Assessing Ecological Departure from Reference Conditions with the Fire Regime Condition Class (FRCC) Mapping Tool

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Abstract—*Knowledge of ecological departure from a range of reference conditions provides a critical context for managing sustainable ecosystems. Fire Regime Condition Class (FRCC) is a qualitative measure characterizing possible departure from historical fire regimes. The FRCC Mapping Tool was developed as an ArcMap extension utilizing the protocol identified by the Interagency Fire Regime Condition Class Handbook to derive spatial depictions of vegetation departure. The FRCC Mapping Tool requires a biophysical setting layer identifying potential vegetation distribution, a current succession class layer allowing for comparison with historical vegetation, and a landscape layer (assessment area boundaries) as input data. The tool then compares existing vegetation composition for each biophysical setting to previously modeled reference conditions for those types. As described in this paper, spatial outputs characterizing vegetation departure at the succession class, biophysical setting, and landscape levels can be used by land managers to identify restoration objectives and priorities.*

Introduction

Severe wildfires in recent years have prompted Federal action to protect communities and restore landscapes and associated fire regimes (USDA Forest Service 2000). A standardized, relatively simple method of landscape assessment was needed to measure progress in ecosystem restoration (Schmidt et al. 2002). The Fire Regime Condition Class (FRCC) assessment method was developed (Hann et al. 2005) to meet this need, and to evaluate departure from a range of reference conditions at multiple scales. Reference conditions include the median values for abundance of seral stages, as well as an estimate of historical fire frequency and severity on landscapes and are developed for each BpS. FRCC is a classification of the amount of departure of conditions at a given time period (such as current or future) from historical ecological reference conditions (Hann et al. 2005). Current policy direction for federal lands management, embodied in the Healthy Forest Restoration Act of 2003 (P.L. 108-148), requires FRCC assessments as part of pre-restoration planning and post-restoration monitoring.

Because of the prominence of FRCC in legal and administrative direction, a number of national and regional trainings in FRCC methods were conducted in 2003 and 2004, with the aim of improving understanding and implementation of FRCC assessments. FRCC training continues at the local level, and is also available on line at www.frcc.gov. An understanding of these methods is a necessary precursor for effective use of the FRCC Mapping Tool.

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Central to the FRCC concept is a classification of landscape integrity relative natural or "reference conditions." We define natural conditions as the range of ecological structure, function, and composition operating on landscapes without post-European settlement influence. Because of uncertainties and lack of information on what this range would be at present, we use the historical range of variation (that prior to European settlement) as an approximation of what the current natural range would be. Given the constraints of currently available data and knowledge, this historical range of variation (HRV) is assumed to represent the best understanding of a properly functioning ecosystem (Landres et al. 1999, Hessburg et al. 1999). When actual historical data are available (tree ring studies, legacy photographs, etc.), the historical range of variation can be described directly, if often incompletely. Usually, however, modeling is required. Modeling this range of historic reference conditions, and then comparing it to current conditions, allows us to infer a departure from conditions presumably influenced by a properly functioning disturbance regime (Cleland et al. 2004).

Moving landscapes closer to the historic range of variation can be useful if the management goal is to restore ecosystems across landscapes. Note, however, that the range of variation is not necessarily the same as a desired future condition. Maintaining wildlife habitat and protecting communities from wildlfire risk are examples where management goals are not necessarily the same as moving landscapes towards HRV.

A simple, intuitive concept in principle, modeling HRV can be fraught with complexity and sources of error. One problem with estimating historic landscapes is that we are generally working with very little data (Gill and McCarthy 1998, Dillon et al. 2005, Marcot 2005). Another problem is that climate change may lead to changing reference conditions; i.e., the historical range of variation becomes obsolete as an approximation of the natural range of variation. Nevertheless, HRV remains our best approximation of a properly functioning system, at least until better models are available.

Dillon et al. (2005) cautioned that modeling HRV has four primary requirements: 1) analyses should be conducted at multiple scales so that important ecological processes are not missed or misrepresented; 2) assessments should consider spatial variation of vegetation patterns across landscapes (see also Arno and Petersen 1983, Johnson and Gutsell 1994); 3) variability can be calculated in several ways, and this should be considered for a more meaningful result (see also Marcot 2005); and 4) consider the role of climate change over time; e.g., climatic conditions during the Little Ice Age (1700-1850), a timeframe often used for the historic range, are very different from those today (see also Millar and Woolfenden 1999).

