Expert Attribution for Auto-Key Improvements (LANDFIRE) and Advancing Methods for integration with the revised US-National Vegetation Classification Standard: GeoArea 2W

FINAL REPORT

Prepared by

NatureServe

For the NPS Vegetation Inventory Program & LANDFIRE

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A Network Connecting Science With Conservation

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Introduction

The Inter-agency LANDFIRE Program implemented a series of new procedures and tools for processing vegetation sample plot data to rapidly supply geo-referenced samples for dynamics modeling and vegetation mapping. This effort made substantial advances in processing several hundred thousand vegetation plots nationwide, including standardizing many sample attributes (species taxonomy, structural classes, etc.) and applying labels reflecting the LANDFIRE map legend. However, given the pace of project activity, there was limited time to identify systematic error within the processing *auto-keys* and internalize lessons learned to improve technical procedures. There was also limited ability to develop an expert-reviewed, independent sample data set for use in map accuracy assessment. Additionally, given recent developments, there is a desire to adopt the revised US-National Vegetation Classification (US-NVC) for future mapping of existing vegetation types as part of the LANDFIRE effort.

This project represents a cooperative research effort with federal agency partners to systematically review the results of automated sample plot labeling (*auto-keys*), identify sources of systematic error, and clarify needs for technical improvements. Through this review process, comparisons between the existing LANDFIRE map legend and new types described the US-NVC were evaluated and documented. The effort has also generated an expert-reviewed, independent sample data set for use in map accuracy assessment nationwide.

Project Goals

- Identify "accuracy" issues with the existing auto-keys and resultant labels.
- Identify spatial or thematic gaps in the current LANDFIRE national reference database.
- Develop recommended solutions/approaches to issues encountered.
- Build an independent data set that could be used in other applicable mapping projects (GAP, regional wildlife, state habitat maps, etc.).
- Identify issues specific to labeling training data based on the newly adopted National Vegetation Classification Standard hierarchy.
- Identify and document appropriate updates to NPS vegetation field methods documentation.

In-kind contributions to this effort have come from federal agency partners, including USGS (Gap Analysis Program and Earth Resources Observation and Science (EROS) Data Center), US Forest Service Rocky Mountain Research Station (RMRS) and Forest Inventory Analysis (FIA)), among others. The National Park Service retains considerable expertise in the use of project outputs and benefits directly from project outcomes. NatureServe ecologists have contributed expertise in U.S. vegetation types and processing procedures, and development of the LANDFIRE *auto-key* tools.

Background on LANDFIRE Auto-keys

A major need and hence objective of LANDFIRE was to compile geo-referenced vegetation data for the entire United States. These data needed to be combined into a single database and attributed in a consistent, repeatable fashion to NatureServe's Terrestrial Ecological Systems or a set of land use or land cover classes. Once attributed with ecological systems, the geo-referenced samples were used as training data in a mapping effort that utilized a modeling process whereby the samples were only one of several inputs to the model. Systems for Environmental Management (SEM), based in Missoula MT, was contracted by LANDFIRE to compile the LANDFIRE Reference Database, or LFRDB, of all relatively recent, geo-referenced vegetation samples (also called "plots") that could be obtained and processed.

LANDFIRE contracted with NatureServe to work with the LANDFIRE team to develop a methodology to automate attribution of the samples contained in the LFRDB to ecological systems or the other standardized land use/land cover classes. Prototyping and testing of this methodology evolved over several months in 2004 into a process involving two components: a set of floristic and structural rules for each vegetation type, and a computer application to use the plots from the LFRDB and the rules as inputs to generate results useable by LANDFIRE's mapping teams. The sets of floristic rules or criteria are now known as Sequence Tables, and the software application is called the Auto-key.

One of the main requirements for LANDFIRE map units was that they be differentiated floristically. Since abiotic variables were not consistently available for every plot, contextual landscape or abiotic information could not be used to differentiate vegetation types represented by the plots. In addition, sequence tables were intended to work with regional-scale patterns, as opposed to more local-scales. Thus keying each plot using only the required floristic data was the best way to assign a map unit to each plot.

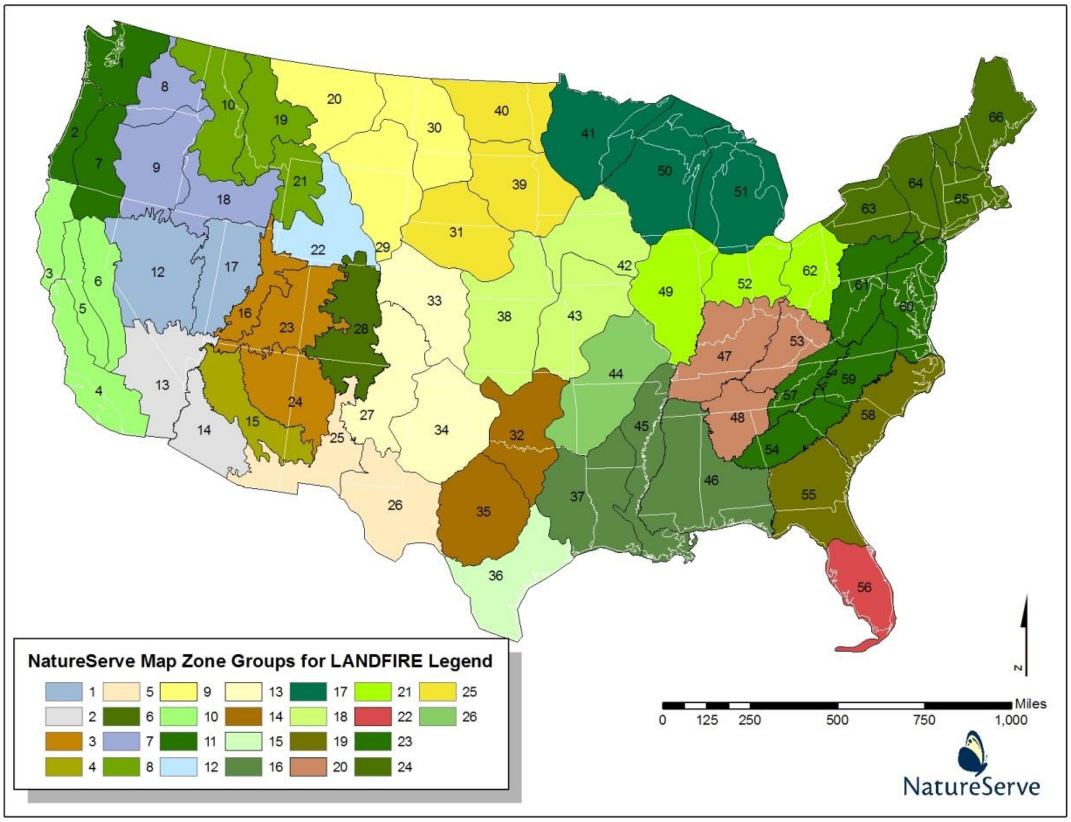
LANDFIRE's short-term needs, and long-term plans, required a repeatable methodology, consistently applied rules to categorize each reference sample, and documentation of the criteria applied. In essence, sequence tables codify the criteria and methods for keying geo-referenced vegetation data to a land cover class, whether it's an ecological system or some other vegetation category. Because of this, the methods are repeatable by anyone who may not necessarily be familiar with the vegetation of the region covered by a particular sequence table.

More details about this methodology include:

1. Each LANDFIRE sequence table was designed to efficiently automate keying of thousands to 10's of thousands geo-referenced vegetation samples to the LANDFIRE map units, which included both Ecological Systems for the 'natural' portions of the landscape, and a variety of land use or land cover classes for the remainder. The objective was to accurately key as many samples as possible, not to attempt to key all samples.
2. Each sequence table was created to key to systems and mappable US-NVC alliances in an ecologically-related geographic area, utilizing the MRLC map zones. There are 66 map zones for the conterminous US. NatureServe developed 26 sequence tables for these 66 map zones (Figure 1).
3. LANDFIRE also contracted with NatureServe to have dichotomous field keys written for all of the U.S. map zones. These keys were developed to cover the same map zones clusters as the sequence tables, and are available in MS Word documents for all of the U.S.
4. From a data processing standpoint, the vegetation samples first had to be formatted to match the specifications of the auto-key program created by USFS Missoula Fire Lab staff. We do not detail these formatting requirements here, as they are rather complex, and are completed by LANDFIRE contractors.
5. The sequence tables and vegetation samples are run through an automated Python application, developed by staff at the Missoula Fire Lab, called the "auto-key". The auto-key program sequentially compares each vegetation sample against criteria contained in the sequence table. Each ecological system type is represented in the sequence table via a set of vegetation composition criteria, which are organized in a particular order, or "sequence" (hence Sequence Table, or SQT). Each plot or point must meet all of the criteria for a particular ecological system, as represented by one sequence. If the sample meets all the criteria, the auto-key attributes the plot with the ecological system code and name. Samples which do not meet the criteria for a system can be attributed either with a more generic label, such as "unclassified forest and woodland", or else go through the entire SQT without keying and are attributed with "none".

Other land cover classes, such as introduced annual grasslands, or introduced riparian woody vegetation, are also included in a SQT to appropriately attribute any vegetation samples representing those land cover classes.

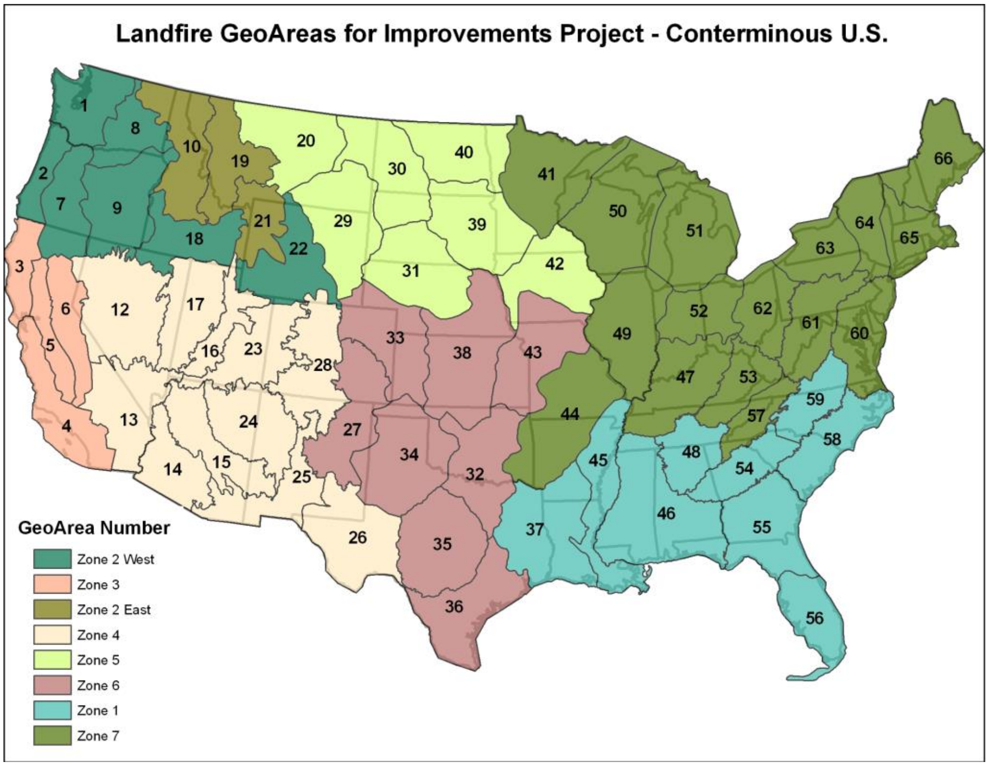
Figure 1. Groups of MRLC map zones that were the analysis units for the LANDFIRE sequence tables in the coterminous U.S.



