green Rabbitbrush Shrubland class, five other classes fell above the 0.35 threshold, but we only included the three classes that contained a green rabbitbrush component and excluded the two big sagebrush classes (Table 4-2). If the focal comparison class was shrub dominated and a purely herbaceous class fell above the 0.35 threshold, we did not assign the herbaceous class to Fuzzy Level 4 for the pair-wise comparison and vice versa. If we accepted all classes above the 0.35 threshold, we could have further improved reported map accuracy, but the goal was not just to increase map accuracy but to produce a more realistic map

Table 4-2. Bray-Curtis community similarity matrix for the Idaho National Laboratory Site vegetation classes. The yellow highlighted cells represent all similarity scores greater than the 0.35 threshold. The highlighted cells outlined in green represent the classes that were assigned to Fuzzy Level 4 for the accuracy assessment. Vegetation class codes are listed below in Table 4-7.

	1/9	2	3	4a	4b	5	6	7	8	10	11ab	11c	11d	12	13	14	15	16a	16b	17a	17b	18	19	20	21	22
1/9	-	0.24	0.37	0.34	0.28	0.43	0.34	0.32	0.39	0.16	0.15	0.14	0.07	0.35	0.26	0.18	0.20	0.32	0.19	0.35	0.14	0.10	0.16	0.18	0.19	0.08
2		-	0.17	0.38	0.33	0.27	0.39	0.38	0.32	0.22	0.24	0.16	0.15	0.20	0.24	0.15	0.06	0.16	0.21	0.13	0.04	0.20	0.23	0.18	0.14	0.08
3			-	0.27	0.21	0.32	0.32	0.21	0.36	0.12	0.12	0.20	0.05	0.48	0.22	0.15	0.16	0.36	0.20	0.26	0.07	0.10	0.15	0.18	0.18	0.10
4a				-	0.58	0.47	0.47	0.48	0.47	0.20	0.20	0.21	0.13	0.29	0.31	0.16	0.14	0.26	0.25	0.18	0.05	0.17	0.27	0.26	0.25	0.11
4b					-	0.40	0.35	0.37	0.39	0.15	0.53	0.33	0.21	0.23	0.21	0.12	0.07	0.20	0.22	0.13	0.04	0.30	0.18	0.14	0.16	0.07
5						-	0.41	0.37	0.40	0.20	0.21	0.17	0.06	0.39	0.23	0.13	0.22	0.33	0.32	0.19	0.06	0.16	0.32	0.20	0.25	0.15
6							-	0.45	0.45	0.17	0.25	0.23	0.16	0.32	0.36	0.21	0.12	0.31	0.32	0.18	0.06	0.21	0.29	0.25	0.30	0.15
7								-	0.34	0.15	0.26	0.20	0.16	0.24	0.29	0.14	0.11	0.25	0.27	0.15	0.05	0.29	0.28	0.21	0.22	0.10
8									-	0.19	0.19	0.24	0.11	0.37	0.31	0.23	0.09	0.37	0.21	0.24	0.16	0.14	0.17	0.22	0.27	0.08
10										-	0.13	0.07	0.04	0.13	0.11	0.12	0.14	0.12	0.12	0.09	0.02	0.09	0.12	0.12	0.08	0.07
11ab											-	0.37	0.24	0.13	0.21	0.09	0.04	0.35	0.36	0.10	0.02	0.34	0.17	0.12	0.12	0.03
11c												-	0.47	0.23	0.16	0.09	0.08	0.27	0.15	0.13	0.03	0.20	0.15	0.19	0.23	0.06
11d													-	0.08	0.14	0.06	0.03	0.10	0.09	0.08	0.04	0.15	0.11	0.08	0.11	0.03
12														-	0.26	0.14	0.16	0.43	0.21	0.27	0.10	0.10	0.17	0.16	0.22	0.10
13															-	0.22	0.08	0.30	0.23	0.31	0.24	0.15	0.16	0.17	0.25	0.05
14																-	0.07	0.14	0.06	0.15	0.12	0.05	0.07	0.09	0.12	0.05
15																	-	0.17	0.16	0.16	0.02	0.03	0.21	0.16	0.08	0.13
16a																		-	0.34	0.29	0.13	0.15	0.24	0.18	0.24	0.10
16b																			-	0.13	0.01	0.25	0.36	0.18	0.25	0.18
17a																				-	0.43	0.06	0.11	0.14	0.20	0.05
17b																					-	0.01	0.01	0.02	0.08	0.01
18																						-	0.17	0.13	0.14	0.02
19																							-	0.15	0.22	0.28
20																								-	0.17	0.05
21																									-	0.08
22																										-

assessment. Once we selected the pair-wise classes to be included in the Fuzzy Level 4 assessment, we repopulated the error matrix using both Method 1 and 2 described above in the Error Matrix Calculation section.

4.3 Results and Discussion

4.3.1 Validation Plot Data

We collected field validation data at 535 plot arrays distributed throughout the INL Site in 2009. Some plots were omitted from the accuracy assessment because they were bisected by a polygon boundary and did not meet the split plot criteria for inclusion. We removed six split plots from the accuracy assessment which was minimal considering the site selection process relied solely on a constrained random selection. There were a greater number of validation plots that had no majority within the plot and four or five classes were present within a single plot array. We removed 26 plots that had no class majority within the plot array, and 21 (80.8%) of these plots were distributed within recent wildfire boundaries (Figure 4-3). This is not unexpected as we observed increased community variability on the ground in recently burned areas. There were times in the field when it was difficult to determine which two classes were the most prevalent

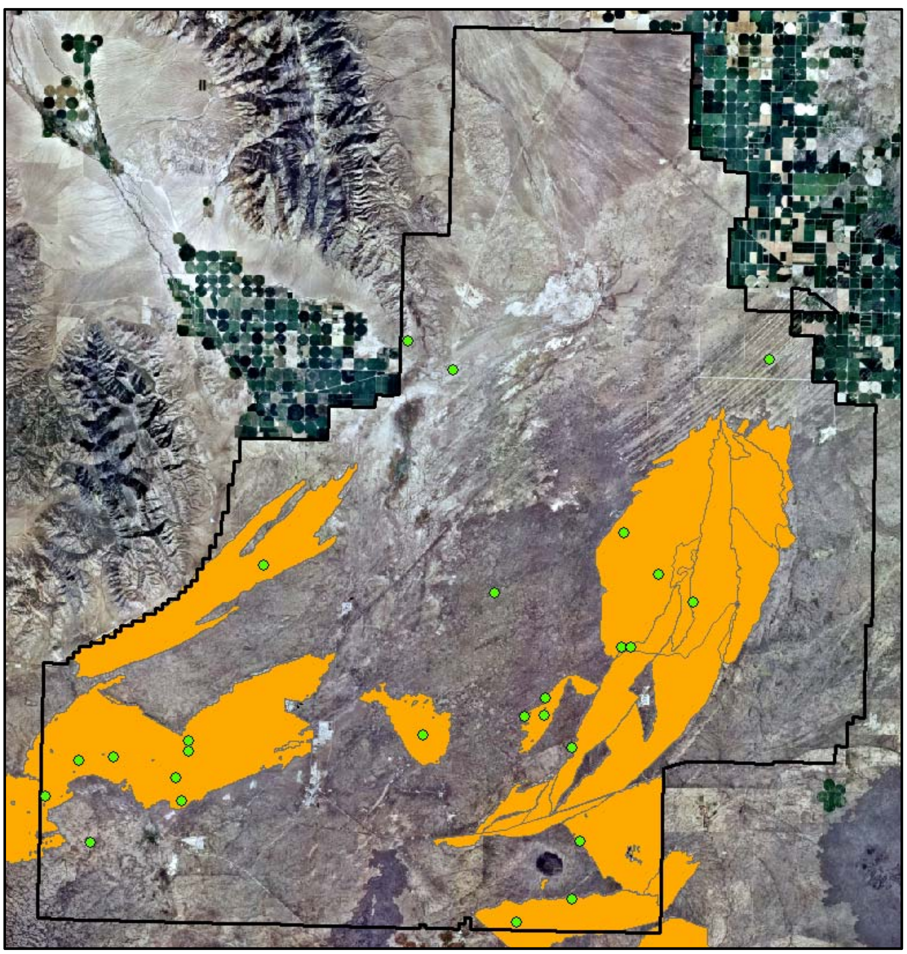


Figure 4-3. The 26 validation plot arrays omitted because within plot class variability did not form a class majority. The plot locations are overlaid on the major wildland fire areas from 1994-2009. Note: two large wildfires burned in 2010 but the validation data were collected prior to these fires and did not impact the accuracy assessment.

across a heterogeneous landscape where three or four vegetation classes commonly occurred. We removed one additional plot that was unintentionally sampled twice by different field crews, which resulted in a total of 502 validation plots (Figure 4-4).