The FRCC Mapping Tool is a menu-driven GIS extension automating and spatially applying FRCC calculations. As designed and with subsequent refinements, it addresses each of these considerations. The practical outcomes of Mapping Tool use, however, are still unfolding as it is implemented and results evaluated. The Mapping Tool can be easily run at multiple scales, providing that input layers are delineated or can be aggregated at those scales, addressing requirement (1) above. FRCC is based largely on variation in spatial patterns, addressing requirement (2). Throughout this paper, the reader should fully realize departure is calculated using an estimated mean or median value of succession stage abundances. Departure from a range of values would be more meaningful, and methods to develop this are under active consideration (requirement 3). Finally, as for climate change (requirement 4), there is nothing in FRCC that precludes modeling different climate scenarios. As climate change effects on vegetation become better understood

and models more widely available, FRCC reference conditions can be adjusted accordingly.

During the initial development of the FRCC methodology, and with subsequent research efforts such as the multi-year LANDFIRE project (www.landfire.gov), reference conditions were modeled to estimate HRV. Specifically, HRV was estimated for vegetative structure and composition, and in terms of fire regime characteristics (fire frequency and severity). Using a combination of literature searches, expert opinion, and simulation modeling, HRV metrics were developed for all major vegetation types, or "Biophysical Settings" (BpS), in the U.S. Biophysical settings are a potential vegetation concept defined using a disturbance-constrained approach; i.e., succession and vegetation development occur within the bounds of historic natural disturbances; non-lethal disturbance frequency and severity can influence successional trajectories (Hann et al. 2005). To date, more than 300 reference condition models provide the basic foundation for diagnosing FRCC at multiple spatial scales.

The FRCC system is an index of departure, with three condition classes. Properly functioning landscapes, defined as exhibiting less than 33 percent departure from the median or average HRV conditions, receive a Condition Class 1 rating. Condition Class 2 represents landscapes with moderate departure (33 to 66 percent departure), and Condition Class 3 lands show high departure (greater than 66 percent). These classes are generally useful for planning and prioritizing ecosystem maintenance and restoration. For example, FRCC data might provide baseline data for pre- and post-treatment planning, monitoring, and accomplishment reporting.

FRCC assessments can be conducted in several ways. Field-based assessments can be made where an evaluator rates the vegetation (succession stage abundance) and fire regime components (current fire frequency and severity) of the landscape using aerial photography, field observation, and fire atlas data. These landscapes are generally in the range of hundreds to thousands of acres. This method is useful for field checking of estimates made at broader scales and for local monitoring. Another alternative is to use the FRCC Mapping Tool with remotely sensed vegetation data in a geographic information system (GIS) to produce maps at various scales. The Mapping Tool evaluates remotely sensed vegetation data to produce spatially specific FRCC diagnoses. A third option, not discussed in this paper, is to download the remotely sensed FRCC map from www.landfire.gov. That data layer, however, was designed for regional and national-scale analyses and may be too coarse for many analyses.

The FRCC Mapping Tool provides an objective, consistent, and spatially specific way to measure post-European settlement changes across multiple geographic scales if suitable data are available. Assessments based on the FRCC Mapping Tool can help managers prioritize landscapes for possible restoration and maintenance activities from fine (e.g., hundreds of acres) to coarse (e.g., millions of acres) scales. Finally, the Mapping Tool is relatively easy to use and understand—not a minor consideration when a standardized method for use at multiple organizational levels is needed.

FRCC Mapping Tool Characteristics

The FRCC Mapping Tool was designed in conjunction with the field-based Standard Landscape Method described in the FRCC Guidebook (Hann and

others 2005). In contrast with field-based FRCC assessments, the Mapping Tool is a GIS application that produces multiple spatial layers to analyze pixel- to landscape scale (ranging from hundreds to millions of acres) departure and FRCC.