Methods

For the LANDFIRE effort, both dichotomous field keys and auto-keys were developed for map legend classes and organized in a series of 17 map zone groupings that spanned the nation. For ongoing maintenance of national map products, the map zone groups have been further aggregated by LANDFIRE into larger geographic areas (GeoAreas). This project was organized around a modified form of these LANDFIRE GeoAreas (Figure 2). Within each GeoArea, project ecologists were provided with a subset of sample data for each relevant LANDFIRE map class (up to 30 sample plots). Using sample data on vegetation composition and structure, along with limited mapped ancillary data (for general orientation and ecological context), ecologists applied a map legend label to each sample. They documented their expert process for making label assignments, highlighting key pieces of information they used to arrive at their determination. The expert assignments were then compared to those previously applied through the LANDFIRE auto-keys assignments on spatially located field plots. Contingency tables were developed, analyzed, and documented. Key outcomes from each expert analysis include the contingency table, systematic discrepancies between expert and auto-key labels, and recommended changes to the auto-keys and technical procedures.

Figure 2. Modified LANDFIRE GeoAreas in the conterminous U.S. for use in this project.



Sample data were segmented by those that were used directly in LANDFIRE map production versus those that were held aside for use in accuracy assessment. Therefore, an expert-reviewed, independent sample data set for accuracy assessment was an additional project outcome. Expert ecologists were also be well-positioned to evaluate the results of auto-key assignments for LANDFIRE map legend classes in light of the related NVC Group and Macrogroup vegetation concepts that have been established and described.

For the expert reviews, the team needed to first determine the plot data available for use in the project and the sample design for selecting a subset of those plots. Secondly an evaluation was required of what kinds of data are contained in the plots that could be used for the expert review. The analysis team obtained counts of plots by map zone, GeoArea and system or land cover type, as well as counts of how many were used as training data in the mapping effort, or were withheld and used as the initial accuracy assessment plots. Additional counts were obtained for the number of plots acquired after the LANDFIRE mapping effort was completed in each GeoArea. A series of calls were held to discuss the number and distribution of plots by system type to be used in a "sample draw" for the expert review. Once the number of plots by system type by GeoArea was decided upon, the sample draw was completed by TNC and EROS team members, by selecting plots for each system randomly across all map zones in the GeoArea, with "independent" plots (not used in the original mapping effort) given selection priority.

The analysis team then reviewed in detail the available data tables and fields that are stored and managed in the LANDFIRE Reference Database (LFRDB). The data in the LFRDB is derived from many source datasets of varying quality and completeness. In addition, many plots in the LFRDB for forest types were provided by the Forest Inventory and Analysis (FIA) program, which has restrictions on sharing of their data. The discussions about what data to provide the experts for use in the labeling centered around:

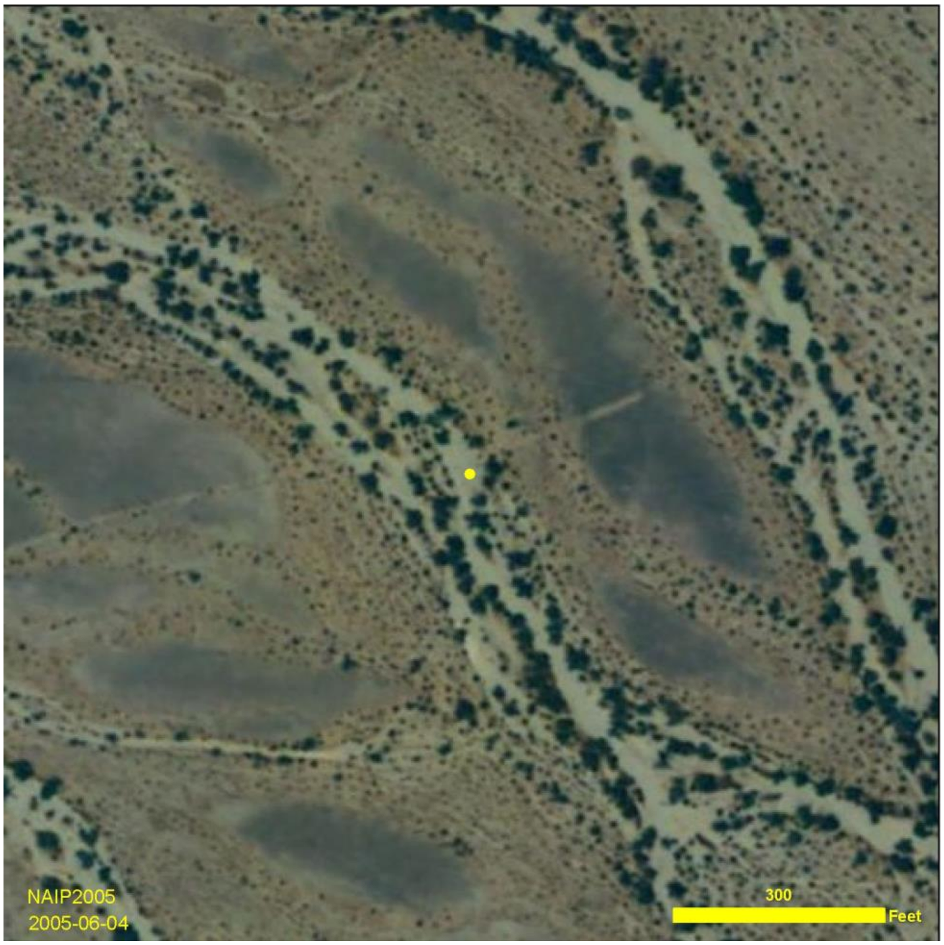
1. Providing the same data as are used in the auto-key procedures
2. Providing additional data that were not originally used in the auto-keys, and
3. Maintaining the "privacy" of the FIA data, ensuring the experts could not determine which plots were FIA vs not

Table 1 is a list of the general categories of data that were extracted from the LFRDB and provided to the experts for use in their review. After much discussion, it was also determined to provide a remotely-sensed image clip for each plot, as well as between 1 and 3 on-the-ground photos for the plot if such were available from the original data providers. These images provide some context for the expert reviewer, without revealing the exact location of the plot. The image clips were created automatically from the plot coordinates, and in the lower 48 were from NAIP imagery. All images were of the same scale, with the plot location a dot in the center of the image (Figure 3 is an example).

Table 1. Categories & fields of data provided to expert during review process.

Data category	Fields	Notes
Vegetation Structure	% cover of trees, shrubs, herbs, trees per acre, height of trees or shrubs	Values are calculated from source data & stored in LFRDB
Floristic composition	complete species list, % cover by species, nativity, height if available	Species list & % cover values are from the original source data, but other fields were derived by LANDFIRE
Dominant species	the 2 most dominant species within the major lifeform of the plot	The dominant and codominant species are provided, with % cover; the species are drawn from the dominant lifeform category of the plot (e.g. shrub dominated plots will have shrub species listed)
Geographic setting	map zone, USFS subsection, TNC ecoregion	These are derived by LANDFIRE from the coordinates of the plot
Landscape setting	elevation, aspect, slope	Values are derived form a DEM for the coordinates of the plot
Field notes	comments from field crew	Original field crew comments, if available
Image clips	Single image, same areal extent/scale for all plots	NAIP imagery was used for coterminous U.S. plots; coordinates in center of the image; no other locational information provided.

Figure 3. Example of an image clip for one plot in GeoArea 4.



NatureServe developed a MS Access 2007 relational database (the Expert Attribution Database, EADB) for use in the project. A user interface was designed to link to the above LFRDB data (provided by EROS in a separate LFRDB), the image clip, and any ground-photos in easily navigated forms for review by the expert. An additional form allowed the expert to select from a subset of system types when labeling plots. The reviewer was required to select from the ecological systems known or highly probable to occur in the GeoArea. If the expert could not label the plot with a system type, then "can't assign" was an additional option. All plots also required a confidence in label assignment (high, medium, low) and the expert was asked to document in comments why they assigned that confidence, or why they could not assign it to an ecological system.

After the expert reviews were completed for a particular GeoArea, the results were run through several quality control procedures to check for plots missing labels, or other discrepancies in the resulting data. Then a number of queries were run in the Access database, to generate summary statistics for each GeoArea, comparing labels on plots from the auto-keys and the experts.

Analysis Team

- Patrick Comer, NatureServe
- NatureServe Regional Ecologists (Marion Reid, Kristin Snow, Mary Harkness, Gwen Kittel, Keith Schulz, Mark Hall, Milo Pyne, Carl Nordman, Judy Teague, Lesley Sneddon, Jim Drake, Shannon Menard)
- Anne Davidson, GAP

- Don Long, USFS RMRS
- Brenda Lundberg, EROS
- Chris Toney, USFS FIA
- Alexa McKerrow, GAP
- Gretchen Meier, EROS
- Chris Lea, NPS
- Jim Smith, TNC, Overall Coordinator

Intended Products of this Effort

2.1 Tabular comparisons (as contingency tables) between LANDFIRE auto-key assignment and expert assignment for each GeoArea data set with an associated interpretation of the outcomes (systematic discrepancies between expert and auto-key labels, and recommended changes).
2.2 A report by each GeoArea detailing processes and results, specifically identifying how they made individual assignments.
2.3 A report that documents procedures and data elements to improve the auto-key process in each GeoArea.
2.4 A report that documents technical procedures to adapt auto-keys for labeling NVCS group, Macrogroup, and Division concepts.
2.5 Full data sets with independent assignments for each GeoArea in standard LFRDB format.
2.6 A single overall report with recommendations for all GeoAreas, including commonalities and unique issues.