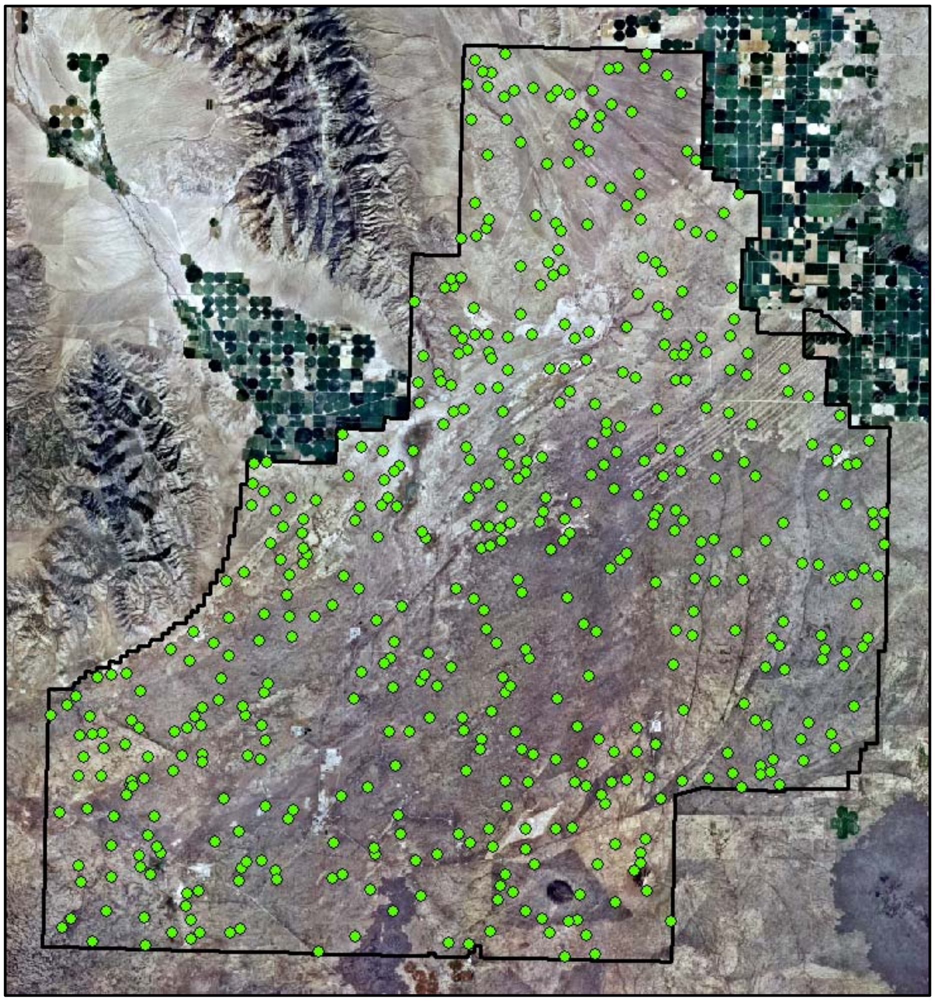


Figure 4-4. The distribution of 502 validation plot arrays collected in 2009 and used to conduct the accuracy assessment of the Idaho National Laboratory Site vegetation map.

Of the 502 validation plots, 186 plots (37.1%) had all five subplots key to the same vegetation class. The majority of plots that had homogenous subplot classes consisted of the (2) Big Sagebrush Shrubland class and the (7) Wyoming Big Sagebrush Shrubland class. There were 226 plots (45%) that were assigned to a single class with at least three of the subplots keying to the same vegetation class. Ninety plots (17.9%) were assigned as two-class complexes.

Random sampling would expectedly result in sample sizes that correspond with the proportional area mapped for each class (i.e., classes with greater mapped area had more validation plots). The downfall of this approach is that the most common classes will have larger sample sizes while rarer classes will have small sample sizes or maybe no samples at all. Although we monitored validation plot samples sizes throughout the 2009 field season, and directed crews to regions of the INL Site to search for rarer communities, many times they were not found or existed as patches too small for our plot arrays to capture.

Validation plot sample sizes varied widely among map classes. We had very large sample sizes for the big sagebrush classes (i.e., Classes 2, 6, and 7) because they cover the largest amount of map area. With low sample sizes, the 90% confidence intervals show a larger range reflecting a greater amount of uncertainty in those class accuracy results. The (16a) Sandberg Bluegrass class had no validation plots, but only had one stand-alone polygon and five other polygons where it was in a complex with another class. The (17b) Remnant Riparian class also had no validation plots, but because it was only mapped one time as a complex with the (6) Basin Big Sagebrush class, it is not unexpected we did not have any validation plots in this class.

One option to increase the validation data sample sizes would be to consider each subplot within a plot array as an independent reference point. This would inflate the 502 plot arrays collected to a total of 2510 individual reference plots. Without understanding the spatial autocorrelation of each community, it is difficult to estimate a reasonable distance for independent sampling. The NPS Vegetation Inventory Program allows reference plots to be spaced at distances 50 m (Bell et al. 2009). Given the class variability evident in the validation plot arrays it seems as though considering the entire array as a sampling unit helps bridge the change in scales that exist between the original 2008 field sampling scale and the mapping scale.

The original NPS Vegetation Inventory Program guidelines recommended estimating sample sizes through proportional allocation based on map class abundance and frequency (Environmental Systems Research Institute et al. 1994). They suggested 30 samples (for abundant and fragmented classes), 20 samples (for abundant, but less fragmented, or less abundant, but more fragmented classes), or five samples or fewer (for rare or very rare classes) per class (Environmental Systems Research Institute et al. 1994). The recently updated guidelines were revised to address the concern that meaningful accuracy estimates were difficult to make for rare map classes (Lea and Curtis 2010). The new guidelines suggest 30 samples for classes that are abundant (more than 50 hectares), 0.6 samples/hectare (for classes that cover at least 8.33 hectares but no more than 50 hectares), and five samples (for rare classes that cover less than 8.33 hectare) (Lea and Curtis 2010).

Aside from the fact that mapping was not complete prior to the validation plot site selection process, area based sample allocation would be difficult to implement for this project. A map class could be in a complex with another map class, but may only be present in localized areas within the larger polygon. We include it in the complex because it can be found commonly throughout the polygon, but not necessarily an equally abundant class which is evenly mixed across the entire polygon area. Consequently, the mapped area overlaps among classes, and final polygon area for each class is not mutually exclusive and tends to overestimate some vegetation class areas. For example, the (17a) Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation class was commonly in a complex with other classes when weedy areas were observed or suspected within a polygon. However, Class 17a does not typically dominate large patches and is included in the polygon complex because it informs the map user that weedy patches are present within the polygon, not because it is equally present. If the polygon that includes Class 17a as a complex was large, area based sample allocation would erroneously consider assigning more plots to this class even though it may have a very limited extent across the INL Site.

4.3.2 Accuracy Assessment

We calculated four separate error matrices using two different methods to populate the matrix, and then a fuzzy assessment of each. All four matrix tables are presented below, and we encourage map user's to consider which accuracy assessment holds the greatest implications for their project. Table 4-7 provides a convenient summary of individual class accuracies across all error matrix results.

Although the approach we took to populate the error matrix is not the standard method due to the two-class complexes, the fundamental information in the error matrix remains the same. One underlying assumption for using the error matrix is that each ground location can be assigned to a single class. We did violate this assumption, however, most studies also violate this assumption because the majority of pixels in digital imagery are mixtures of surface features and rarely can all map or validation sites be unequivocally designated to a single class. In the field, we commonly found multiple vegetation classes present in mapped polygons, and assigning two-class complexes was a way to capture the class mixtures we commonly observed and provides the map user with additional information to consider.

Using Method 1 to populate the error matrix resulted in an overall map accuracy of 70.7%, a Kappa of 0.65, and individual vegetation class accuracies varied greatly (Table 4-3). As expected, error matrix Method 2 resulted in a substantially lower overall map accuracy of 52.4%, a lower Kappa of 0.44, and lower individual vegetation class accuracies (Table 4-4). Method 2 employed a stringent rule-set that required both classes in a complex to always be present in the validation plot data. Our field observations suggest that class complexes on the INL Site more often form patchwork mosaics, and the accuracy assessment using Method 1 may be the most meaningful. The lowest (0%) and highest (100%) individual class accuracies generally occurred with vegetation classes that had low validation plot sample sizes making it difficult to adequately assess these map classes, and additional validation plots would help refine our accuracy estimates.

The NPS Vegetation Inventory Program allows for multiple calls per plot, meaning multiple vegetation classes can be recorded at a single plot. Sometimes the multiple calls would be incorporated into fuzzy sets during the accuracy assessment (Salas et al. 2005). The NPS Thematic Accuracy Assessment Procedures no longer supports the use of fuzzy set theory because there is not a nationally consistent fuzzy set standard, and each project developed their own criteria for assigning classes to fuzzy levels making it difficult to compare results among park units (Lea and Curtis 2010). Although fuzzy set theory is no longer officially supported in NPS protocols, multiple calls per plot can still be considered in the accuracy assessment (Bell et al. 2009). Considering multiple calls per plot is similar to allowing two-class complexes assigned to validation plots, however we did not have to choose which class would be evaluated and included both.

Our fuzzy assessment resulted in substantial improvements to overall map accuracy and also individual class accuracies. Using Method 1, overall map accuracy increased to 94.2% and Kappa increased to 0.93 (Table 4-5). Many individual vegetation class accuracies showed large increases in accuracy with the fuzzy assessment. Correspondingly, Method 2 also showed a large improvement with an overall map accuracy of 70.1% and a Kappa of 0.65 (Table 4-6). It is important to note that a few individual vegetation class accuracies did not improve with the Method 2 fuzzy assessment, and those that did improve generally exhibited a smaller increase in accuracy compared to the Method 1 fuzzy assessment results.

The NPS Vegetation Inventory Program originally set a mapping accuracy goal of 80% for all parks mapped under this program (Environmental Systems Research Institute et al. 1994). The 80% level of accuracy refers to both overall map accuracy and individual class accuracies. This level of accuracy can be difficult to achieve with a large number of map classes. Across many NPS park units these map accuracy goals were rarely achieved (Lea and Curtis 2010). Hierarchical grouping of NVC Associations into Alliances is one method that has been used to increase map accuracy by distilling the complexity present with vegetation Associations and generalize those classes to more encompassing broad map classes. Even though our fuzzy assessment resulted in an overall map accuracy of 94.2%, we still had some individual classes that did not meet the 80% accuracy standard (Table 4-7). Although we did not achieve 80% accuracy for all map classes on the INL Site, the majority of classes (especially those with large sample sizes) and overall map accuracy clearly exceeded this standard.