Both FRCC methods use similar principles to evaluate landscape departure and condition class. Field-based assessments evaluate existing vegetation and fire frequency/severity, whereas the FRCC Mapping Tool currently assesses only the departure of existing vegetation from reference vegetation conditions. To date, the software team developing the mapping tool has not been able to develop a way to effectively evaluate post-European settlement fire frequency and severity for a given landscape. This is primarily because these data layers are lacking or inconsistent for most areas of the country, not because of software limitations. Nonetheless, for many biophysical settings the existing condition indicates changes in fire regimes compared to the reference range.

Because of the similarity between the two FRCC methods, potential users of the Mapping Tool should first seek FRCC certification (see www.frcc.gov). In addition, users should have a firm understanding of geographic information systems (GIS) and experience using raster data and ArcMap (Version 9.0 or later) software. The Mapping Tool software, user guide, and systems requirements can be downloaded at www.frcc.gov.

The FRCC Mapping Tool uses three input layers to produce six output layers. (See Figure 1 for a diagram of the mapping process used in the Tool.) The Mapping Tool also produces a summary spreadsheet known as the Management Report. This report shows the current acres in each BpS succession class, and the area that would need to be converted to restore a landscape with a range of conditions similar to the historical range.

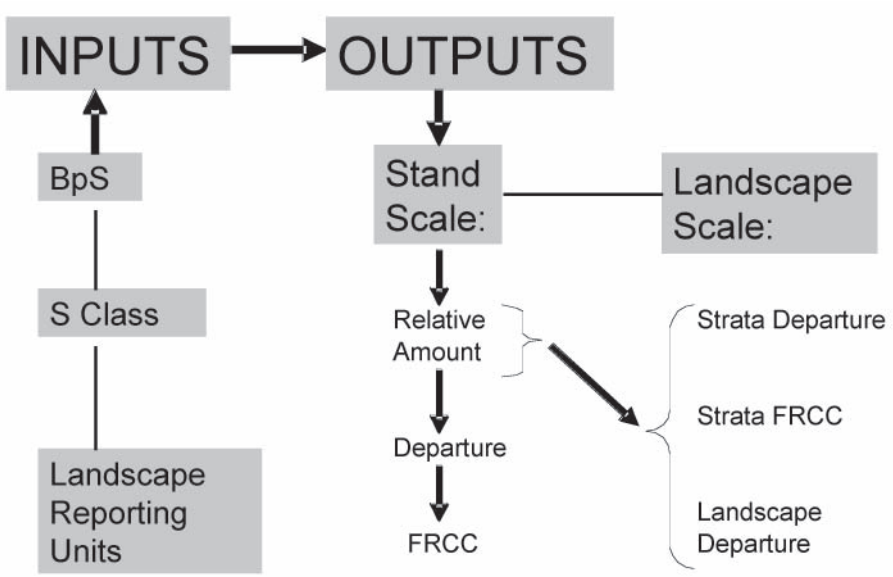

Figure 1—Diagram of the FRCC Mapping Tool process.

Input Data Layers

The Mapping Tool derives its suite of FRCC attributes from three user-provided input layers. These data sources can range widely, from coarse field-level data, to data derived from satellite imagery, to photo-interpreted vegetation mapping with extensive field checking. Because FRCC is a scale-dependent variable (Hann and others 2005), users must first provide a map to support scale-appropriate succession class analysis. This *Landscape Layer* should identify the appropriate spatial scale and boundaries for assessing FRCC. It may vary by BpS or geographic area. The Mapping Tool allows up to three landscape levels for consideration. For example, a tri-level nested hierarchy of area hydrologic units or similar nested classification can be used. When based on hydrologic units, for example, the map units might range from subwatersheds, to watersheds, to subbasins (nested watersheds of increasing area, Figure 2). These hierarchical maps allow the FRCC Mapping Tool to analyze Succession Classes according to ecologically appropriate scales, which differ among fire regimes. For example, a subwatershed scale can be used where small or patchy fires predominated historically (fire regime groups I and II [Hann and others 2005]). Conversely, BpS's influenced primarily by large replacement fires (Regimes IV and V) should be analyzed at the largest landscape scale because large fires can falsely appear to skew the statistical distribution of succession classes for small study areas. Hann and others (2005) have developed guidelines for analyzing FRCC based on fire regime-topography combinations (Table 1).