Results

The following results for GeoArea 2W are organized according to these primary product deliverable categories:

2.1 Tabular comparisons (as contingency tables) between LF auto-key assignment and expert assignment for each GeoArea data set with an analysis and reports document (identified, systematic discrepancies between expert and auto-key labels, and recommended changes).
2.2 A report by each GeoArea detailing processes and results, specifically identifying how they made individual assignments.
2.3 A report that documents procedures and data elements to improve the auto-key process in each GeoArea.
2.4 A report that documents technical procedures to adapt auto-keys for labeling NVCS group, macrogroup, and division concepts.

GeoArea 2W: Northwest Basins and Coastal Ranges

GeoArea 2W encompasses 7 map zones (Figure 2): Northern Cascades (1), Oregon Coastal Range (2), Cascade Mountain Range (7), Grande Coulee Basin of the Columbia Plateau (8), Blue Mountain Region (9), Snake River Plain (18), and Wyoming Basin (22). These map zones were originally clustered for purposes of designing and implementing auto-keys (**Error! Reference source not found.**). The total umber of plots in this Geo Area analysis was 3,827. A total of 105 natural ecological system types were assigned to a total of 3,551 plots by the auto-keys. A total of 121 system types were assigned by experts (i.e., these included individual types that had been aggregated to broader classes by LANDFIRE for either sparsely vegetated types or wetland/riparian types).

Seventeen types were assigned by the auto-key but were not assigned by experts:

- Mediterranean California Mesic Serpentine Woodland and Chaparral
- Mediterranean California Subalpine Meadow
- Middle Rocky Mountain Montane Douglas-fir Forest and Woodland
- Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland
- Western Great Plains Shortgrass Prairie
- Inter-Mountain Basins Montane Riparian Systems
- Inter-Mountain Basins Sparsely Vegetated Systems
- Mediterranean California Sparsely Vegetated Systems
- North Pacific Sparsely Vegetated Systems
- North Pacific Swamp Systems
- Pacific Coastal Dunes and Other Sparsely Vegetated Systems
- Pacific Coastal Marsh Systems
- Rocky Mountain Alpine/Montane Sparsely Vegetated Systems
- Rocky Mountain Montane Riparian Systems
- Rocky Mountain Subalpine/Upper Montane Riparian Systems
- Western Great Plains Floodplain Systems
- Western Great Plains Sparsely Vegetated Systems

Twelve of these types are the aggregated types used by the LANDFIRE but the first five are Ecological Systems that could have been selected by the experts. The concepts and descriptions for these types may need to be revisited, with the likelihood of occurrence in the GeoArea reevaluated. All 5 of them are peripheral to the map zones in this GeoArea. If the type is still expected to occur additional guidance on how to apply the system relative to this GeoArea may need to be incorporated into the descriptions.

Comparison of Auto-key and Expert Assignments

2.1 Tabular comparisons (as contingency tables) between LF auto-key assignment and expert assignment for each GeoArea data set with an analysis and reports document (identified, systematic discrepancies between expert and auto-key labels, and recommended changes).

Of the 93 natural types assigned labels by the auto-keys, 15 types (16%) had fewer than 10 samples available for this analysis (Table 2). These under sampled types tended to include types that are found on the periphery of their range within this GeoArea (e.g. Great Basin Semi-Desert Chaparral, Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland, Mediterranean California Subalpine Meadow and Western Great Plains Shortgrass Prairie), others are within this range but are relatively rare types (Rocky Mountain Alpine Fell-Field, and Rocky Mountain Alpine Turf). Some such as the North Pacific Montane Grassland and Northern Rocky Mountain Western Larch Savanna are types that may not be well understood or are obsolete. These concepts may need to be revisited and removed or refined.

Table 2. Under-sampled types within GeoArea 2W.

EVTCode	EVT Name	System elcode	Total Plots

2103	Great Basin Semi-Desert Chaparral	CES304.001	7
2086	Rocky Mountain Lower Montane-Foothill Shrubland	CES306.822	7
2138	North Pacific Montane Grassland	CES204.100	6
2144	Rocky Mountain Alpine Turf	CES306.816	7
2052	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	CES306.825	6
2137	Mediterranean California Subalpine Meadow	CES206.940	5
2143	Rocky Mountain Alpine Fell-Field	CES306.811	5
2012	Rocky Mountain Bigtooth Maple Ravine Woodland	CES306.814	5
2149	Western Great Plains Shortgrass Prairie	CES303.672	3
2062	Inter-Mountain Basins Curl-leaf Mountain-mahogany Woodland and Shrubland	CES304.772	4
2107	Rocky Mountain Gambel Oak-Mixed Montane Shrubland	CES306.818	2
2034	Mediterranean California Mesic Serpentine Woodland and Chaparral	CES206.928	1
2114	California Lower Montane Blue Oak-Foothill Pine Woodland and Savanna	CES206.936	1
2054	Southern Rocky Mountain Ponderosa Pine Woodland	CES306.648	1
2010	Northern Rocky Mountain Western Larch Savanna	CES306.837	1

Of the 76 adequately-sampled types, 17 had >80% agreement between expert and auto-key assignments. Table 3 provides a summary of adequately-sampled types where agreement between expert and auto-key ranged from just below 80% down to zero. These types total 59, or 71% of the total types assigned. Further analysis of those grouped within the 60-80% agreement range suggests subtleties within types that left the expert with greater or lesser confidence in their assignment. Fourteen of the types in Table 3 had 40% or more of the expert assigned plots assigned with moderate or low confidence; the names of these types are bolded within the table.

There are a wide variety of reasons for expert unease with their assignments but some patterns may warrant further exploration. Rocky Mountain Foothill Limber Pine-Juniper Woodland was often confused with the Colorado Plateau Pinyon-Juniper Woodland, which reduced expert confidence. Additional clarification on how to distinguish these two systems may be necessary. North Pacific Montane Shrubland showed uncertainty on whether to assign plots to this shrub system or a forested type because the plot was in harvested area. Greater clarification on how to handle these disturbed areas may be helpful in increasing certainty when assigning these types of plots. The Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland ecosystem had moderate and low confidence due to uncertainty on whether to place the plot in an Aspen-Mixed conifer system or into the aspen component of a conifer dominated system. Low and moderate plot confidence associated with the Inter-Mountain Basins Semi-Desert Shrub-Steppe indicated some confusion on whether to use this system or other sagebrush systems, especially when a high degree of exotic species were present, further reducing expert confidence in assigning plots to this system. Comments associated with the Sierran-Intermontane Desert Western White Pine-White Fir Woodland indicate some uncertainty on whether to assign this system or Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland or the California Montane Jeffrey Pine-(Ponderosa Pine) Woodland. Comments related to the Columbia Plateau Steppe and Grassland plots indicated that experts had difficulty selecting between this system and the similar to Columbia Basin Foothill and Canyon Dry Grassland. Often the systems which exhibited lower expert confidence in assigning plots also exhibited lower agreement with the auto-key assigned plots.

Table 3. Summary of types with adequate samples where agreement between auto-key and expert was below 80%.

				Plots with Expert Matches				
EVT Code	EVT Name	System Elcode	Total Plots	Total	%	High conf	Med conf	Low conf
2053	Northern Rocky Mountain Ponderosa Pine Woodland	CES306.030	19	15	79%	15	0	0
2018	East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	CES204.086	50	38	76%	34	4	0
2081	Inter-Mountain Basins Mixed Salt Desert Scrub	CES304.784	50	38	76%	31	6	1
2039	North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest	CES204.002	50	37	74%	35	2	0
2049	**Rocky Mountain Foothill Limber Pine-Juniper Woodland**	CES306.955	50	37	74%	17	20	0
2029	Mediterranean California Mixed Oak Woodland	CES206.909	11	8	73%	7	1	0
2008	North Pacific Oak Woodland	CES204.852	50	36	72%	36	0	0
2011	Rocky Mountain Aspen Forest and Woodland	CES306.813	50	36	72%	32	4	0
2140	**Northern Rocky Mountain Subalpine-Upper Montane Grassland**	CES306.806	49	35	71%	21	13	1
2060	East Cascades Oak-Ponderosa Pine Forest and Woodland	CES204.085	37	26	70%	23	3	0
2042	North Pacific Mesic Western Hemlock-Silver Fir Forest	CES204.097	50	33	66%	27	6	0
2028	Mediterranean California Mesic Mixed Conifer Forest and Woodland	CES206.915	50	33	66%	30	3	0
2047	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	CES306.802	50	33	66%	29	4	0
2084	**North Pacific Montane Shrubland**	CES204.087	14	9	64%	5	4	0
2098	**California Montane Woodland and Chaparral**	CES206.925	14	9	64%	4	5	0
2043	Mediterranean California Mixed Evergreen Forest	CES206.919	50	32	64%	32	0	0
2065	Columbia Plateau Scabland Shrubland	CES304.770	50	32	64%	21	9	2
2156	North Pacific Lowland Riparian Forest and Shrubland	CES204.869	30	19	63%	17	2	0

				Plots with Expert Matches				
EVT Code	EVT Name	System Elcode	Total Plots	Total	%	High conf	Med conf	Low conf
2070	Rocky Mountain Alpine Dwarf-Shrubland	CES306.810	21	13	62%	8	5	0
2106	Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	CES306.994	50	29	58%	24	5	0
2135	Inter-Mountain Basins Semi-Desert Grassland	CES304.787	19	10	53%	7	3	0
2038	North Pacific Maritime Mesic Subalpine Parkland	CES204.837	50	26	52%	20	6	0
2027	Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	CES206.916	50	26	52%	24	2	0
2079	**Great Basin Xeric Mixed Sagebrush Shrubland**	CES304.774	50	26	52%	7	15	4
2045	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	CES306.805	50	25	50%	25	0	0
2139	Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland	CES306.040	50	24	48%	20	4	0
2037	North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	CES204.001	50	23	46%	22	1	0
2171	North Pacific Alpine and Subalpine Dry Grassland	CES204.099	50	23	46%	21	2	0
2178	North Pacific Hypermaritime Western Red-cedar-Western Hemlock Forest	CES204.842	50	23	46%	20	3	0
2061	**Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland**	CES304.776	50	23	46%	13	9	1
2063	North Pacific Broadleaf Landslide Forest and Shrubland	CES204.846	50	21	42%	16	5	0
2055	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	CES306.828	50	20	40%	16	3	1
2127	**Inter-Mountain Basins Semi-Desert Shrub-Steppe**	CES304.788	50	19	38%	11	7	1
2115	**Inter-Mountain Basins Juniper Savanna**	CES304.782	16	6	38%	2	4	0
2056	Rocky Mountain Subalpine Wet-Mesic Spruce-Fir Forest and Woodland	CES306.830	11	4	36%	4	0	0