While the Table 4-4 and 4-6 error matrices provides valuable information for interpreting map accuracy, the assumption that both classes in each two-class complex must be present in ground plots does not support the majority of our observations from the field, and these estimates of map accuracy may be unrealistic. When large increases in user's and producer's accuracy are shown between Table 4-4 and 4-6, this suggests the mapping errors occurred between similar vegetation classes assigned to Fuzzy Level 4. When class accuracies increase very little between Table 4-4 and 4-6, there can be two possible explanations. The mapping errors either occurred between dissimilar vegetation classes not assigned to Fuzzy Level 4, or the map and validation plot comparison was conducted between single classes and two-class complexes. Mapping errors will always be tabulated when a map polygon was assigned to a single class but was compared to a two-class complex in the validation data or vice versa because there will always be a fractional error tally under this scenario. This serves to lower the calculated class accuracy and is also the reason the average class accuracies are consistently lower using Method 2.

We are not able to compare our new vegetation mapping results with any previous vegetation maps of the INL Site because there has never been a quantitative evaluation of any other map product. Qualitative comparisons to previous vegetation maps suggest that map class accuracies were generally lower than the results we present here. The INL Site vegetation map should be considered a dynamic data product that can and should be updated following large disturbances (e.g., wildland fire) or when additional field data are available to contribute to a more robust accuracy assessment for classes with small sample sizes.

Table 4-3. Idaho National Laboratory Site vegetation map error matrix produced using Method 1. The map class code descriptions are listed in Table 4-7.

	Validation (Ground Reference) Data																											
Map Class	1/9	2	3	4a	4b	5	6	7	8	10	11ab	11c	11d	12	13	14	15	16a	16b	17a	18	19	20	22	Totals	User's Accuracy	90% Confidence Interval	
Predicted (Map) Data: 1/9	23.5	0.5	1.5	2.0	1.0	0.5		1.0		0.5						0.5	1.0	0.5	0.5						33	71.2%	56.7%	85.7%
2	0.5	99.0		2.5	0.5	0.5	3.5	44.0	1.0	3.5				1.0	1.0						0.5				157.5	62.9%	56.2%	69.5%
3	1.0	0.5	12.5	2.0			0.5							1.0				0.5							18	69.4%	48.8%	90.1%
4a	1.5	1.0	1.0	28.0	1.5			0.5	0.5	1.5						1.0									36.5	76.7%	63.8%	89.6%
4b	0.5			0.5	13.0			6.0	0.5	1.0					0.5	0.5				1.0					23.5	55.3%	36.3%	74.3%
5	0.5			1.5	0.5	14.5											1.0								18	80.6%	62.4%	98.7%
6		4.0					4.0																		8	50.0%	14.7%	85.3%
7	0.5	19.0		1.5		0.5		88.5											1.5			0.5			112	79.0%	72.2%	85.8%
8	0.5	0.5	0.5	2.5					7.5								1.0								12.5	60.0%	33.2%	86.8%
10		0.5		0.5				1.5		14.5															17	85.3%	68.2%	100.0%
11ab	0.5								0.5		5.0									1.5					7.5	66.7%	31.7%	100.0%
11c												6.0	1.5												7.5	80.0%	49.3%	100.0%
11d													4.0												4	100.0%	87.5%	100.0%
12	1.0		1.5	0.5	0.5			0.5	0.5					8.0					0.5						13	61.5%	35.5%	87.6%
13		1.0						0.5							1.5										3	50.0%	0.0%	100.0%
14																4.0									4	100.0%	87.5%	100.0%
15																	2.0								2	100.0%	75.0%	100.0%
16a																		0.0							0	0.0%	0.0%	0.0%
16b																			5.0			0.5			5.5	90.9%	61.7%	100.0%
17a	0.5														0.5					0.0					1	0.0%	0.0%	50.0%
18		1.5						1.5					0.5								7.0				10.5	66.7%	38.0%	95.4%
19																			0.5			3.0			3.5	85.7%	40.7%	100.0%
20																							1.0		1	100.0%	50.0%	100.0%
22																								3.5	3.5	100.0%	85.7%	100.0%
Totals	30.5	127.5	17	41.5	17	16	8	144	10.5	21	5	6	6	10	3.5	6	5	1	8	2.5	7.5	4	1	3.5	502 Total Plots (355 Corrrect)			
Producer's Accuracy	77.0%	77.6%	73.5%	67.5%	76.5%	90.6%	50.0%	61.5%	71.4%	69.0%	100.0%	100.0%	66.7%	80.0%	42.9%	66.7%	40.0%	0.0%	62.5%	0.0%	93.3%	75.0%	100.0%	100.0%	Overall Accuracy = 70.7%			
90% Confidence Interval	62.9%	71.2%	53.0%	54.3%	56.6%	75.5%	14.7%	54.4%	43.7%	50.1%	90.0%	91.7%	26.7%	54.2%	0.0%	26.7%	0.0%	0.0%	28.1%	0.0%	71.7%	26.9%	50.0%	85.7%	Kappa Coefficient = 0.65			
	91.2%	84.1%	94.1%	80.6%	96.3%	100.0%	85.3%	68.5%	99.1%	88.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	86.0%	50.0%	96.9%	20.0%	100.0%	100.0%	100.0%	100.0%				

Table 4-4. Idaho National Laboratory Site vegetation map error matrix produced using Method 2. The map class code descriptions are listed in Table 4-7.

	Validation (Ground Reference) Data																											
Predicted (Map) Data: Map Class	1/9	2	3	4a	4b	5	6	7	8	10	11ab	11c	11d	12	13	14	15	16a	16b	17a	18	19	20	22	Totals	User's Accuracy	90% Confidence Interval	
1/9	**14.5**	1.5	3.5	3.5	1.5	1.5		2.5	0.5	0.5				1		0.5	1.5	0.5	0.5				0.5		34	42.6%	27.2%	58.1%
2	2.5	**83.5**	1	2.5	0.5	0.5	3.5	45	1	4.5				1	1				0.5		2				149	56.0%	49.0%	63.1%
3	1.5	1.5	**6.5**	4			0.5		1.5					1		0.5		0.5							17.5	37.1%	15.3%	59.0%
4a	2	3.5	1	**16.5**	2	1		2	2	1.5				2.5		1									35	47.1%	31.8%	62.5%
4b	1.5	5		5	**7**			6	1	1	1.5				0.5	0.5				1					30	23.3%	9.0%	37.7%
5	1.5	0.5		1	0.5	**9**		2						0.5			1.5							0.5	17	52.9%	30.1%	75.8%
6		4.5	0.5				**2.5**																		7.5	33.3%	0.0%	68.3%
7	6.5	19.5	1	2.5		2.5		**72.5**		0.5				0.5			0.5		2		1	0.5			109.5	66.2%	58.3%	74.1%
8	1.5	0.5	1.5	5	0.5				**4**						0.5		1								14.5	27.6%	4.8%	50.3%
10		0.5		0.5				3		**11.5**				0.5											16	71.9%	50.3%	93.5%
11ab	0.5			0.5	2				0.5		**3**							0.5		1.5					8.5	35.3%	2.4%	68.1%
11c				0.5								**4**	1.5						0.5						6.5	61.5%	22.5%	100.0%
11d													**4**												4	100.0%	87.5%	100.0%
12	2	0.5	3.5	0.5	0.5			1	0.5					**4.5**					1	0.5					14.5	31.0%	7.6%	54.5%
13		1						0.5							**1.5**	0.5									3.5	42.9%	0.0%	100.0%
14							0.5									**2.5**									3	83.3%	31.3%	100.0%
15						0.5		0.5									**1**								2	50.0%	0.0%	100.0%
16a																		**0**							0	0.0%	0.0%	0.0%
16b												0.5	0.5						**3.5**			0.5			5	70.0%	26.3%	100.0%
17a	0.5	0.5			0.5									0.5	0.5	1				**0**					3.5	0.0%	0.0%	14.3%
18	0.5	3.5		1				2.5					0.5								**4.5**				12.5	36.0%	9.7%	62.3%
19										0.5									0.5			**3**			4	75.0%	26.9%	100.0%
20								1															**1**		2	50.0%	0.0%	100.0%
22																								**3**	3	100.0%	83.3%	100.0%
Totals	35	126	18.5	43	15	15	7	138.5	11	20	4.5	4.5	6.5	12	4	6.5	5.5	1.5	8.5	3	7.5	4	1.5	3.5	502 Total Plots (263 Corrrect)			
Producer's Accuracy	41.4%	66.3%	35.1%	38.4%	46.7%	60.0%	35.7%	52.3%	36.4%	57.5%	66.7%	88.9%	61.5%	37.5%	37.5%	38.5%	18.2%	0.0%	41.2%	0.0%	60.0%	75.0%	66.7%	85.7%	Overall Accuracy = 52.4%			
90% Confidence Interval	26.3%	58.9%	14.2%	25.0%	22.1%	35.9%	0.0%	45.0%	8.0%	36.8%	19.0%	53.4%	22.5%	10.3%	0.0%	0.0%	0.0%	0.0%	7.5%	0.0%	23.9%	26.9%	0.0%	40.7%	Kappa Coefficient = 0.44			
	56.6%	73.6%	56.1%	51.7%	71.2%	84.1%	72.6%	59.7%	64.8%	78.2%	100.0%	100.0%	100.0%	64.7%	89.8%	77.5%	54.3%	33.3%	74.8%	16.7%	96.1%	100.0%	100.0%	100.0%				

Table 4-5. Idaho National Laboratory Site vegetation map error matrix produced using Fuzzy Level 4 Method 1. The map class code descriptions are listed in Table 4-7.