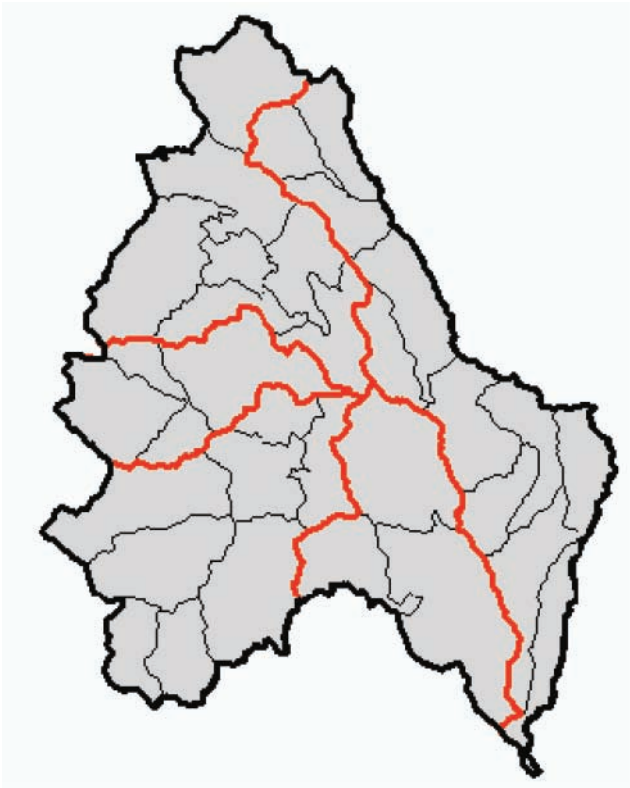

Figure 2—Example of tri-nested landscape hierarchy based on hydrologic units (from Hann et al. 2005). Such ecologically based classifications are useful for FRCC analysis, where potential analysis units range from the subwatershed to the subbasin scales.

Table 1—Scale guidelines for determining FRCC (Hann and others 2005). Suggested analysis area size range is based on dominant fire regime type and is inversely related to slope steepness and land dissection.

	Terrain	
Fire regime group[1]	**Flat to rolling (lightly to moderately dissected)**	**Steep (moderately to highly dissected)**
	acres	
I, II	50-2000	50-1000
III	500-2000	250-1000
IV,	5000-1,000,000	2000-250,000
V (replacement severity)	5000-1,000,000	2000-250,000
V (mixed severity)	50-10,000	50-10,000

[1] I (0-35 yr/low to mixed severity); II (0-35 yr/stand replacement); III (35-200 yr/mixed severity); IV (35-200 yr/stand replacement); V (200+ yr/stand replacement [but can include any severity type]).

To summarize input requirements for the landscape layer, the user must: 1) provide a base map containing up to three nested landscape sizes, such as hydrologic units or ecological units (Winthers et al. 2005), and 2) in an associated table, specify for the Mapping Tool which landscape levels are appropriate for FRCC analysis based on BpS, dominant fire regime types and associated terrain dissection. The Mapping Tool then concurrently analyzes BpS vegetation succession classes according to each user-specified landscape level in the area.

The FRCC Mapping Tool also requires a *Biophysical Settings* input layer, which shows BpS distribution within the analysis area. The Mapping Tool analyzes this layer in tandem with a user-provided Reference Condition table to document the estimated average amount of each succession class historically. For instance, results from a given BpS model might suggest up to 20 percent of the type occurred in the early seral succession class, 40 percent occurred in the mid-seral open class, 10 percent occurred in the mid-seral closed class, and so on.

The LANDFIRE reference condition tables for the entire U.S. will load automatically after installing the Mapping Tool software, or users can develop custom reference condition tables based on local data. These tables must contain three pieces of information for the Mapping Tool: 1) a comprehensive list of all BpS within the study area, 2) reference condition amount (in percent) for each BpS succession class, and 3) the appropriate landscape reporting scale for each BpS type. Determining this scale generally means identifying a scale large enough to encompass the normal range of disturbance (fire) sizes and frequency for the question of interest.