				Plots with Expert Matches				
EVT Code	**EVT Name**	**System Elcode**	**Total Plots**	**Total**	**%**	**High conf**	**Med conf**	**Low conf**
2172	**Sierran-Intermontane Desert Western White Pine-White Fir Woodland**	CES204.101	50	18	36%	3	15	0
2056	Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland	CES306.830	39	14	36%	13	1	0
2030	Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland	CES206.923	50	17	34%	15	2	0
2174	North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest	CES204.098	50	16	32%	14	2	0
2126	Inter-Mountain Basins Montane Sagebrush Steppe	CES304.785	50	16	32%	11	4	1
2145	Rocky Mountain Subalpine-Montane Mesic Meadow	CES306.829	50	16	32%	10	5	1
2169	Northern Rocky Mountain Subalpine Deciduous Shrubland	CES306.961	50	14	28%	11	2	1
2031	California Montane Jeffrey Pine(-Ponderosa Pine) Woodland	CES206.918	20	5	25%	5	0	0
2125	Inter-Mountain Basins Big Sagebrush Steppe	CES304.778	49	11	22%	8	2	1
2123	**Columbia Plateau Steppe and Grassland**	CES304.083	50	8	16%	2	4	2
2161	**Northern Rocky Mountain Conifer Swamp**	CES306.803	13	2	15%	0	2	0
2158	North Pacific Montane Riparian Woodland and Shrubland	CES204.866	50	7	14%	6	1	0
2053	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	CES306.030	31	4	13%	4	0	0
2035	North Pacific Dry Douglas-fir (-Madrone) Forest and Woodland	CES204.845	50	5	10%	5	0	0
2033	**Mediterranean California Subalpine Woodland**	CES206.910	12	1	8%	0	1	0
2142	**Columbia Basin Palouse Prairie**	CES304.792	50	4	8%	0	2	2
2165	**Northern Rocky Mountain Foothill Conifer Wooded Steppe**	CES306.958	50	4	8%	1	2	1
2083	North Pacific Avalanche Chute Shrubland	CES204.854	50	0	0%	0	0	0
2173	North Pacific Wooded Volcanic Flowage	CES204.883	50	0	0%	0	0	0
2044	Northern California Mesic Subalpine Woodland	CES206.911	50	0	0%	0	0	0

				Plots with Expert Matches				
EVT Code	EVT Name	System Elcode	Total Plots	Total	%	High conf	Med conf	Low conf
2167	Rocky Mountain Poor-Site Lodgepole Pine Forest	CES306.960	50	0	0%	0	0	0
2021	Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	CES206.917	41	0	0%	0	0	0
2022	Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland	CES206.914	31	0	0%	0	0	0
2166	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	CES306.959	25	0	0%	0	0	0

Systems with lower expert confidence that also exhibited lower agreement with the auto-key assignments were evaluated through a contingency table (in the Results Workbook for GA 2W). Three types of disagreement between somewhat floristically similar types in the plot assignments became apparent through this analysis: where change occurs along an elevation gradient or along a moisture gradient and where types have different geographic ranges.

- **Confusion amongst systems determined along an elevation gradient reduced agreement** - In this mountainous GeoArea there are a number of Ecological Systems that grade into other somewhat similar systems, but ones that occur at different elevations.
    1. Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland and Northern Rocky Mountain Subalpine-Upper Montane Grassland

    2. Northern Rocky Mountain Montane-Foothill Deciduous Shrubland and Northern Rocky Mountain Subalpine Deciduous Shrubland

    3. Inter-Mountain Basins Big Sagebrush Steppe and Inter-Mountain Basin Montane Sagebrush Steppe

    4. North Pacific Maritime Mesic Subalpine Parkland North Pacific Mountain Hemlock Forest

Confusion between some of these pairs of systems is very high and reduced the agreement between auto-key and expert assignments, for example including plots assigned to the Northern Rocky Mountain Subalpine-Upper Montane Grassland to the totals for the Northern Rocky Mountain Lower Montane Foothill and Valley Grassland increases agreement between the autokey and expert assignments from 49-63 percent. Some assignment overlap between these types is to be expected and is likely unavoidable due to their occurrence along an ecological gradient and the many species that they share.

The descriptions for most of these types are already relatively detailed with extensive lists of characteristic understory species. The problem when classifying plots to these systems arises when a plot has some species that are characteristic of each system. In this case the expert weighs the coverage of each species and attempts to determine which of the two system descriptions the plot fits most closely. The addition of elevation information to the sequence table process should help to improve classification of these types and the development of more nuanced rules determining which species presence (or prevalence) trumps the presence of other more generalist species would help provide more consistency in how these systems are assigned through either process.

- **Confusion amongst systems determined along a moisture gradient--** Evaluation of the contingency table indicates that confusion between drier systems and a similar but more mesic system was also a factor in reducing agreement between the auto-key and expert assignments. Example of these type of systems include:
    1. Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
       Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest

    2. Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
       Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodlands

    3. Northern Rocky Mountain Subalpine-Upper Montane Grassland
       Rocky Mountain Subalpine-Montane Mesic Meadow

    4. North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest
       North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest

    5. North Pacific Mesic Western Hemlock-Silver Fir Forest
       North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest

As with the elevation gradient systems, some assignment overlap between these types is to be expected. Development of clearer rules on how to handle plots contained elements of both the drier and more mesic systems would also be helpful in increasing system assignment consistency.

- **Confusion amongst floristically similar systems with different ranges** - Another type of disagreement between the auto-key and expert assignments appears to have arisen due to the application of different geographic ranges to determine the assignment of two somewhat floristically similar systems. Examples of this type of confusion included:

    - Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
        - California Montane Jeffery Pine- (Ponderosa Pine) Woodland
        - Northern Rocky Mountain Foothill Conifer Wooded Steppe

    - Intermountain Basins Juniper Savanna
        - Great Basin Pinyon-Juniper Woodland
        - Rocky Mountain Foothill Limber Pine Juniper Woodland

    - North Pacific Hypermaritime Western Red-cedar-Western Hemlock Forest
        - North Pacific Mesic Western Hemlock-Silver Fir Forest

One example of this type of confusion is that 22 of the 57 plots assigned to the California Montane Jeffrey Pine-(Ponderosa Pine) Woodland by the experts were assigned to the Northern Rocky Mountain Ponderosa Pine Woodland and Savanna by the auto key. Similarly 10 of the same 57 plots assigned to the California Montane Jeffrey Pine-(Ponderosa Pine) Woodland by the experts were assigned to the Northern Rocky Mountain Foothill Conifer Wooded Steppe by the auto key.

Better application of reviewed and established ranges documenting where each system occurs and the other does not would greatly reduce this type of disagreement. In areas where two similar systems both occur, the development of more detailed guidance on each systems occurrence and the use of elevation, soil and other non-floristic variables to make plot assignments would increase plot assignment accuracy.

- **Other points of interest in contingency table evaluation**
    1. **Inter-Mountain Basins Big Sagebrush Shrubland and Intermountain Basins Big Sagebrush Steppe-** There was considerable disagreement between expert and auto-key plots assigned to Inter-Mountain Basins Big Sagebrush Shrubland and Inter-Mountain Big Sagebrush Steppe. Twenty of the 94 plot assigned to the Inter-Mountain Basins Big Sagebrush Shrubland by the experts were assigned to the Inter-Mountain Basins Big Sagebrush Steppe by the auto-key. Confusion in the other direction also occurred but was not as substantial-- 5 of the 46 plots the experts assigned to the Inter-Mountain Basins Big Sagebrush Steppe were assigned to the Inter-Mountain Basins Big Sagebrush Shrubland by the auto-key. Developing greater clarification on how to distinguish these two systems should help to reduce this disagreement.

    2. **Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland**- Only forty-seven percent of the auto-key plots assigned this system were assigned it by the experts, while 100% of the plots assigned to this system by the experts were also assigned by the auto-key. The majority of the extra plots assigned this system by the auto-key were assigned to a conifer forest type by the experts. This indicates that the experts were looking for a higher coverage of *Populus tremuloides* before assigning this system and/or a more restricted range than the auto-key used. This is an example of a system where the concept of it's geographic range and composition may not be consistently applied by the auto-keys or experts, and requires review.

    3. **Substantial confusion occurred amongst Columbia Plateau grassland types**. The Columbia Plateau Steppe and Grassland will be used as an example as it exhibited the most extensive confusion. The experts and the auto-key both assigned a similar number of plots to this system (52 and 50) but had less than 16% agreement between these assignments. Fourteen of the plots assigned by the experts to this system were assigned by the auto-key to the Columbia Basin Palouse Prairie, with the Inter-Mountain Basin Semi-Desert Shrub-Steppe being the next highest source of disagreement. Twelve of the plots assigned to this system by the auto-key were assigned to the Northern Rocky Mountain Lower Montane Foothill and Valley Grassland and 10 were assigned to the Columbia Basin Foothill and Canyon Dry Grassland. Lower in elevation but similar types of disagreement among the low elevation grassland types in the central portion of this GeoArea indicates a need for better clarification of differences in these types. Some expert comments indicate that the addition of soil and slope information to the assignment process would help to clarify these types.

    4. The **North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-Field and Meadow** system was easily confused with the **North Pacific Alpine and Subalpine Dry Grassland** system**.** They are floristically similar, and occur adjacent to each other often in an inter-

digitated fashion. More nuanced floristic and local environmental information would help clarify the differences between these two ecosystems.

5. The **North Pacific Broadleaf Landslide Forest and Shrubland** was easily confused with the **North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest.** These systems occur within the same geography and elevation and have differences in the abundance of certain key species, indicating recent disturbance. Detailed information that was available to the experts in aerial photographs (proximity to human development) and the percent slope were important additional variables that need to be incorporated into the auto-key.

6. **Mediterranean California Mixed Evergreen Forest** was often miss-labled by the auto key as **Mediterranean California Lower Montane Black Oak-Conifer Forest and Woodland, North Pacific Dry Douglas-fir-(Madrone) Forest and Woodland, Mediterranean California Mesic Mixed Conifer Forest and Woodland,** or the **Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland.** More detailed information on geographic location and species composition is necessary to differentiate between these systems, as they share many of the same floristic details.