	Validation (Ground Reference) Data																										
Predicted (Map) Data: Map Class	1/9	2	3	4a	4b	5	6	7	8	10	11ab	11c	11d	12	13	14	15	16b	17a	18	19	20	22	Totals	User's Accuracy	90% Confidence Interval	
1/9	24.5	0.5	1.5	0.5				1		0.5						0.5	1.5	0.5						31	79.0%	65.4%	92.7%
2		162		1.5					0.5	3				0.5	1									168.5	96.1%	93.4%	98.9%
3		0.5	15																					15.5	96.8%	86.2%	100.0%
4a	0.5		0.5	34						1.5						1								37.5	90.7%	81.5%	99.8%
4b	0.5				14.5					1					0.5	0.5			1					18	80.6%	62.4%	98.7%
5						19											1							20	95.0%	84.5%	100.0%
6							9.5																	9.5	100.0%	94.7%	100.0%
7	0.5			1				111.5										1						114	97.8%	95.1%	100.0%
8		0.5	0.5						13.5								0.5							15	90.0%	73.9%	100.0%
10										14.5														14.5	100.0%	96.6%	100.0%
11ab	0.5										4.5								1.5					6.5	69.2%	31.8%	100.0%
11c												8												8	100.0%	93.8%	100.0%
11d													4											4	100.0%	87.5%	100.0%
12									0.5					10.5				0.5						11.5	91.3%	73.3%	100.0%
13															1.5									1.5	100.0%	66.7%	100.0%
14																4								4	100.0%	87.5%	100.0%
15																	2							2	100.0%	75.0%	100.0%
16b																		6						6	100.0%	91.7%	100.0%
17a															0.5				0					0.5	0.0%	0.0%	100.0%
18																				6				6	100.0%	91.7%	100.0%
19																					4			4	100.0%	87.5%	100.0%
20																						1		1	100.0%	50.0%	100.0%
22																							3.5	3.5	100.0%	85.7%	100.0%
Totals	26.5	163.5	17.5	37	14.5	19	9.5	112.5	14.5	20.5	4.5	8	4	11	3.5	6	5	8	2.5	6	4	1	3.5				
Producer's Accuracy	92.5%	99.1%	85.7%	91.9%	100.0%	100.0%	100.0%	99.1%	93.1%	70.7%	100.0%	100.0%	100.0%	95.5%	42.9%	66.7%	40.0%	75.0%	0.0%	100.0%	100.0%	100.0%	100.0%	502 Total Plots (473 Corrrect)			
90% Confidence Interval	82.1%	97.6%	69.1%	83.2%	96.6%	97.4%	94.7%	97.2%	78.7%	51.8%	88.9%	93.8%	87.5%	80.6%	0.0%	26.7%	0.0%	43.6%	0.0%	91.7%	87.5%	50.0%	85.7%	Overall Accuracy = 94.2%			
	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	89.7%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	86.0%	100.0%	20.0%	100.0%	100.0%	100.0%	100.0%	Kappa Coefficient = 0.93			

Table 4-6. Idaho National Laboratory Site vegetation map error matrix produced using Fuzzy Level 4 Method 2. The map class code descriptions are listed in Table 4-7.

Validation (Ground Reference) Data

Predicted (Map) Data

Map Class	1/9	2	3	4a	4b	5	6	7	8	10	11ab	11c	11d	12	13	14	15	16a	16b	17a	18	19	20	22	Totals	User's Accuracy	90% Confidence Interval	
1/9	15	1.5	4	3.5	0.5	1.5		2.5	1	0.5				1		0.5	1.5		0.5				0.5		34	44.1%	28.6%	59.6%
2	2.5	132	1	2.5	0.5	0.5			1	4.5				1	1				0.5		2				149	88.6%	84.0%	93.2%
3	1	2	8	2.5					3.5							0.5									17.5	45.7%	23.3%	68.2%
4a	2	3	0.5	20	0.5			2.5	1	1.5				3		1									35	57.1%	42.0%	72.3%
4b	1.5	11		4	8.5				0.5	1	1.5				0.5	0.5				1					30	28.3%	13.1%	43.5%
5	0.5	0.5				11.5		2						0.5			1.5							0.5	17	67.6%	46.0%	89.3%
6			0.5				7																		7.5	93.3%	71.7%	100.0%
7	7		1	2.5		2		92		0.5				0.5			0.5		2		1	0.5			109.5	84.0%	77.8%	90.2%
8	1	0.5	1.5	2.5	0.5				7						0.5		1								14.5	48.3%	23.2%	73.3%
10		1.5						2	0.5	11.5				0.5											16	71.9%	50.3%	93.5%
11ab	0.5			0.5	2.5						3							0.5		1.5					8.5	35.3%	2.4%	68.1%
11c				0.5								5.5							0.5						6.5	84.6%	53.6%	100.0%
11d													4												4	100.0%	87.5%	100.0%
12	2	1	2			1		0.5	0.5					6					1	0.5					14.5	41.4%	16.7%	66.1%
13		0.5					1								1.5	0.5									3.5	42.9%	0.0%	100.0%
14							0.5									2.5									3	83.3%	31.3%	100.0%
15						0.5		0.5									1								2	50.0%	0.0%	100.0%
16a																		0							0	0.0%	0.0%	0.0%
16b												0.5	0.5						4						5	80.0%	40.6%	100.0%
17a	0.5	0.5			0.5									0.5	0.5	1				0					3.5	0.0%	0.0%	14.3%
18	0.5	3.5		1				2.5				0.5									4.5				12.5	36.0%	9.7%	62.3%
19										0.5												3.5			4	87.5%	47.8%	100.0%
20								1															1		2	50.0%	0.0%	100.0%
22																								3	3	100.0%	83.3%	100.0%
Totals	34	157.5	18.5	39.5	13.5	17	8.5	105.5	15	20	4.5	6.5	4.5	13	4	6.5	5.5	0.5	8.5	3	7.5	4	1.5	3.5				
Producer's Accuracy	44.1%	83.8%	43.2%	50.6%	63.0%	67.6%	82.4%	87.2%	46.7%	57.5%	66.7%	84.6%	88.9%	46.2%	37.5%	38.5%	18.2%	0.0%	47.1%	0.0%	60.0%	87.5%	66.7%	85.7%				
90% Confidence Interval	28.6%	78.7%	21.6%	36.3%	37.6%	46.0%	55.0%	81.4%	22.1%	36.8%	19.0%	53.6%	53.4%	19.6%	0.0%	0.0%	0.0%	0.0%	13.0%	0.0%	23.9%	47.8%	0.0%	40.7%				
	59.6%	89.0%	64.9%	65.0%	88.3%	89.3%	100.0%	93.0%	71.2%	78.2%	100.0%	100.0%	100.0%	72.7%	89.8%	77.5%	54.3%	100.0%	81.1%	16.7%	96.1%	100.0%	100.0%	100.0%				

502 Total Plots (352 Corrrect)

Overall Accuracy = 70.1%

Kappa Coefficient = 0.65

Table 4-7. Idaho National Laboratory Site vegetation map class accuracy assessment summary.

Class Code	Community Class Name	Method 1		Method 2		Fuzzy 1		Fuzzy 2	
		User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
1/9	Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation	71.2%	77.0%	42.6%	41.4%	79.0%	92.5%	44.1%	44.1%
2	Big Sagebrush Shrubland	62.9%	77.6%	56.0%	66.3%	96.1%	99.1%	88.6%	83.8%
3	Needle and Thread Herbaceous Vegetation	69.4%	73.5%	37.1%	35.1%	96.8%	85.7%	45.7%	43.2%
4a	Green Rabbitbrush Shrubland	76.7%	67.5%	47.1%	38.4%	90.7%	91.9%	57.1%	50.6%
4b	Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation	55.3%	76.5%	23.3%	46.7%	80.6%	100.0%	28.3%	63.0%
5	Green Rabbitbrush - Winterfat Shrubland	80.6%	90.6%	52.9%	60.0%	95.0%	100.0%	67.6%	67.6%
6	Basin Big Sagebrush Shrubland	50.0%	50.0%	33.3%	35.7%	100.0%	100.0%	93.3%	82.4%
7	Wyoming Big Sagebrush Shrubland	79.0%	61.5%	66.2%	52.3%	97.8%	99.1%	84.0%	87.2%
8	Green Rabbitbrush/Desert Alyssum Shrub Herbaceous Vegetation	60.0%	71.4%	27.6%	36.4%	90.0%	93.1%	48.3%	46.7%
10	Crested Wheatgrass Semi-natural Herbaceous Vegetation	85.3%	69.0%	71.9%	57.5%	100.0%	70.7%	71.9%	57.5%
11ab	Bluebunch Wheatgrass - Sandberg Bluegrass Herbaceous Vegetation	66.7%	100.0%	35.3%	66.7%	69.2%	100.0%	35.3%	66.7%
11c	Utah Juniper Wooded Shrub and Herbaceous Vegetation	80.0%	100.0%	61.5%	88.9%	100.0%	100.0%	84.6%	84.6%
11d	Utah Juniper Woodland	100.0%	66.7%	100.0%	61.5%	100.0%	100.0%	100.0%	88.9%
12	Indian Ricegrass Herbaceous Vegetation	61.5%	80.0%	31.0%	37.5%	91.3%	95.5%	41.4%	46.2%
13	Cheatgrass Semi-natural Herbaceous Vegetation	50.0%	42.9%	42.9%	37.5%	100.0%	42.9%	42.9%	37.5%
14	Great Basin Wildrye Herbaceous Vegetation	100.0%	66.7%	83.3%	38.5%	100.0%	66.7%	83.3%	38.5%
15	Sickle Saltbush Dwarf Shrubland	100.0%	40.0%	50.0%	18.2%	100.0%	40.0%	50.0%	18.2%
16a	Sandberg Bluegrass Herbaceous Vegetation	0.0%	0.0%	0.0%	0.0%	N/A	N/A	0.0%	0.0%
16b	Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation	90.9%	62.5%	70.0%	41.2%	100.0%	75.0%	80.0%	47.1%
17a	Tall Tumblemustard - Cheatgrass Semi-natural Herbaceous Vegetation	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
18	Three-tip Sagebrush Shrubland	66.7%	93.3%	36.0%	60.0%	100.0%	100.0%	36.0%	60.0%
19	Low Sagebrush Dwarf Shrubland	85.7%	75.0%	75.0%	75.0%	100.0%	100.0%	87.5%	87.5%
20	Spiny Hopsage Shrubland	100.0%	100.0%	50.0%	66.7%	100.0%	100.0%	50.0%	66.7%
22	Shadscale Dwarf Shrubland	100.0%	100.0%	100.0%	85.7%	100.0%	100.0%	100.0%	85.7%
		Overall Accuracy							
		70.7%		**52.4%**		**94.2%**		**70.1%**	
		Kappa Statistic							
		0.65		**0.44**		**0.93**		**0.65**	