Finally, the user must provide a *Succession Classes* layer showing the current distribution of succession classes within the analysis area. This layer can be generated from local current vegetation layers crosswalked to the appropriate FRCC succession class. This allows the Mapping Tool to compare the current amount of each succession class to the estimated historical amounts, thus assessing FRCC departure and condition class diagnoses. The LANDFIRE project represents a good source of data for succession class and other information. Upon completion in 2009, comprehensive U.S. map coverage will be available for succession classes, BpS, and other layers.

Output Data

To date, the FRCC Mapping Tool produces six output raster (pixel-based) GIS coverages (map layers) describing various Fire Regime Condition Class metrics. The Mapping Tool also generates a report summarizing the raster data. Two additional rasters are now in the final stages of development, as discussed below. For more detailed information on all layers, see the FRCC Guidebook (Chapter 4 in Hann and others 2005).

Output layers generated by the Mapping Tool fall into two groups: those at the BpS/landscape scales and those at the succession class/stand scales. The first group (BpS/landscape scales) includes three layers. The first of these, the *Strata Departure* layer summarizes Departure for each BpS, (or landscape "stratum," Hann et al. 2005). (Note that the soon-to-be-replaced FRCC Guidebook uses the now outdated name "S*tratum S-Class Departure*" for this layer.) The *Strata Departure* layer integrates the landscape strata according to a number of percent Departure classes. The next layer is the "*Strata FRCC*" layer (previously called the "*Stratum S-Class FRCC*" layer) (Figure 3). This data layer classifies the various BpS departure results according to the three FRCC Condition Classes described above. The final raster currently available is the "*Landscape Departure*" layer. Here, the Mapping Tool rates landscape-scale Departure by calculating an area-weighted average of the various strata departure percents, then by generating an overall rating for the appropriate landscape scale. When an area is dominated by large replacement fires, for instance, the tool bases the departure rating on the largest landscape scale defined by the user, such as a watershed occupying tens of thousands of acres.