7. The confirmation of soil information (especially the presence of serpentine soils) would greatly aid in the correct identification of these systems **Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland** and **Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland** from their surrounding and often similar floristic forests.

Expert Assignments

2.2 A report by each GeoArea detailing processes and results, specifically identifying how they made individual assignments.

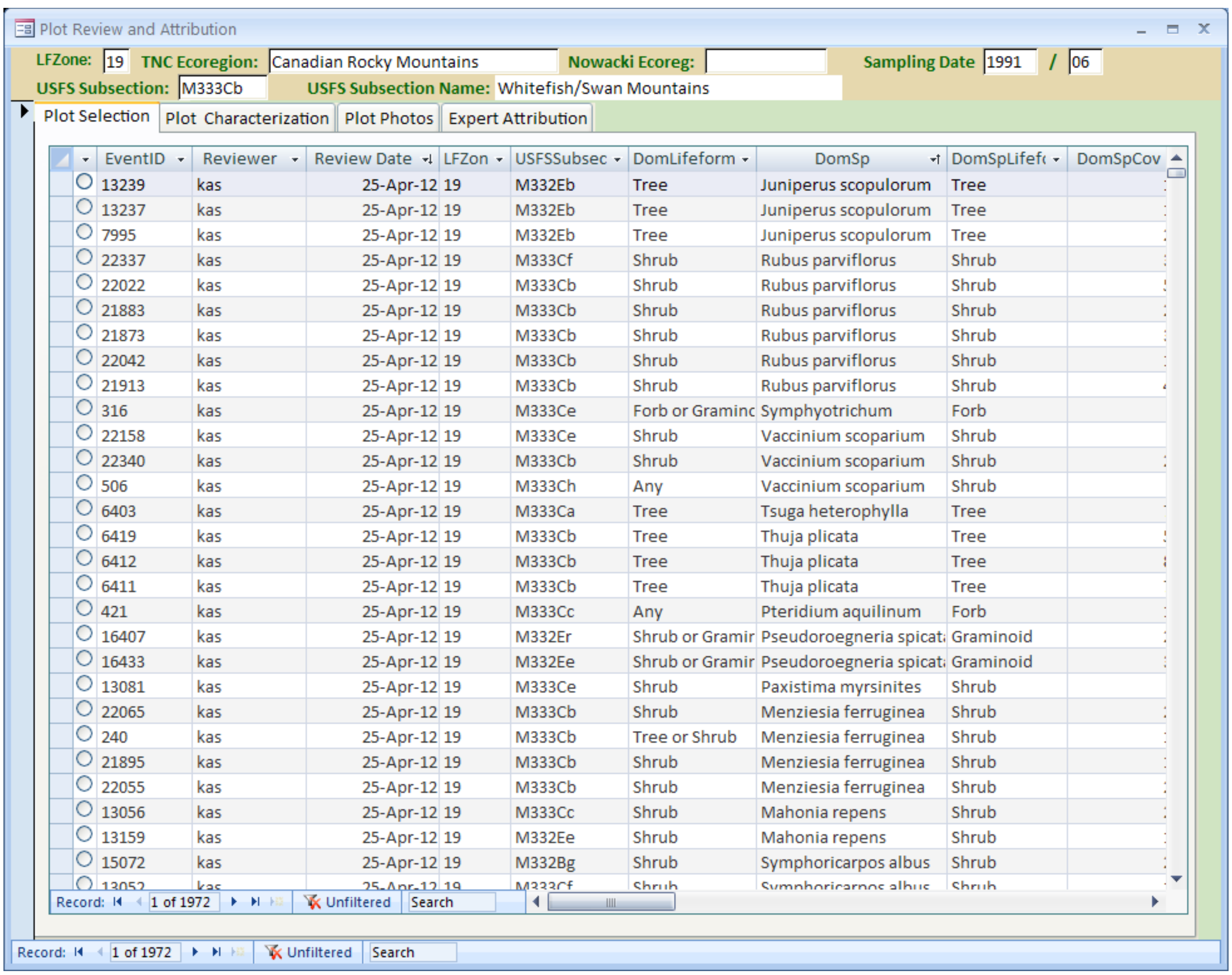
As described in the methods section above, the expert reviewers worked directly in the expert attribution database (EADB). Since GeoArea 2W had nearly 4,000 plots to review, a systematic, efficient process for reviewing and labeling plots was required. The forms provided in the EADB allowed the reviewer to sort and filter on subsets of plots to select groups of them with similar characteristics. For instance, the reviewer could select all plots found within a particular USFS Section or MapZone, then select all plots dominated by trees, then sort alphabetically by the dominant species. The reviewer could also select all treed plots, then select all plots with the same dominant tree species (such as *Picea engelmannii;),* then sort by % cover of that species, from high to low. Figure 4 shows the main form in the EADB which has these data fields. Additional fields were provided from which to select or sort plots, such as elevation, aspect, slope, and total cover by lifeform in the plot.

Once the reviewer had selected a subset of plots for reviewing, the next step was to select an individual plot to review and label. If the expert was working on treed plots first, then they had a further option of selecting the set of ecological systems from which to pick a label for the plots. This was accomplished via a filter on the NLCD land cover class applied to all systems (such as forest and woodland, shrubland, herbaceous, woody wetlands, and so on).

For each plot, the expert reviewed environmental and geographic setting, as well as the floristic and vegetation structural characteristics of the plot. In many cases the expert could then assign an ecological system label with no further information. However, in some cases the reviewer might consult the descriptions for a group of similar ecological systems to clarify their understanding of differences in concept, geographic distribution, floristics, or structural characteristics.

As an example, in GeoArea 2W Engelmann spruce may occur in a large variety of ecological systems including Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland, Rocky Mountain Subalpine Mesic-Wet Spruce-Fir Forest and Woodland, Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest, Northern Rocky Mountain Mesic Montane Mixed Conifer Forest, Northern Rocky Mountain Subalpine Woodland and Parkland, Rocky Mountain Lodgepole Pine Forest, Northern Rocky Mountain Conifer Swamp, and Rocky Mountain Subalpine-Montane Riparian Woodland. For a plot containing a high coverage of Engelmann spruce the experts must select the best of these choices using information on a site's elevation, slope, species dominance, tree canopy cover, presence of other tree species, mesic or xeric understory species, photographs, hydrology and soil and geologic information if available.

Figure 4. Screen shot of EADB form, showing some of the data the expert reviewer could select from or sort on to efficiently review similar plots.


Plot Review and Attribution

LFZone: 19 TNC Ecoregion: Canadian Rocky Mountains Nowacki Ecoreg: Sampling Date 1991 / 06

USFS Subsection: M333Cb USFS Subsection Name: Whitefish/Swan Mountains

Plot Selection | Plot Characterization | Plot Photos | Expert Attribution

EventID	Reviewer	Review Date	LFZon	USFSSubsec	DomLifeform	DomSp	DomSpLifef	DomSpCov
13239	kas	25-Apr-12	19	M332Eb	Tree	Juniperus scopulorum	Tree	
13237	kas	25-Apr-12	19	M332Eb	Tree	Juniperus scopulorum	Tree	
7995	kas	25-Apr-12	19	M332Eb	Tree	Juniperus scopulorum	Tree	
22337	kas	25-Apr-12	19	M333Cf	Shrub	Rubus parviflorus	Shrub	
22022	kas	25-Apr-12	19	M333Cb	Shrub	Rubus parviflorus	Shrub	
21883	kas	25-Apr-12	19	M333Cb	Shrub	Rubus parviflorus	Shrub	
21873	kas	25-Apr-12	19	M333Cb	Shrub	Rubus parviflorus	Shrub	
22042	kas	25-Apr-12	19	M333Cb	Shrub	Rubus parviflorus	Shrub	
21913	kas	25-Apr-12	19	M333Cb	Shrub	Rubus parviflorus	Shrub	
316	kas	25-Apr-12	19	M333Ce	Forb or Graminc	Symphyotrichum	Forb	
22158	kas	25-Apr-12	19	M333Ce	Shrub	Vaccinium scoparium	Shrub	
22340	kas	25-Apr-12	19	M333Cb	Shrub	Vaccinium scoparium	Shrub	
506	kas	25-Apr-12	19	M333Ch	Any	Vaccinium scoparium	Shrub	
6403	kas	25-Apr-12	19	M333Ca	Tree	Tsuga heterophylla	Tree	
6419	kas	25-Apr-12	19	M333Cb	Tree	Thuja plicata	Tree	
6412	kas	25-Apr-12	19	M333Cb	Tree	Thuja plicata	Tree	
6411	kas	25-Apr-12	19	M333Cb	Tree	Thuja plicata	Tree	
421	kas	25-Apr-12	19	M333Cc	Any	Pteridium aquilinum	Forb	
16407	kas	25-Apr-12	19	M332Er	Shrub or Gramir	Pseudoroegneria spicat	Graminoid	
16433	kas	25-Apr-12	19	M332Ee	Shrub or Gramir	Pseudoroegneria spicat	Graminoid	
13081	kas	25-Apr-12	19	M333Ce	Shrub	Paxistima myrsinites	Shrub	
22065	kas	25-Apr-12	19	M333Cb	Shrub	Menziesia ferruginea	Shrub	
240	kas	25-Apr-12	19	M333Cb	Tree or Shrub	Menziesia ferruginea	Shrub	
21895	kas	25-Apr-12	19	M333Cb	Shrub	Menziesia ferruginea	Shrub	
22055	kas	25-Apr-12	19	M333Cb	Shrub	Menziesia ferruginea	Shrub	
13056	kas	25-Apr-12	19	M333Cc	Shrub	Mahonia repens	Shrub	
13159	kas	25-Apr-12	19	M332Ee	Shrub	Mahonia repens	Shrub	
15072	kas	25-Apr-12	19	M332Bg	Shrub	Symphoricarpos albus	Shrub	
13052	kas	25-Apr-12	19	M333Cf	Shrub	Symphoricarpos albus	Shrub	

Record: 1 of 1972 Unfiltered Search

Record: 1 of 1972 Unfiltered Search

In cases like this, the determination of which system type to assign to the plot might require:

a) review of the image clip for the context of the plot,
b) review of where the plot was located geographically (USFS Subsections provide local scale geographic location), to distinguish Columbia Plateau from Northern Rocky Mountain systems for example..
c) consideration of topographic setting (e.g. north-facing slopes at lower elevations could support ponderosa pine woodlands),
d) consideration of any available height data for the plot (e.g. were the ponderosa pines all tall, apparently mature trees; or were they short),
e) careful consideration of the full floristic composition of the plot and cover for each species.
f) awareness of possible errors in the plot data, such as mis-identification of juniper species by the field crews, unevenness in how the cover values were estimated in the field or converted into the LFRDB (e.g. cover for trees estimated by a person standing on the ground vs an aerial view of the plot).