4.3.3 Vegetation Class Summary

To simplify the interpretation of map class accuracy, our discussion will be primarily focused on the first error matrix (Method 1; Table 4-3), and the first fuzzy error matrix results (Fuzzy 1; Table 4-5).

Table 4-7 provides a convenient summary of individual class accuracies across all error matrix results. To assist with interpretation of the error matrix results, we provide brief summary interpretations for each map class below.

Class 1/9 - Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation

This map class was most commonly complexed with other classes, including both shrubland and herbaceous classes. The original (1) Green Rabbitbrush/Streambank Wheatgrass Shrub Herbaceous Vegetation class covered a broad spectrum of compositional variability from communities dominated by green rabbitbrush shrubs to communities almost entirely dominated by herbaceous streambank wheatgrass (*Elymus lanceolatus*). After Class 9 (Western Wheatgrass Herbaceous Vegetation) was combined with this class, the variability further increased which makes identifying this class in the imagery difficult because the spectral response overlaps with a number of other similar vegetation classes.

This class had mapping errors across a broad range of classes with a user's and producer's accuracy of 71.2% and 77.0%, respectively (Table 4-3). There was some improvement in class accuracy with the fuzzy assessment and user's accuracy improved to 79.0% while producer's accuracy showed a greater improvement to 92.5% (Table 4-5). This class has a greater number of commission errors, suggesting it is over-mapped and included in more map polygons than it was found in validation plots.

This class tends to dominate localized areas and is patchily distributed across the landscape in vegetation complexes. The patchy nature of this class may have been responsible for the greater number of errors present, because depending on where the validation plot falls on the landscape, this class would not likely be equally abundant across large regions. The user's and producer's accuracy showed little improvement between the initial error matrix and the fuzzy error matrix (Table 4-7), suggesting it was regularly a component of two-class complexes but was often not included in the validation plot data.

Class 2 - Big Sagebrush Shrubland

This map class was the most widespread and abundant vegetation class mapped on the INL Site. Class 2 was complexed with both shrubland and herbaceous vegetation classes, although the greatest amount of mapped area was as a stand-alone class.

In the imagery, the big sagebrush vegetation classes appear very similar, and discriminating between those classes can be difficult and likely contributed to some of the mapping errors. Big sagebrush has a characteristic rough, darker texture created by the shrub canopy. As shrubs become larger and structurally more complex, they look darker, which is likely due to scattering of light in the shrub crown. Class 2 generally appears darker than stand-alone Class 7, but not as dark as Class 6.

Class 2 had numerous initial mapping errors, however the vast majority of those errors occurred between the similar (7) Wyoming Big Sagebrush Shrubland class (Table 4-3). These errors were expected and understandable because Class 2 can actually contain areas locally dominated by Class 7, and Class 2 represents the mixed big sagebrush and/or hybridized big sagebrush communities. We observed numerous locations on the ground where large sagebrush communities contained patches of both stand-alone Class 7 and other areas (typically on subtle slopes of basalt outcrops or regions of greater moisture accumulation) where this class was mixed with the (6) Basin Big Sagebrush class.

Both Class 7 and Class 6 were assigned to Fuzzy Level 4 due to the inherent similarity between these vegetation classes. The fuzzy assessment showed a marked improvement in class accuracy with user's and producer's accuracy increasing to 96.1% and 99.1%, respectively (Table 4-5). These results show that nearly all mapping errors in Class 2 occurred between the other two big sagebrush classes.

Class 3 - Needle and Thread Herbaceous Vegetation

This map class was most commonly complexed with other herbaceous classes, particularly the (12) Indian Ricegrass Herbaceous Vegetation class. This class was most prevalent in regions of the INL Site that have burned recently, and in these areas Class 3 and Class 12 regularly mix at fine spatial scales and are difficult to distinguish in the imagery.

The majority of mapping errors occurred between this class and other vegetation classes which are also common in recently burned areas. The fuzzy assessment shows a marked improvement with a user's accuracy of 96.8% and producer's accuracy of 85.7%. We observed substantial vegetation class variability across wildland fire scars where multiple classes can be found in localized areas.

Class 4a - Green Rabbitbrush Shrubland

This map class was commonly complexed with both shrub and herbaceous communities, but was also occasionally mapped as a stand-alone class. Mapping errors were found among both shrub and herbaceous dominated classes. The significantly lower class accuracies reported using Method 2 (Tables 4-4 and 4-6) suggests this class was included in numerous complexes where it was not recorded in the validation plot data.

The fuzzy assessment showed improvement with a user's and producer's accuracy of 90.7% and 91.9%, respectively. The errors remaining after the fuzzy assessment were predominantly due to confusion with the big sagebrush communities (Classes 2, 6, and 7). These errors are understandable because green rabbitbrush can be an abundant or even co-dominant species within big sagebrush communities. It is important to note that the three big sagebrush classes, when compared with this class, were all above the Bray-Curtis similarity threshold we selected. However, we eliminated these combinations from consideration when we decided to limit the number of classes assigned to Fuzzy Level 4. However, we could have further increased the reported class accuracy by including the big sagebrush classes. The dichotomous key used during field validation data collection was weighted toward the big sagebrush classes even when green rabbitbrush was abundant in the plot. This scenario likely contributed to some of the mapping errors between these classes when green rabbitbrush was identified in the imagery, and was possibly co-dominant in the field, but the field crews keyed the validation plot to one of the big sagebrush classes.

Class 4b - Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation

This map class was most commonly complexed with other classes including both shrubland and herbaceous classes. Mapping errors error occurred across a wide variety of Class 4b vegetation class complexes.

This class initially had a below average user's accuracy of 55.3%, while the producer's accuracy was notably better at 76.5%. The fuzzy assessment showed a large improvement in class accuracy with a producer's accuracy of 100%. User's accuracy remained consistently lower in all error matrix accuracy assessments, but especially in the two matrices populated using Method 2 (Tables 4-4 and 4-6). Low user's accuracy indicates the commission error rate (overpredictions) is high and this class was included in complexes more often than it was recorded in the validation plot data.

Some of the overpredictions of this class can be explained by one large map polygon. A single map polygon 81.8 km^2 (20,232.2 acres) on the western side of the INL Site north of State Highway 20/26 was mapped as a (2) Big Sagebrush Shrubland and (4b) Green Rabbitbrush/Bluebunch Wheatgrass Shrub Herbaceous Vegetation class complex. Field observations and plots sampled in 2008 indicate the presence of Class 4b, but the validation plots primarily recorded Class 2. This single polygon contained 20 validation plots due to the area it covers, and because Class 4b was not regularly recorded in the validation plot data, it is responsible for a large number of the mapping errors reported.

Class 5 - Green Rabbitbrush - Winterfat Shrubland

This map class occurred most frequently in class complexes with other shrub or dwarf shrub vegetation classes. Class 5 includes high compositional variability, ranging from communities that closely resemble other green rabbitbrush shrublands when winterfat is present with lower cover, to the opposite end of the spectrum, where winterfat is clearly dominant, almost forming a monotypic stand with little to no green rabbitbrush presence.

When this class is dominated by winterfat it is characterized by low vegetative cover causing brighter image pixels which are distinct from most other classes except for some of the salt desert shrub classes (e.g., [15] Sickle Saltbush Dwarf Shrubland). When green rabbitbrush dominates this class, it appears more similar to other rabbitbrush-dominated communities in the imagery, and becomes more difficult to identify.

Class 5 had some of the highest initial class accuracies with a user's and producer's accuracy of 80.6% and 90.6%, respectively. The few errors that occurred with this class were from confusion between other green rabbitbrush-dominated communities (e.g., [1/9] Green Rabbitbrush/Streambank Wheatgrass (Western Wheatgrass) Shrub Herbaceous Vegetation and [4a] Green Rabbitbrush Shrubland). The fuzzy assessment accounted for most of these mapping errors, resulting in a user's and producer's accuracy of 95% and 100%, respectively.

Class 6 - Basin Big Sagebrush Shrubland

This map class had a much more limited distribution and abundance compared to the other big sagebrush classes. Class 6 was most commonly mapped as a stand-alone class across many small polygons with a mean size of only 30 acres.