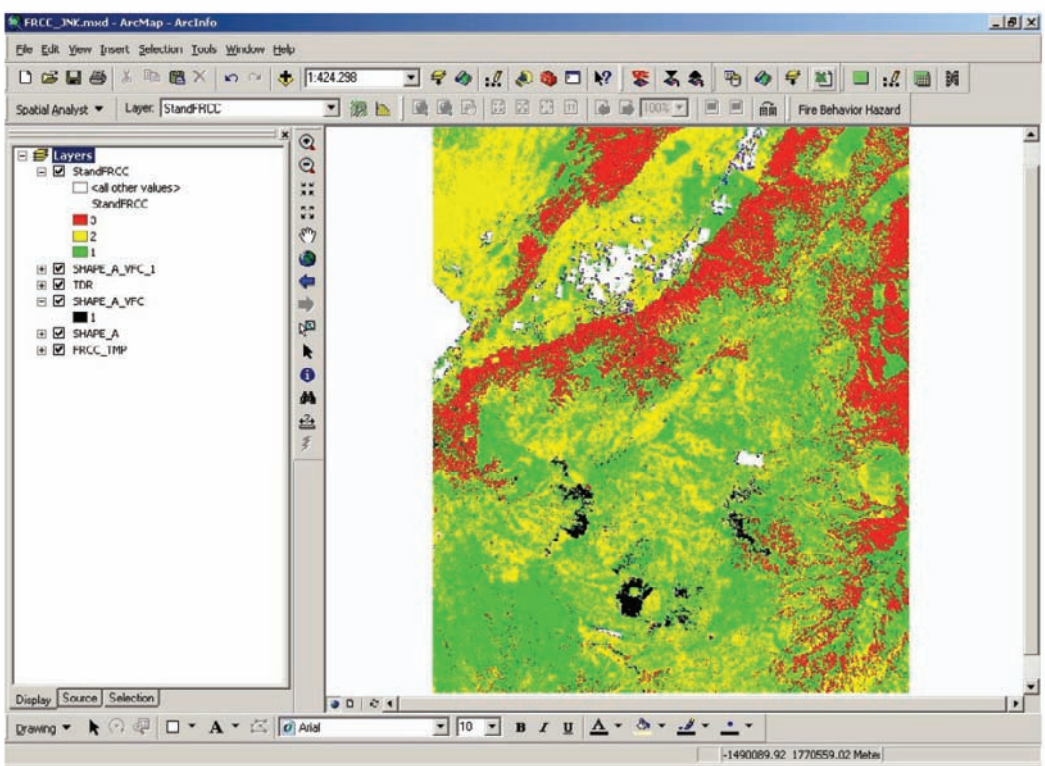

Figure 3—Example of FRCC Mapping Tool output for a hypothetical analysis area. Map shows Fire Regime Condition Class for the various landscape Strata, which typically represent an area's biophysical settings (*Key*: green is Condition Class 1, yellow is Condition Class 2, red is Condition Class 3 [white polygons indicate "No Data"]).

In the second group (succession class/stand scales), the first data layer generated by the FRCC Mapping Tool is the *Succession Class Percent Difference* layer. This output compares the amount of each BpS succession class during the current period to the estimated average amounts for the Reference period. In this case the measurement scale ranges from -100% to +100%, with zero representing similar amounts, negative values indicating deficient amounts, and positive percents representing excessive amounts. That is, the layer shows the most deficient to the most excessive (relative to the historic median) succession classes on today's landscape.

The next output layer is the *Succession Class Relative Amount*. (The current version of the FRCC Guidebook (Hann et al. 2005) uses the now outdated name "Stratum S-Class Relative Amount" for this layer.) This layer simply classifies the percent difference data according to the FRCC Guidebook (Hann and others 2005)(Figure 4). For example, pixels with a percent difference value of between minus 33 and minus 66 percent are "under-represented," whereas values between plus 33 and plus 66 percent are considered "over-represented." Classifying the myriad results from the percent difference layer thus helps users more easily identify which succession classes should be maintained, versus those that could be reduced or recruited, in order to emulate average BpS Reference Conditions.

Finally, the *Stand Condition Class* (FRCC) layer, previously called "*Stand Level FRCC*" (Hann et al. 2005), further classifies the above results. Here, the Mapping Tool rates the relative amount output according to the three Condition Classes mentioned earlier. For example, pixels in the "similar," "under-represented," and "trace" relative amount classes are rated as Stand Condition Class 1. Pixels in the "over-represented" relative amount class are considered to be Stand Condition Class 2, and those in the "abundant" relative amount class are Stand Condition Class 3. This layer was developed primarily to facilitate reporting and accomplishment. We stress this layer should not be used as a proxy for the landscape condition class layer, because the latter is a more appropriate layer for identifying FRCC, a landscape-scale measure. It is better to think of stands as having *membership* in successional stage classes that are either over-abundant, under-abundant, or within the historic range.

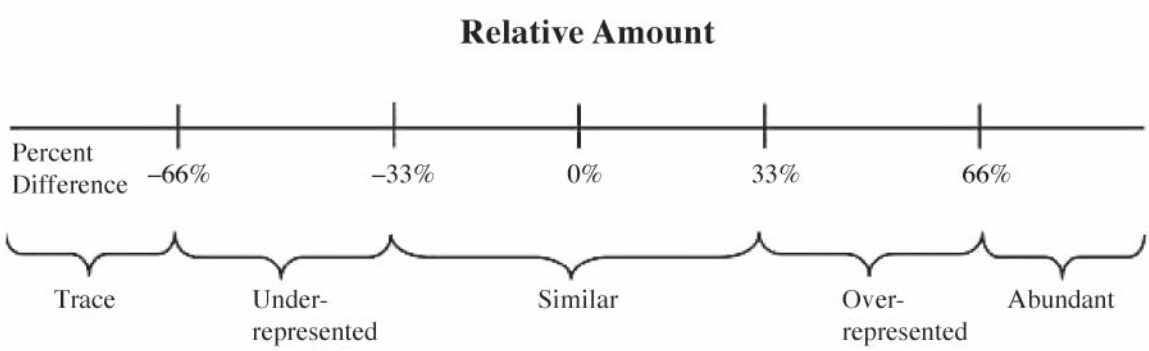

Figure 4—The Percent Difference- and Relative Amount scales used for FRCC assessments.