Given all of the above, the reviewer had to make a decision for the plot, and assign an ecological system label. In cases where the assignment was not made with high confidence, the reviewer was requested to provide comments as to the factors they used to assign a label to the plot, or what the alternative assignment could be. Report Section 2.3 below discusses some of the results pertinent to confidence of assignment.

Improving the auto-key process

2.3 A report that documents procedures and data elements to improve the auto-key process in each GeoArea.

Of the 121 types assigned to plots by experts, 44 had fewer than 10 samples, so are excluded from this particular analysis. From the remaining 77 types, the numbers of samples labeled to a given type ranged from 154 (North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest) down to 10 (5 systems). For all of these types, experts reported at least moderate confidence in their labels for at least 20% of the type's plots. 2 types indicated low confidence for at least 20% of the type's plots. These statistics are listed in the Results Workbook. A small sampling of expert comments related to moderate or low confidence plots are included in Table 4.

Table 4. A selection of expert comments related to labeling sample plots for types where their confidence was reported as moderate or low.

Type Name	Expert Comment
Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	Need geomorphology, soils and hydrologic info to determine type of wetland. This may be shrub-swamp or bog/fen.
Mediterranean California Mixed Oak Woodland	May be the Med Cal Lower Montane Black Oak woodland without the Ponderosa Pine
North Pacific Bog and Fen	Need soils information to determine type of wetland (organic soils)
Rocky Mountain Alpine Turf	high forb & gram cover, high elevation, but not really alpine turf species, could also be subalpine mesic meadow
Rocky Mountain Alpine Bedrock and	Not sure if I can assume that the coverage not accounted for

Scree	in the species list is rock but assuming that it is and there were not other species on the plot that were not recorded I would go with this system.

These and other comments point to several important aspects for consideration. Some ecological systems concepts are better known and understood than others. Therefore, a certain degree of classification refinement is likely needed in order to improve auto-keys. Also, the inclusion of some landform, soil, and or landscape context information could assist with some determinations within the key, or by a subsequent expert reviewer. Similarly, repeated references to photos further indicates the need for expert review of many moderate-low confidence types where auto-keys might be prone to error. Additional floristic information is cited in some cases where suspected limitations provide the primary source of expert uncertainty in labeling.

Other samples were labeled by auto-keys to aggregates of multiple ecological system types. This was because LANDFIRE had mapping objectives focused on uplands where fire regimes are prevalent. That meant that many individual wetland and sparsely-vegetated ecological system types were not treated within the auto-keys. Expert labeling of these samples, however, provides an indication of the feasibility of their inclusion in updated auto-keys. Of 311 samples, experts were able to assign 282 (91%) to an individual ecological system type; a total of 63 individual ecological system types were assigned to these samples. This result indicates the potential for inclusion of these types within subsequent mapping efforts. We cannot yet comment on the issues associated including these types within future regional auto-keys, but this appears to be an issue worthy of exploration.

Another set of samples did not contain enough information for the auto-keys to assign a system or system aggregate, or were introduced types with no relevant system; these samples were labeled with broad "unclassified" types, such as "Unclassified Grassland" or "Introduced Upland Vegetation-Shrub". Of 276 samples, experts were able to assign 203 (74%) to an individual ecological system type; a total of 69 individual ecological system types were assigned to these samples.

Adapting auto-keys for NVC Groups, Macrogroups, and Divisions

2.4 A report that documents technical procedures to adapt auto-keys for labeling NVCS group, macrogroup, and division concepts.

US-NVC Groups

In an effort to understand the potential implications of adapting LANDFIRE autokeys for use with the revised US-NVC, we first compared the mapped ecological system types within this GeoArea to their related US-NVC Group concepts. These two classification concepts, with the NVC designed solely using existing vegetation, and ecological systems combining existing vegetation and biophysical factors, are most closely related at the Group level of the revised US-NVC hierarchy. Since these two classifications have been thoroughly related to each other, these relationships should provide insight for the task of updating autokeys for use with the NVC.

Within this GeoArea, some 179 terrestrial ecological system types could occur. Of these, 57 have a practical 1:1 relationship with NVC Group concepts, and 91 nest cleanly within 45 NVC Group concepts (1:many group:system relationship), for a total of 148 or 83% of ecological system concepts with a clean relationship to an NVC Group. There is some potential for slight differences among floristic elements among these NVC Groups relative to ecological systems. For example, one or more associations linked to a given terrestrial ecological system type may now be linked to a different NVC Group concept. There is some limited potential that the floristic information found within the autokey would need to be revisited to account for this, but within this GeoArea, we believe that this instance is quite limited.

Where the relationship between ecological systems and NVC Groups is more complex, there is potential need for substantive changes to existing autokeys. Within this GeoArea, 29 (16%) ecological system types have a more complex relationship with NVC Group concepts (Table 5). A review of these more complex ecological system to NVC Group relationships indicates that, while revisions to the autokey would be necessary to use the NVC Groups for plot assignments the changes required for GeoArea 2W do not appear to be prohibitively substantive and would likely improve the plot classification process in this GeoArea. The simplification of the geographic modifiers from the riparian types would help to clear up some confusion in the classification of these types that often share many species. The addition of a riparian forest Group would help to differentiate two rather distinct habitats that have been previously been combined (i.e. shrubland and forest). The splitting of the Northern Rocky Mountain Avalanche Chute Shrubland into a more general high elevation shrubland Group and a riparian Group should help to make the classification of this type less difficult and error prone. Similarly the change from the North Pacific Avalanche Chute Shrubland to a more general Vancouverian Alder - Salmonberry - Willow Shrubland Group should be an improvement as accurate classification of the Avalanche Chute Shrubland systems typically required expert photo review and the changes made moving to the NVC Group should reduce the need for this time intensive review. Splitting the Northern Rocky Mountain Mesic Montane Mixed Conifer Forest into two NVC Groups, with one that recognizes the unique Western Red-cedar - Western Hemlock Forest, is a welcome change that should be relatively easy to accomplish with minor revisions to the auto-key. The inability to distinguish these biologically important forest types from the more common mesic grand-fir forests is a common criticism of the current land cover maps for the region. Breaking the Rocky Mountain Alpine-Montane Wet Meadow into two Groups distinguished by elevation also seems beneficial. Currently this system is used to map a very wide variety of wet alpine and montane habitats and more definition in these areas seems warranted.

One area of concern is the combination of many of the sagebrush systems into only two NVC-Groups [Note: there are other sagebrush Groups for the dwarf-sages, such as black sage, low sage; and montane sagebrush steppe remains as a seaprate NVC Group]. While assigning sagebrush plots to systems is difficult and agreement between auto key and experts assignments was often low for these types, they represent complex habitats and caution should be used to avoid oversimplification in these types. While the geographic modifiers associated with the sagebrush systems can cause confusion, usually because it is difficult to decide where one type ends and the other begins, many reviewers of the land cover maps suggest that their projects require more detailed information on the sagebrush types than is currently provided. We should be careful to make sure the NVC-Groups provide an adequate level of definition for these diverse types.

Table 5. Ecological Systems of GeoArea 2W that have complex relationships with NVC Groups. Interrelated Systems and Groups are shown in the heavy-outline boxes. The number of NVC Groups each system is related to is shown in the Groups column, and the number of Ecological Systems each NVC Group is related to is shown in the Systems column.

Ecological System	NVC Group	Groups	Systems
Columbia Basin Foothill Riparian Woodland and Shrubland	G503 Rocky Mountain & Great Basin Lowland & Foothill Riparian Forest	2	4

Ecological System	NVC Group	Groups	Systems
Columbia Basin Foothill Riparian Woodland and Shrubland	G526 Rocky Mountain & Great Basin Lowland & Foothill Riparian & Seep Shrubland	2	5
Columbia Plateau Silver Sagebrush Seasonally Flooded Shrub-Steppe	G526 Rocky Mountain & Great Basin Lowland & Foothill Riparian & Seep Shrubland	1	5
Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	G503 Rocky Mountain & Great Basin Lowland & Foothill Riparian Forest	2	4
Great Basin Foothill and Lower Montane Riparian Woodland and Shrubland	G526 Rocky Mountain & Great Basin Lowland & Foothill Riparian & Seep Shrubland	2	5
Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	G503 Rocky Mountain & Great Basin Lowland & Foothill Riparian Forest	2	4
Northern Rocky Mountain Lower Montane Riparian Woodland and Shrubland	G526 Rocky Mountain & Great Basin Lowland & Foothill Riparian & Seep Shrubland	2	5
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	G503 Rocky Mountain & Great Basin Lowland & Foothill Riparian Forest	2	4
Rocky Mountain Lower Montane-Foothill Riparian Woodland and Shrubland	G526 Rocky Mountain & Great Basin Lowland & Foothill Riparian & Seep Shrubland	2	5
Columbia Basin Palouse Prairie	G273 Northern Rocky Mountain Lower Montane, Foothill & Valley Grassland	2	2
Columbia Basin Palouse Prairie	G275 Northern Rocky Mountain Montane-Foothill Mesic Deciduous Shrubland	2	2
Northern Rocky Mountain Lower Montane, Foothill and Valley Grassland	G273 Northern Rocky Mountain Lower Montane, Foothill & Valley Grassland	1	2
Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	G275 Northern Rocky Mountain Montane-Foothill Mesic Deciduous Shrubland	2	2
Northern Rocky Mountain Montane-Foothill Deciduous Shrubland	G272 Northern Rocky Mountain Montane-Foothill Dry Deciduous Shrubland	2	1
East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	G212 East Cascades Mesic Grand Fir - Douglas-fir Forest	2	1
East Cascades Mesic Montane Mixed-Conifer Forest and Woodland	G217 Central Rocky Mountain Interior Western Red-cedar - Western Hemlock Forest	2	2
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	G211 Central Rocky Mountain Mesic Grand Fir - Douglas-fir Forest	2	2
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	G217 Central Rocky Mountain Interior Western Red-cedar - Western Hemlock Forest	2	2
Northern Rocky Mountain Western Larch Savanna	G211 Central Rocky Mountain Mesic Grand Fir - Douglas-fir Forest	1	2
Columbia Plateau Steppe and Grassland	G302 Intermountain Mesic Tall Sagebrush Shrubland & Steppe	1	3