This class was commonly confused with the (2) Big Sagebrush Shrubland class which caused low initial class accuracies of 50%. Considering Class 6 can be locally present in Class 2, errors between these classes were expected and are of less concern than other mapping errors. The fuzzy assessment accounted for all map errors and improved both user's and producer's accuracies to 100%. This class does have a smaller validation sample size compared to the other big sagebrush classes, but the distribution is limited and this class is generally rare on the INL Site. This class may be locally present within areas mapped as Class 2, but typically occurs on a small spatial scale within a larger mosaic of big sagebrush communities.

Class 7 - Wyoming Big Sagebrush Shrubland

This map class was widespread and has the second largest mapped area on the INL Site. Class 7 was most commonly mapped as a stand-alone class.

In the imagery, this class has the characteristic rough, dark texture associated with the big sagebrush classes. Class 7 generally had slightly lighter texture than either the (2) Big Sagebrush Shrubland or the (6) Basin Big Sagebrush class, but these classes appear similar and distinct from other shrub-dominated classes on the INL Site.

This class was most often confused with Class 2, and had moderate user's and producers' class accuracies with 79% and 61.5%, respectively. Class 7 can be a component of Class 2, and consequently these errors were expected and not interpreted as significant mapping problems. After the fuzzy assessment, user's and producer's accuracy improved to 97.8% and 99.1%, respectively. This class is likely the most widespread and abundant across the INL Site, because much of the area mapped as Class 2 contains large patches of Class 7. However, we could not always discriminate between the two in the imagery.

Class 8 - Green Rabbitbrush/Desert Alyssum Herbaceous Vegetation

This class was rarely mapped as a stand-alone class, and was most commonly complexed with other shrub-dominated classes. Class 8 was most commonly confused with the (4a) Green Rabbitbrush Shrubland class.

In the imagery, Class 8 and Class 4a appear very similar and knowledge of past and/or present disturbance regimes can aid in the separation of these classes. Simply, if the map polygon looks like Class 4a in the imagery but has burned recently and/or has been overgrazed by livestock, it is likely Class 8. This was confirmed from ground observations while we were assigning vegetation classes to mapped polygons.

All green rabbitbrush-dominated classes were assigned to Fuzzy Level 4. Correspondingly, there was a significant increase in class accuracy after the fuzzy assessment with a user's and producer's accuracy of 90% and 93.1%, respectively.

Class 10 - Crested Wheatgrass Semi-natural Herbaceous Vegetation

This map class is most prevalent along roadsides across the INL Site, and in regions where it has been seeded in the past. Class 10 was mapped as a stand-alone class most often, but also complexes with numerous shrubland and herbaceous vegetation classes.

There were some areas in the imagery where this class was easily identifiable, and other areas where known ground locations were not even partially visible. We suspect that differential senescence (i.e., some plants were already senescent while other were still active) across the INL Site contributed to the visual differences in the imagery making it more difficult to delineate this class in some areas.

The fuzzy assessment showed an improvement in the user's accuracy resulting in a class accuracy of 100%. Producer's accuracy increased by less than 2% after the fuzzy assessment, resulting in a class accuracy of 70.7%. A low producer's accuracy means the omission error rate was high, suggesting we did not map this class in a number of locations where a validation plot recorded Class 10 present. Some of the mapped area for Class 10 occurred along roadsides that were excluded from our validation plot site selection strategy (i.e., 100 m road buffers), although field observations confirm many of these areas even though no validation plots were actually sampled.

Class 11ab - Bluebunch Wheagrass- Sandberg Bluegrass Herbaceous Vegetation

This map class was predominantly distributed in regions that have experienced recent wildland fire without additional disturbances. Class 11ab commonly complexed with both shrub and herbaceous vegetation classes, and was only mapped as a stand-alone class three times.

The most common mapping errors occurred with the (17a) Tall Tumblemustard-Cheatgrass Semi-natural Herbaceous Vegetation class. Both Class 11ab and Class 17a tend to be distributed in areas that have experienced recent disturbance. We observed localized patches of Class 17a in old stream channels within large areas dominated by Class 11ab (particularly in the southeast corner of the INL Site), and this was likely the reason for the errors between these classes.

Producer's accuracy was 100% after the initial assessment but user's accuracy was notably lower at 61.5%. The fuzzy assessment only showed a slight increase in users' accuracy to 69.2%, suggesting that this class was over-mapped. It is important to recognize that validation plot sample sizes for this class were lower than expected. Additional validation plots would help refine our accuracy estimates.

Class 11c - Utah Juniper Wooded Shrub and Herbaceous Vegetation

This map class forms a distinct patchy distribution across the landscape with characteristic interspaces between trees where shrub and herbaceous classes dominate. This class was commonly complexed with the (16b) Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation class and we regularly observed Class 16b on slopes particularly near the Lemhi Range.

This map class was one of the easiest to visually identify in the imagery as individual juniper crowns are clearly recognizable. Defining the class boundaries was more difficult because juniper trees tended to gradually become sparse on lower slopes with interspace gaps increasing and eventually transitioning into the lower elevation vegetation classes.

This class was commonly mistaken for the (11d) Utah Juniper Woodland class because it basically represents the same class but with greater total juniper canopy cover. All of the initial map errors were between Class 11d, and class accuracies increased to 100% after the fuzzy assessment.

Class 11d - Utah Juniper Woodland

This class was most often mapped as a stand-alone class. This map class has the same spatial pattern as the (11c) Utah Juniper Wooded Shrub and Herbaceous Vegetation class where there are distinct gaps in the tree canopy and understory vegetation dominates. Class 11d differs from Class 11c in that the juniper canopy cover is greater, and trees are generally distributed more densely.

This map class was easily identified in the imagery as regions where individual juniper tree crowns were more closely spaced contributing to greater canopy cover. The main difficulty delineating this class was deciding where to digitize the polygon boundary, as this class is usually contained within larger stands of Class 11c.

Nearly all of the initial mapping errors occurred with Class 11c, because slope in the terrain can make Class 11c erroneously appear more dense in the imagery. Class accuracies improved to 100% after the fuzzy assessment.

Class 12 - Indian Ricegrass Herbaceous Vegetation

This class was mapped with both shrubland and herbaceous class complexes, and was only mapped as a stand-alone class four times. Class 12 was most frequently complexed with the (3) Needle and Thread Herbaceous Vegetation class.

Both Class 12 and Class 3 are prevalent in regions that have recently burned and tend to form even mixtures at fine spatial scales across the burned area. Class 12 can be difficult to identify in the imagery and appears similar to other herbaceous classes.

Class accuracies increased considerably after the fuzzy assessment with a producer's and user's accuracy of 91.3% and 95.5%, respectively.

Class 13 - Cheatgrass Semi-natural Herbaceous Vegetation

The distribution of this class was widespread across the INL Site, but cheatgrass is rarely dominant outside of areas that have been greatly disturbed, resulting in small patch sizes. This class is likely present more often in localized patches throughout many of the big sagebrush map classes (e.g., the (2) Big Sagebrush Shrubland class polygon located across the core of the INL Site), but never encompasses enough area to warrant adding this class to a map complex.

This class exhibits a distinct reddish appearance in the imagery, which is likely caused by the early senescence of cheatgrass while native species are still green. The reddish spectral cue can be confused with the (17a) Tall Tumblemustard- Cheatgrass Semi-natural Herbaceous Vegetation class which also contains cheatgrass as a class component.

Initial class accuracies were low with a user's and producer's accuracy of 50% and 42.9%, respectively. The fuzzy assessment resulted in a user's accuracy of 100%, but producer's accuracy showed no improvement and remained low at 42.9%. A low producer's accuracy means there were areas identified on the ground where Class 13 was not assigned to the map polygon. The high user's accuracy means that if Class 13 was mapped present, it was always found there. It is important to note that the validation sample size for this class is limited, and our estimates of map class accuracy could be improved. Additional validation data for this class would better estimate the map accuracy.

Class 14 - Great Basin Wildrye Herbaceous Vegetation

This map class is fairly widespread but limited in total acreage. Class 14 was commonly mapped as a stand-alone class when remnant playa features were large enough to be delineated. When the (14) Great Basin Wildrye Herbaceous Vegetation class was complexed, it was generally in areas where numerous small playas could be found distributed across the landscape. Often times this class was included in a two-class complex, however, it generally covers much less total area than the class it's complexed with.

This map class is fairly distinct in the imagery and has a unique appearance compared to other herbaceous classes. Class 14 can be recognized as brighter, yellowish patches with a smooth texture in the imagery.

User's accuracy was 100% after the initial assessment, but producer's accuracy was significantly lower at 66.7%. Class 14 had no other classes assigned to Fuzzy Level 4, therefore the fuzzy assessment did not improve the producer's accuracy. The validation plots were limited for this class, and were generally located in two-class complexes. The stand-alone Class 14 polygons were typically too small for validation plots to randomly fall within their extent.

Class 15 - Sickle Saltbush Dwarf Shrubland

This map class was limited in distribution to areas around the historical Big Lost River (BLR) floodplain near the BLR Sinks wetland, and also in the low-lying region of historical Lake Terreton. Class 15 was mapped as a stand-alone class more often that it was complexed.

This map class has a distinct signature in the imagery, characterized by very bright image pixels. The low total vegetative cover associated with Class 15, as well as the other salt-desert shrub classes, creates the distinctive bright pixels and makes it easy to recognize across the INL Site. Discriminating between the salt desert shrub communities can be more difficult as they all appear similar.

After the initial assessment, user's accuracy was 100%, but producer's accuracy was substantially lower at 40.0%. There were no other classes assigned to Fuzzy Level 4, and the fuzzy assessment did not contribute to any improvement in the producer's accuracy. Validation plot sample sizes for this class are low because the map polygon sizes where this community is present are generally small and do not support multiple validation plots within an array.