Software for two additional rasters currently is being developed, yielding an eventual total of eight data layers. Specifically, a *Stand Departure* layer and a *Landscape Condition Class (FRCC)* layer will likely be available by late 2006. The *Stand Departure* layer will base departure at the local (stand) scale on each stands membership in an seral stage abundance class compared to the historic average. The *Landscape Condition Class* layer will generate a single FRCC call for a landscape (delineated by the user) that is the weighted average of its member *Strata Condition Classes.*

The FRCC Mapping Tool also generates a Management Report spreadsheet to accompany the output rasters. The spreadsheet serves as the primary tool for analyzing and interpreting the GIS results, helping to support various planning needs. For instance, the data helps identify the ecological condition of an individual BpS or for multiple BpS in a given analysis area. The GIS data can also help managers identify ecological conditions and prioritize treatments ranging in scale from individual stands to entire landscapes. Such FRCC data can also be useful for fulfilling various reporting requirements, for developing budgets, and for supporting public education.

Mapping Tool Limitations

The FRCC Mapping Tool has several limitations. First, unlike field-based assessments, the Mapping Tool cannot be used to document post-settlement trends in fire frequency and severity. In many cases, however, the remotely sensed vegetation condition serves as an indirect measure of current fire potential, essentially serving as a proxy for those two FRCC metrics. Using remotely sensed data to identify numerous vegetation types and current conditions also can be difficult. Distinguishing between closely related BpS types and among the various succession classes is frequently challenging, particularly when types occupy closely similar terrain. In the western U.S., for example, the distinction between early successional Class "A" in pinyon pine (*Pinus edulis*)-juniper (*Juniperus* spp.) woodlands and similarly grass-dominated succession classes in adjacent sagebrush (*Artemisia* spp.) types can be difficult, especially for broad ecotones. Identifying various types of FRCC-defined "Uncharacteristic" succession classes also can be difficult when using remotely sensed data. Examples include areas invaded by varying amounts of exotic cheatgrass (*Bromus tectorum*), and woodland-grassland ecotones experiencing tree encroachment as a result of post-1900 fire exclusion. To help mitigate such interpretation errors, users of the FRCC Mapping Tool might need to conduct local field sampling to help improve the digital "signatures" for the remotely sensed data.

Management Applications

To date, land managers have used the FRCC Mapping Tool to support various planning activities. Introduced in late 2004 during a number of training sessions in the western U.S., the FRCC Mapping Tool is gaining acceptance and use. Although the Tool has not yet been fully implemented, enough practical experience has emerged that we can highlight several management oriented examples and issues here. As of 2006, the mapping tool has been used to determine FRCC on National Forests throughout much of the Pacific Northwest Region. One of the software's main strengths as reported by users is the personnel time saved with its use. The Tool has helped automate a GIS process that would otherwise require a number of time-consuming steps. The FRCC Mapping Tool has also helped promote a standardized approach

to determining FRCC (Jane Kertis, Siuslaw National Forest, pers. comm.), facilitating communication among land managers.

Improper or inconsistent use of the Mapping Tool, rather than software design and function, seems to be the main issue to date. The Mapping Tool will not run if the input layers do not agree with each other and with the reference condition table. For example, if a BpS on the map layer is not included in the reference conditions table, the software will not run. Hence the importance of consistent input data without errors. Also, using inappropriate landscape input maps can be expected to produce varying degrees of FRCC estimation error for similar vegetation types. Experienced users are currently helping to educate their peers about the FRCC scale issue and the appropriate uses of the Mapping Tool. Instructions on use of the Mapping Tool can be found in the FRCC Guidebook (Hann et al. 2005).

The FRCC Mapping Tool will be used to assess subregions, such as northwest Oregon (Jane Kertis, Siuslaw National Forest, pers. comm.). Similarly, the USDA Forest Service Pacific Northwest Region's standardized existing vegetation mapping effort, known as the Interagency Mapping and Assessment Process (IMAP) also will examine the potential utility of the Mapping Tool for assessing FRCC and related metrics at more local landscape scales than LANDFIRE does. Given the vast amount of area in the U.S. currently in need of ecological assessments, newly emerging GIS software such as the FRCC Mapping Tool will become increasingly important to land managers.

Acknowledgments

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