Ecological System	NVC Group	Groups	Systems
Great Basin Xeric Mixed Sagebrush Shrubland	G303 Intermountain Dry Tall Sagebrush Shrubland	1	3
Inter-Mountain Basins Big Sagebrush Shrubland	G302 Intermountain Mesic Tall Sagebrush Shrubland & Steppe	2	3
Inter-Mountain Basins Big Sagebrush Shrubland	G303 Intermountain Dry Tall Sagebrush Shrubland	2	3
Inter-Mountain Basins Big Sagebrush Steppe	G302 Intermountain Mesic Tall Sagebrush Shrubland & Steppe	2	3
Inter-Mountain Basins Big Sagebrush Steppe	G303 Intermountain Dry Tall Sagebrush Shrubland	2	3
North Pacific Alpine and Subalpine Dry Grassland	G354 Vancouverian Alder - Salmonberry - Willow Shrubland	1	4
North Pacific Avalanche Chute Shrubland	G305 Northern Rocky Mountain High Montane Mesic Shrubland [Provisional]	2	3
North Pacific Avalanche Chute Shrubland	G354 Vancouverian Alder - Salmonberry - Willow Shrubland	2	4
North Pacific Montane Grassland	G354 Vancouverian Alder - Salmonberry - Willow Shrubland	1	4
North Pacific Montane Shrubland	G354 Vancouverian Alder - Salmonberry - Willow Shrubland	1	4
Northern Rocky Mountain Avalanche Chute Shrubland	G305 Northern Rocky Mountain High Montane Mesic Shrubland [Provisional]	2	3
Northern Rocky Mountain Avalanche Chute Shrubland	G504 Rocky Mountain & Great Basin Montane Alder & Birch Riparian Shrubland	2	1
Northern Rocky Mountain Subalpine Deciduous Shrubland	G305 Northern Rocky Mountain High Montane Mesic Shrubland [Provisional]	1	3
North Pacific Hardwood-Conifer Swamp	G256 North Pacific Maritime Hardwood-Conifer Rich Swamp	2	3
North Pacific Hardwood-Conifer Swamp	G610 North Pacific Maritime Poor Swamp & Bog Forest	2	2
North Pacific Shrub Swamp	G256 North Pacific Maritime Hardwood-Conifer Rich Swamp	3	3
North Pacific Shrub Swamp	G322 Vancouverian Wet Shrubland	3	4
North Pacific Shrub Swamp	G610 North Pacific Maritime Poor Swamp & Bog Forest	3	2
North Pacific Intertidal Freshwater Wetland	G254 North Pacific Lowland Riparian Forest & Woodland	1	3
North Pacific Lowland Riparian Forest and Shrubland	G254 North Pacific Lowland Riparian Forest & Woodland	2	3
North Pacific Lowland Riparian Forest and Shrubland	G322 Vancouverian Wet Shrubland	2	4
North Pacific Montane Riparian Woodland and Shrubland	G322 Vancouverian Wet Shrubland	2	4
North Pacific Montane Riparian Woodland and Shrubland	G507 North Pacific Montane Riparian Woodland	2	1

Ecological System	NVC Group	Groups	Systems
Rocky Mountain Alpine-Montane Wet Meadow	G520 Vancouverian & Rocky Mountain Subalpine Snowbed, Wet Meadow & Dwarf-Shrubland	2	1
Rocky Mountain Alpine-Montane Wet Meadow	G521 Vancouverian & Rocky Mountain Montane Wet Meadow	2	2
Temperate Pacific Subalpine-Montane Wet Meadow	G521 Vancouverian & Rocky Mountain Montane Wet Meadow	1	2
North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-Field and Meadow	G317 North Pacific Alpine-Subalpine Dwarf-Shrubland & Heath	2	1
North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-Field and Meadow	G320 North Pacific Alpine-Subalpine Turf & Herbaceous Meadow	2	1

US-NVC Macrogroups

Ecological Systems can be fairly comfortably rolled up to broader US-NVC Macrogroups, which cover the existing-vegetation component of their related ecological systems. Using LANDFIRE autokeys for US-NVC Macrogroups instead of ecological systems could potentially resolve disagreements between experts and autokeys found at the ecological systems level. To evaluate the potential effect of using the autokey for Macrogroups, we arranged the ecological system types by US-NVC Macrogroup in the expert-autokey contingency table in the Results Workbook, and also compared the percent of expert-autokey matches at the system level versus the Macrogroup level (Table 6).

There are 25 US-NVC Macrogroups represented among natural mapped classes in this GeoArea. Rolling up to the Macrogroup improves auto-key and expert agreement for 17 of these 25 Macrogroups when compared to agreement for the ecological system level. For 8 of these Macrogroups that show increased levels of agreement, improvement is by 20% or more.

While the results in Table 6 suggest rolling up to Macrogroup would yield a higher level of agreement, consideration must be given to the fact that many of these Macrogroups are in fact very broad concepts, and include ecologically diverse system types. For example the Northern Rocky Mountain Montane & Foothill Grassland & Shrubland contains 7 ecological systems and encompasses most (in terms of map area) of the non-forest habitats in the mountainous portions of the GeoArea. These types range from very dry foothill grasslands to very mesic sub-alpine shrublands; combining them into one class would not be advantageous for many applications.

Table 6. Comparison of auto-keyed results when plots keyed to systems are rolled up to Macrogroups, showing percent of matches at the system level compared to Macrogroup level.

Macrogroup	# auto-keyed systems	# plots	% expert matches at system level	% expert matches at MG level
Great Basin Saltbrush Scrub Macrogroup	2	78	82%	83%
Great Basin & Intermountain Tall Sagebrush Shrubland & Steppe Macrogroup	5	249	41%	65%

Great Basin & Intermountain Dwarf Sage Shrubland & Steppe Macrogroup	3	150	77%	77%
Great Basin & Intermountain Dry Shrubland & Grassland Macrogroup	2	69	42%	54%
Quercus agrifolia - Quercus lobata - Umbellularia californica - Cupressus spp. - Pinus spp. Forest & Woodland Macrogroup	2	51	35%	35%
Quercus garryana - Quercus kelloggii - Pseudotsuga menziesii - Arbutus menziesii Forest & Woodland Macrogroup	5	198	54%	73%
Northern Rocky Mountain Lower Montane & Foothill Forest Macrogroup	9	326	48%	70%
Rocky Mountain Subalpine & High Montane Conifer Forest Macrogroup	8	348	53%	64%
Southern Rocky Mountain Lower Montane Forest Macrogroup	3	12	50%	100%
Calocedrus decurrens - Pinus (lambertiana, jeffreyi, monticola) - Abies concolor var. lowiana Forest Macrogroup	7	243	34%	70%
Tsuga heterophylla - Picea sitchensis - Sequoia sempervirens - Acer macrophyllum Forest Macrogroup	8	400	49%	80%
Abies magnifica - Abies X shastensis - Tsuga mertensiana - Pinus contorta var. murrayana Forest Macrogroup	6	262	60%	90%
Intermountain Singleleaf Pinyon - Western Juniper Woodland Macrogroup	6	132	85%	95%
Rocky Mountain Two-needle Pinyon - Juniper Woodland Macrogroup	1	14	100%	100%
Rocky Mountain & Great Basin Flooded & Swamp Forest Macrogroup	1	13	15%	92%
Vancouverian Flooded & Swamp Forest Macrogroup	2	80	33%	43%
Rocky Mountain Alpine Scrub, Forb Meadow & Grassland Macrogroup	4	33	48%	48%
Vancouverian Alpine Scrub, Forb Meadow & Grassland Macrogroup	1	50	88%	88%
Northern Rocky Mountain Montane & Foothill Grassland & Shrubland Macrogroup	8	338	40%	72%
Southern Rocky Mountain Montane Grassland & Shrubland Macrogroup	2	9	33%	33%
Rocky Mountain-Vancouverian Subalpine & High Montane Mesic Grass & Forb Meadow Macrogroup	2	55	29%	29%
Northern Vancouverian Lowland & Montane Grassland & Shrubland Macrogroup	2	56	41%	52%
Great Plains Shortgrass Prairie & Shrubland Macrogroup	1	3	0%	0%
Cool Interior Chaparral Macrogroup	2	21	67%	71%
Cool Semi-Desert Alkali-Saline Wetland Macrogroup	1	50	80%	82%

US-NVC Divisions

NVC Divisions are substantially simplified vegetation concepts relative to terrestrial ecological system types, so autokeys designed for these concepts would be relatively simple to develop. For within this

GeoArea, we would recommend starting from a new baseline starting point in order to adequately design one autokey to encompass the 10 natural US-NVC Division concepts that occur here.

Discussion

The LANDFIRE reference database is the first attempt by a single agency to compile comprehensive georeferenced vegetation data for the United States. As such it is a powerful tool for use in many different applications, but there are caveats that must be clearly understood by the user(s) of the data and the results. Sequence tables are an innovative method for rapidly and efficiently keying thousands of vegetation samples; for LANDFIRE they were developed to key to ecological systems and land cover classes, but could be modified to key to any floristically-based vegetation types, such as the Group level of the NVC hierarchy.

Fundamentally, a sequence table as used by LANDFIRE is a set of criteria. Each vegetation sample has to meet some combination of criteria in the SQT to be labeled with an ecological system, or some other land cover class. Simply put, if the plot doesn't meet any criteria contained in the sequence table, then it may be mis-keyed, or not key to anything. Given our incomplete knowledege of the structural and floristic variability of each classification unit, it is nearly impossible to establish criteria in a sequence table - for regional application - to successfully and accurately key 100% of vegetation samples. However, with new field-based inventory and increasing ecological understanding, over time sequence tables can be revised and improved so as to accurately key increasing percentages of vegetation samples.

There are a number of reasons why a sequence table may not successfully key all samples run through it:
a) the unknown floristic quality of the vegetation data (how complete, how well collected, does it accurately represent the vegetation concept being keyed);
b) our limited knowledge of the variability in species composition, vegetation structure, and the distribution of ecological systems; and
c) the comprehensiveness (or lack thereof) in field inventory for any particular system (e.g., many from one small area, few to none from elsewhere in the region).

Each of these are discussed below.