Class 16a - Sandberg Bluegrass Herbaceous Vegetation

This map class was rarely included in other class complexes and was only mapped as a stand-alone class one time. Although this class can be found as localized small patches in a number of other map classes, it rarely dominates a large enough area to include as a complex. There was only one validation plot collected where Class 16a represented the plot majority, and only a single validation plot where 16a was complexed with another class.

Map class accuracies are both poor with 0% in both the initial error matrix and fuzzy assessments. This class only has mapping errors present in the initial error matrix with no true positives. Class 16a was removed from the fuzzy error matrix (Table 4-6) because it contained no errors or correct tallies. If we had completed the delineations prior to collecting the validation data, we may have been able to select a plot within mapped polygons to do a better job assessing the accuracy of this class. Addition validation data would help refine the estimates of map class accuracy.

Class 16b - Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation

This map class is fairly common across the northern half of the INL Site, especially in and around the Lemhi Mountain Range. Class 16b regularly forms complexes with both juniper classes ([11c] Utah Juniper Wooded Shrub and Herbaceous Vegetation and [11d] Utah Juniper Woodland) throughout the Lemhi Mountain Range where it is found on slopes between juniper trees. Class 16b is also found in small patches within a larger mosaic of big sagebrush communities associated with changes in topography.

The initial user's accuracy was high with 90.9% while the producer's accuracy was lower with 62.5%. The (19) Low Sagebrush Dwarf Shrubland class was the only other class assigned to Fuzzy Level 4. The fuzzy assessment did not account for most errors present in the map and only slightly improved the producer's accuracy to 75%.

Class 17a - Tall Tumblemustard- Cheatgrass Semi-natural Herbaceous Vegetation

Class 17a was commonly mapped as a complex with both shrubland and herbaceous classes. This class is predominantly found in areas that have experienced past or ongoing disturbance(s).

This map class has a reddish appearance in the imagery which is very similar to the (13) Cheatgrass Semi-natural Herbaceous Vegetation class. Cheatgrass can be abundant in each of these classes and is likely responsible for the red tones visible in the imagery.

This map class had the lowest accuracies in the accuracy assessment, and mapping errors were evident across a number of other vegetation classes. All accuracy assessments resulted in 0% class accuracy. The most common mapping errors occurred with the (11ab) Bluebunch Wheatgrass-Sandberg Bluegrass Herbaceous Vegetation class. Regardless of the negative results calculated from the validation data, there are areas where field observation confirmed the presence of this class in mapped polygons. Additional validation plots are needed to refine the estimates of class accuracy.

Class 17b - Remnant Riparian Shrub Herbaceous Vegetation

This map class is very limited in size, and distribution is limited to a single polygon in the historical Birch Creek drainage near the northern extent of the INL Site. There are numerous small patches along the BLR channel where remnant riparian vegetation still exists, but these patches never become large enough to be identified at the mapping scale used for this project.

The map polygon that includes this class complex was identified through field observation and not from a distinct spectral signature in the imagery.

This class is generally linear in shape with a narrow spatial extent which makes it difficult to fit a validation plot array inside the polygon. Consequently, we did not collect any validation data for this class. Considering there is only one polygon where this class is present, the accuracy assessment process was not hindered by the low validation plot sample sizes.

Class 18 - Three-tip Sagebrush Shrubland

This map class was limited in distribution primarily to the southern half of the INL Site and was always complexed with another class. On the southwest and southeast corners of the INL Site, this class was observed in flat and/or low lying areas within a larger matrix dominated by the big sagebrush classes ([2] Big Sagebrush Shrubland and [7] Wyoming Big Sagebrush Shrubland). In the region between Middle Butte and East Butte, this class was mapped in multiple complexes with the (11c) Utah Juniper Wooded Shrub and Herbaceous Vegetation class as well as the big sagebrush classes previously mentioned.

This class has the same characteristic texture as the other big sagebrush classes in the imagery and is not easily distinguished from those classes. Field observations were used to confirm this class' presence as image interpretation alone was inadequate.

The initial user's accuracy was 66.7%, and almost all errors were attributed to confusion with Class 2 and Class 7 in map complexes. Producer's accuracy was substantially higher at 93.3%. There were no additional classes assigned to Fuzzy Level 4.Because this class was only mapped as a complex, the fuzzy assessment accounted for the complex errors between the big sagebrush classes. Consequently, the fuzzy assessment resulted in a user's and producer's accuracy of 100%.

Class 19 - Low Sagebrush Dwarf Shrubland

This map class was limited in distribution to the northern extent of the INL Site. There is one large map class that extends both directions from State Highway 22 near Richard's Butte. This class occasionally forms complexes with nearby polygons ranging west toward the historical Birch Creek channel. Due to the limited distribution of this class, it was difficult to collect additional field validation plots that were independent and not in close proximity to previous plots.

Class 19 does not have the same characteristic rough, dark texture that is evident across the big sagebrush classes. This class appears smoother and lighter colored in the imagery, and can almost be confused with herbaceous classes.

Initial class accuracies were high with a user's and producer's accuracy of 85.7% and 75.0%, respectively. The (16b) Black Sagebrush/Sandberg Bluegrass Dwarf-shrub Herbaceous Vegetation was the only corresponding class assigned to Fuzzy Level 4. The fuzzy assessment improved the user's and producer's accuracies to 100%. Given the small range and area this map class covers, the low validation sample size was acceptable.

Class 20 - Spiny Hopsage Shrubland

This map class is limited in area across the northern half of the INL Site. Class 20 was most commonly mapped as a complex with the (7) Wyoming Big Sagebrush Shrubland class, but can also occur at fine spatial scales across the INL Site in a number of other map classes.

One validation plot was collected where this class represented the majority, and it was mapped correctly resulting in 100% class accuracies. The validation plot sample size was very low, but considering the limited size and distribution of this class, it would have been difficult to select additional plot locations.

Class 21 - Dwarf Goldenbush Dwarf Shrubland

This class occurs at very small spatial scales well below the mapping scale used in this project. This class is found on exposed basalt outcrops and occurs locally among numerous map classes. The area this class covers would not be effectively sampled using our validation plot array design, and an alternative validation sampling strategy would need to be developed to adequately sample this class in the field.

Class 22 - Shadscale Dwarf Shrubland

This map class was mostly limited in distribution to the northern region of the INL Site, primarily in the area around the historical Birch Creek Playa and Lake Terreton. Class 22 was mapped as a stand-alone class and also included in two-class complexes.

In the imagery, this map class appears characteristically bright and can almost look white because of the low vegetative cover and large reflectance caused by exposed soil. Even though this class has a unique signature in the imagery compared to the majority of vegetation classes on the INL Site, it appears similar to other salt desert shrub classes and can be confused with them.

User’s and producer’s accuracy were both 100% prior to the fuzzy assessment. The area and distribution of this map class is limited, and although the validation plot sample size is low, it was acceptable for the accuracy assessment.

4.3.4 Mapping Summary

The accuracy assessment methods presented in this Chapter were developed to accommodate the two-class complex scenarios employed throughout this project. This approach is a modification of standard methods, which resulted in accuracy metrics common to most mapping studies and makes interpretation and comparisons to other map products feasible. Until alternative statistical methods are developed to address multiple class comparisons, our approach provides and objective evaluation and foundation for understanding the map accuracy.

The vegetation accuracy assessment found highly accurate results for the overall map and also individual class accuracies for most vegetation classes. Although there has never been a quantitative evaluation of previous INL Site vegetation maps, the new map is the most detailed and likely the most accurate ever produced. The lowest class accuracies were associated with vegetation classes that had small validation sample sizes. In many cases, the small sample sizes were a consequence of a limited distribution and/or small geographic extent. Most classes that had widespread distributions and covered large amount of mapped area, were well represented by validation plots and the resulting class accuracies were high.

Of all the vegetation map classes, the three big sagebrush-dominated classes may be some of the most important vegetation classes on the INL Site. The two most common big sagebrush classes ([2] Big Sagebrush Shrubland and [7] Wyoming Big Sagebrush Shrubland) had the largest validation sample sizes, and were found to be very accurate with the fuzzy assessment ranging from 96%-100% for both user's and producer's accuracy in each class. Big sagebrush communities support sagebrush obligate species (e.g., greater sage-grouse [*Centrocercus urophasianus*]), many of which are declining range-wide. The ability to accurately identify the distribution of sagebrush habitat has important implications for conservation management planning and the development of predictive species models on the INL Site.

5.0 Map Applications and Other Considerations

5.1 Using the INL Site Vegetation Map

Although our approach to this classification and mapping project was based on commonly accepted methodologies, we explored some novel approaches to specific components of the process which may affect the overall interpretation and use of the products. In addition, there are limitations to all classifications and mapping products that should be considered by end users. We encourage all potential users to understand how the classification and map were derived and to consider the strengths and limitations of the products as they apply to various applications.

Each plant community will encompass a range of variability in both vegetative cover and species composition, and overlap among classes is a standard result of classification analyses. Interpreting plant communities into meaningful and mapable units requires designations which result in vegetation classes which are inherently variable. The ambiguity associated with classification results often stems from species distributions which vary continuously across the landscape (Anderson 1991). The same is true of the vegetation classes defined for the Idaho National Laboratory (INL) Site; therefore, users of the INL Site vegetation map are encouraged to consider the range of community variability which is represented by each vegetation class and relationships between vegetation classes when using the class descriptions, dichotomous key, and map.