A. Quality of vegetation data

First and foremost, the completeness and quality of the data as collected in the field, as well as the documentation of how the data were collected (the metadata) are primary issues for how well the sequence table process works. There are many different kinds of issues with the data collection, only a few of which are listed here as possible sources of problems:

- Was the species composition adequately sampled (complete species list)?
- Were only trees recorded (e.g., some FIA plots)? Only "dominant" or "most characteristic" species (e.g., SWReGAP training data)?
- Was the sample plotless, or within a plot or some other measured area?
- Or were the samples derived along transects?
- How was the cover or abundance data collected, or was it presence/absence?

- Was the sample area across an ecotone (for example across the transition from a wet valley bottom into the adjacent upland slope)?
- Does the sample adequately represent an occurrence of the vegetation type being sampled?
- Was the species taxonomy accurately recorded (many species are difficult for untrained crews to identify, such as *Carex* spp., or *Salix* spp.)?
- Were difficult species "lumped up" into broader taxon, such as genus, or even family?
- Was the sample location heavily or recently disturbed?

Many datasets obtained by the LANDFIRE team had inadequate metadata associated with them. Inadequate documentation of the sampling design or of what the values in the data tables represented, could result in incorrect processing of the data for use in the sequence tables.

The sampling design under which vegetation data was collected is an often neglected piece of metadata. A particular dataset could have many hundreds of plots in it, but the purpose(s) for which they were collected could be such as to negate their value for identifying floristically distinct vegetation types. For example, samples collected in a systematic grid without regard for sampling distinct vegetation types will often cross multiple ecological systems, and hence result in data that give erroneous results in an auto-key process.

An example of poor documentation of the collection protocols would include species names collected and provided as 4- or 6-letter acronyms, without a complete list of what species each acronym represents. The processing of the data into the LFRDB converts acronyms to full species utilizing the current NRCS PLANTS 'symbols'. So, POTR could be *Populus tremuloides*, *Poa tracyi,* or *Poa trivialis*, all valid species. But using PLANTS, POTR = *Poa tracyi*, while *Populus tremuloides* is POTR5. Each dataset has to be reviewed for its species taxonomy to ensure any acronyms are converted to the correct taxa, but without adequate metadata errors can creep in.

Another example would be where the species abundance data were collected in generalized "cover classes", and these had to be converted to "real cover" by using the mid-point of the class. If the metadata did not include documentation of what the classes represent, then the mid-points could be incorrectly converted, or even unobtainable. For example, cover class 3 could mean 5-25% cover (mid-point of 15%), or it could mean 25-35% cover (mid-point 30%). The sequence table process utilizes cover criteria for indicator species extensively, so incorrectly interpreted cover classes will lead to errors in the results.

B. Constraints within sequence table

Ecological systems are classified using a multi-factorial approach, including environmental factors, ecological processes and vegetation structure and composition. However, the sequence table process as currently developed and used by LANDFIRE does not allow use of local-scale environmental factors which might assist with distinguishing among floristically similar ecological systems. For example, how would one use avalanche slopes in an automated plot keying process? Or high-gradient vs. low gradient stream flow-regime? These are diagnostic features of one or more ecological systems that facilitate ready recognition in the field, but if floristic information is limited there may be no way to identify individual plots that occur on these features.

The early versions of the auto-key only allowed use of vegetation structure and composition data. The most recent auto-key does allow the use of elevation data which is helpful in accurately labeling plots to ecological systems that can be readily distinguished by elevation zones. The auto-key allows use of regional-scale variables, such as occurrence in a TNC ecoregion, or a USFS Section. Beyond these 2 variables (elevation and general geographic location) the auto-key does not currently allow use of any other more local-scale environmental variables, such as aspect, slope, landforms, soils conditions, etc.

Over time, as our knowledge of the floristic composition and structure of vegetation in the United States becomes more complete, local-scale variables may not be needed. If the plot data themselves are complete (meaning the species composition has been adequately sampled and recorded for the plot) we can infer environmental setting and characteristic ecological dynamics through the use of indicator species. For example, *Heracleum maximum* to indicate mesic or wet understory conditions for wetland and riparian ecological systems or *Juncus drummondii* and *Caltha leptosepala* to indicate alpine wetland sites, or the predominance of *Festuca idahoensis* as a montane or subalpine grassland indicator. However, it's generally the <u>combination</u> <u>of multiple species</u> in varying abundance that are used in a sequence table to key plots; hence incomplete or poorly collected species compositional data generate poor results from the auto-keying process.

In comparison, dichotomous field keys to the ecological systems of a region do allow incorporation of the environmental or ecological "context" of a vegetation sample. In a field key, you can explicitly state "if you are in a marsh, then go to this part of the key.…" or "if you are in the alpine, go here…", or "if this place is in the path of regular avalanches, go to this part of the key…". One of the LANDFIRE products is a set of dichotomous keys to be used in the field, for all ecological systems and land cover classes in groups of MRLC map zones.

C. Developing automated keys for large geographic areas

Each sequence table was constructed to work across relatively large geographic areas, on the order of 2-5 USFS Sections (Figure 1). Hence each sequence table/auto-key included tens of ecological system types, and each system has some degree of compositional and structural variability across that region.

It's difficult to account for all compositional or structural variability that might occur in a single system type across a large geographic area. For example, western coniferous forests can vary from 25% tree cover to well over 90% cover, but in some patches may be less than 25%. Montane coniferous forests and woodlands on the Colorado Plateau are highly variable, with total tree cover ranging from 15% to >75%, with a diverse array of shrub associates, or sometimes no shrubs, and with little to no herbaceous component, or very high herbaceous cover. There are at least 4 different ecological systems for these montane forests; while the tree species are not particularly diverse, the possible shrub or herbaceous indicators are highly diverse. So, in this case the trees are not good indicators of the different ecological systems, and the shrubs are also only partially adequate. It is the herbaceous component that is particularly useful to key these systems, but when the plots are lacking in herbaceous data the task becomes much more difficult.

Another example is montane riparian shrublands of the southern Rocky Mountains, which are primarily placed into one ecological system. But to correctly key plots to the riparian system, the auto-key needs to account for every possible dominant shrub that might be found in a plot in the riparian zone (e.g., *Salix bebbiana, Salix geyeriana, Crataegus rivularis, Forestiera pubescens, Prunus virginiana, Rhus trilobata, Salix irrorata, Salix lucida, Shepherdia argentea, Betula occidentalis, Alnus incana, Salix exigua, Salix lasiolepis, Salix lutea, Salix ligulifolia,* etc.).

D. Cost/benefit & efficiency

The purpose of the auto-key process is to accurately key many hundreds of vegetation samples for each desired map class (ecological system or land cover) to feed into a mapping process. While a single georeferenced sample may be lacking in the complete floristics of an occurrence of an ecological system, the sequence table process aims to attribute many dozens to hundreds of plots to each ecological system or land cover class.

Auto-keys take a significant amount of time to develop for a region, and then to test, review, refine, and test again. A single auto-key for LANDFIRE typically took somewhere between 4 and 7 person days to create and refine. And, that assumes an agency such as SEM has already completed data compilation and processing for use. Some auto-keys for regions with large numbers of samples (for example map zones 1, 2, and 7 in the Pacific Northwest had over 100,000 plots) probably took closer to 10 person days to develop.

However, sequence tables can be refined over and over. The identification of combinations of species indicative of particular geographic or ecological settings is an ongoing effort amongst vegetation ecologists, and a repeatable and refine-able method such as this has distinct advantages. As we become more knowledgeable, field data becomes more comprehensive, and well collected datasets become more numerous, sequence tables can be improved until they successfully key 95% or more of the plots fed through them. This is a huge advantage for regional and national classification and mapping efforts, especially when it is desired to repeat them over some specified time frame with new imagery or new mapping methods.

Recommendations (draft)

[Note: yellow highlighted comments below are from the Report writer].

This report section requires further development and interpretation; this is preliminary material. After other GeoAreas have been analyzed this section will be more completely written up. Recommendations may vary somewhat across the country, but we anticipate some general patterns relevant to all sequence tables and GeoAreas.

Adjustments to Auto-key procedures – inclusion of locational/biophysical information for pre-processing plots and/or inclusion of features in auto-keys

Can we include a pre-processing step that makes sure the physiognomic class indicated by the vegetation in the plot is consistent with what is currently on the ground? This should help identify areas where the vegetation has changed significantly since the data was collected through logging or other methods and should help identify plots that may be inaccurate (due to location errors, data collection errors, or misunderstanding of field data when applying the auto-keys)

Some systems, for example the Rocky Mountain Poor-Site Lodgepole Pine Forest may be benefited from a two step auto-key process. Run the plots through the auto-key and see which key to the Rocky Mountain Lodgepole Pine Forest. Then for appropriate FS Sections where poor site conditions are thought to occur pull in other variables such as soil information and expert review to identify the poor site plots.

When first considering the addition of variables like slope and elevation to the auto-key process it seems that the addition of these variables would be beneficial but with further consideration it is difficult to envision general rules using these variables that would not end up eliminating correct points from type classes. In order to work the rules would need to be fairly location specific and would therefore be time intensive to develop. Perhaps it would be better to include these variables in a check process which would flag plots that seem outside of the normal range for the system for additional review.

Narrowing vs. broadening the geographic application of the auto-key – FS Sections? In certain areas? Would this likely lead to greater accuracy?

It seems like the use of the FS Sections would help to improve auto-key accuracy in GeoArea 2W. Their use would help to prevent points getting to assigned to systems outside their range of occurrence.

Adjustment to auto-keys – additional requirements for vegetation sample data; primarily ground cover data.

It is important to make sure that when vegetation data is collected information on non-vegetative elements is also collected and considered. Obviously a site where aspen is the only plant species recorded and aspen covers 80% of the canopy is very different than a site where aspen is the only vegetation recorded but it provides 5% canopy coverage and the majority of the site is bedrock.

Expert review and labeling of plots for types of low confidence from auto-key.

Expert review should be incorporated into the auto-key process where possible. Perhaps experts could review some percentage of all plots (5-20%) and look for patterns in where the auto-key may be mislabeling. Then the autokeys could be revised and improvement looked for. If improvement was not possible for certain systems or geographic areas could be flagged for more extensive review by experts. In GeoArea 2W systems that probably benefited the most from expert review were the alpine, wetland, riparian, bareground, avalanche, and subalpine parkland systems. These systems seem to present challenges to the auto-key that can often be resolved by experts through the review of photos and other context information.

Adjustments to Map Legends – moving to Group/Macrogroup concepts where systems level remains challenging – which ones?

Coping with uncertainty; what proportion of types could NOT be adequately handled through any of the above adjustments?

Careful review of the dominant tree, shrub, or grass elements shared among related types, should be the focus of auto-key improvements for these types.