The vegetation class map contains numerous map polygons that were assigned to two-class complexes. It is important for map users to recognize that when visiting polygons in the field, one should not expect to find both vegetation classes present in all locations within a polygon. Some map classes are inherently patchy and should not be expected to occur evenly across a map polygon. Conversely, there may be times when both vegetation classes assigned to the map polygon are found evenly mixed in a localized area. More often, each class will be found locally abundant but distributed in a larger patchwork mosaic across the landscape. A map user can refer to the vegetation class Fact Sheets (Appendix D) to understand which classes are inherently patchy and which classes can form even mixtures within a complex. By complexing multiple vegetation classes, standard map accuracy calculations are complicated and evaluation methods must be modified.

There are a variety of accuracy metrics that can be produced from an error matrix, and although we report multiple measures of map and class accuracy, there are other metrics (e.g., misclassification rate, false positive rate, etc.) that may be best suited for some studies. For example, depending on the goals of individual research projects, certain errors may be considered more costly than others and associated error weights can be assigned to improve modeling and predictive abilities. We have included each of the raw error matrix tables in Chapter 4 to enable map users to calculate whatever other accuracy metrics are most pertinent for their intended application.

The vegetation classes were mapped at a 1:12,000 scale and may provide too much detail for some projects that are only concerned with major cover type distributions (e.g., shrublands, grasslands, etc.). Map polygons can always be hierarchically collapsed into more general map classes to facilitate comparisons to other data products or simplify the dataset for models that only require vegetation cover types rather than detailed classes and class complexes. For example, if a project was seeking to predict habitat for sagebrush obligate species, all the classes that contained a sagebrush-dominated community could be selected and exported using a Geographic Information System (GIS) to create a new combined sagebrush class.

5.2 Comparison of Classification and Mapping Results other Projects

Many agencies are currently working towards completing inventories and maps of natural resources, including vegetation. Each program has defined different goals and objectives based on their specific needs. Consequently, there are a variety of products available, and while many products can be reasonably compared, there are notable differences between any two classification and mapping efforts. There are also substantial differences between this product and those previously published for the INL Site. Here, we discuss some of the differences between this map product and others, including some similarities and differences in methodologies and our assessment of those utility of those methods as they applied to this effort.

Classification methodologies can range from observational and qualitative in nature to quantitative and statistically rigorous. Our approach to classifying plant communities required the use of some informed decision making but was primarily quantitative in terms of the data collected and the analytical approach applied. By selecting the multivariate model and appropriate number of vegetation classes using optimality criteria, we arrived at a solution which was less arbitrary and more standardized than methods that had been previously applied to INL Site vegetation data. Though this approach had some limitations, particularly for rare communities, we concluded that it is more reproducible than many of the currently described alternate options.

Our vegetation community classification effort and previous classifications resulted in a similar total number of classes for INL Site vegetation. The most abundant classes from this classification, in terms of total area, were similar to abundant classes which had been described by previous classification efforts. The notable differences between this classification and others were in rare community types and communities dominated by non-native species. These differences were likely a result of our focus on identifying wildlife habitat and non-native communities which could affect the quality of habitat.

Association-level crosswalks between the classes identified by this local classification effort and the National Vegetation Classification (NVC; NatureServe 2010) were not always possible. In some cases, the classes identified through our analyses were not floristically detailed enough to be crosswalked at the Association level due to continuously variable understory compositions in spatially abundant classes or due to the localized nature of rare communities which resulted in sample sizes. In other instances, the NVC did not contain enough information to facilitate a crosswalk to the classes identified for this project. Nonetheless, the NVC was a valuable resource which helped in interpreting INL Site vegetation classes and it provides an important bridge between INL Site vegetation classes and those identified for resource management applications by neighboring agencies.

We initially recognized the possible limitation of automated image classifications (e.g., unsupervised or supervised) in a semi-arid environment where total vegetative cover is low and the spectral signature of vegetation classes overlap considerably in the imagery. There were numerous classes that were difficult to discriminate relying on image interpretation alone, and only through field observations were we able to identify some classes present on the ground. The manual mapping approach worked well for this project, and even though it may be more time consuming, it is likely the most accurate mapping method available given the image datasets we used for this project.

It is difficult to make comparison between the new vegetation map and previous vegetation maps, because there has never been a quantitative assessment of previous vegetation map products on the INL Site. The new vegetation map contains greater spatial detail as well as a greater number of vegetation classes (including the two-class complexes) than previously mapped on the INL Site. Craters of the Moon National Monument and Preserve (CRMO) completed a vegetation map in 2009 using the same imagery and similar processing methods (Bell et al. 2009). The map products are very comparable, in terms of the number of vegetation classes identified and the corresponding map class accuracies, however the vegetation class types vary considerably at CRMO.

An important factor to consider is the influence of scale on the mapping project, and this issue was recognized early in the National Park Service (NPS) Vegetation Inventory Program (TNC and ESRI 1994). The sampling scale used to collect vegetation to support the community classification is much finer than the mapping scale used during the image delineations. Vegetation classes defined from data sampled at 400 m2 plots may not directly translate to the 1:12,000 mapping scale. This can help explain why the map polygons were often assigned to two-class complexes rather than a single discrete class. Sampling at a fine scale captures the ecological pattern present in that specific locality; however, ecological patterns of plant communities can change as the sampling scale is increased.

The 1:12,000 mapping scale used during this project is larger than most regional vegetation or habitat datasets, such as Idaho GAP Analysis (Scott 1993) and U.S. Geological Survey (USGS) SAGEMAP (USGS 2011), which are both intended to be used at a 1:100,000 scale. The INL Site vegetation map classes can be collapsed to more general classes to facilitate the crosswalk with other regional datasets. The INL Site vegetation map can be utilized in broad-scale models intended for use at the 1:100,000 scale; however, the user needs to be cautious when incorporating coarser regional datasets into analyses conducted at scales larger than the intended use.

We anticipated that some of the defined vegetation classes would begin to mix and form mosaics and complexes at a coarser scale, so we designed our field validation sampling to address this. We collected field validation data in a plot array comprised of five subplots, each of which was keyed to one of the vegetation classes. We embraced the class variability within a plot array by developing rules to either assign the plot to a single class or a two-class complex. Although the two-class complexes required us to develop some novel approaches to accuracy assessment, we were pleased with the conceptual idea of the plot array. The plot array served to help bridge the gap between the field sampling scale and the mapping scale.

Fuzzy set theory allows for multiple class memberships when there are mixtures of classes that complicate the process of assigning a single class label to the map polygon. Fuzzy assessments are especially pertinent when classes overlap and share dominant species composition which was common for a number of vegetation classes defined at the INL Site. This approach allowed for a more meaningful interpretation of map errors and has been implemented previously by the NPS Vegetation Inventory Program (Hansen et al. 2004a, b, c; Salas et al. 2005). If appropriate data were available, a fully quantitative approach like that proposed by Townsend (2000) would be appropriate and informative to this process.

5.3 Recommendations for Vegetation Classification and Mapping Updates

Future plant community classification efforts on the INL Site could be improved by attempting to split relatively inclusive shrubland classes based on dominant understory species. Adequately targeting, sampling, and characterizing locally rare vegetation classes should also be a priority for updating this classification. Additionally, we recommend revisiting the approach to classifying communities dominated by non-native species because plots dominated by locally abundant non-native species with very restricted distributions (e.g., *Halogeton glomeratus* and *Salsola kali*) did not cluster independently from native classes.

Quantitatively sampling and classifying vegetation data at the intended mapping scale would be logistically difficult and resource intensive. However, reconciling the classification and mapping scale is an important consideration when using this mapping approach. In this and other mapping projects, class complexes have been used to address this scale issue. We recommend exploring novel quantitative sampling and experimental designs (like the plot array design we used for the accuracy assessment) to address overcoming scale limitations inherent to the community classification data.

The vegetation map could potentially benefit from additional remotely sensed datasets to update or refine the vegetation map if they become available site-wide. There have been a number of small research projects across the INL Site that have had more advanced sensor acquire imagery, but the data do not cover the entire INL Site. Hyperspectral imagery collects many spectral bands (i.e., tens to hundreds) which may improve the capability to discriminate between vegetation classes that appear the same in four-band color-infrared imagery used to create this vegetation map. Light Detection and Ranging (LIDAR) sensors collect high resolution topographic data models of the landscape. Using processing algorithms, LIDAR data can be analyzed to calculate surface feature heights. If we had information about vegetation heights, it may be possible to further refine two-class complexes where shrubland and herbaceous classes are both included. Herbaceous classes would expectedly have little to no vegetation heights captured with LIDAR data, where shrubland classes would have measurable height values.

The vegetation map should be considered a dynamic dataset that is continually updated through time, especially following disturbances that can alter vegetation classes across the landscape. Following large wildland fires, we suggest waiting until the first growing season post-fire to assign the new polygon(s) to a vegetation class. If digital imagery is collected to map the fire, the same image dataset can be used to modify or delineate new class boundaries. If no new image data are acquired, coarser resolution satellite imagery (e.g., Landsat TM) can be downloaded for free and used to delineate the new burn scar.

Aside from changes caused by large disturbance, the vegetation map should be reviewed and updated periodically to prevent it from becoming outdated. The new vegetation map provides a basemap template from which future revisions and modifications can be made directly to the map rather than starting an entirely new mapping effort. The National Agricultural Imaging Program (NAIP) collects high resolution digital imagery on a three-five year return interval across the entire State of Idaho. The NAIP image datasets are free to the public, have the same or similar specifications to the image datasets used during this mapping project, and are collected on an interval that would be appropriate to update the INL Site vegetation map.

Producing and maintaining high-quality vegetation maps can benefit many agencies, such as the Department of Energy, whose primary function is not land management. Vegetation maps can provide support for project planning and site selection studies, resource protection and rehabilitation, and sensitive and endangered species protection.

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