First Implementation of Mid-Scale Fire Regime Condition Class Mapping

Louis Provencher[1&], *Jeff Campbell*[2], *Jan Nachlinger*[1]

[1]The Nature Conservancy, 1 East First Street, Suite 1007, Reno, NV 89509, USA.

[2]Spatial Solutions, Inc., 60575 Billadeau Road, Bend, OR 97702, USA.

[&]Corresponding author: Telephone: +1 775-322-4990 x20; fax: +1 775-322-5132; email: lprovencher@tnc.org

For *International Journal of Wildland Fire*

Abstract. Mid-scale Fire Regime Condition Class (FRCC) mapping provides the necessary data layers to plan fuels restoration project serving anthropogenic and resource management goals. We implemented for the first time in the USA the mid-scale methodology proposed by Shlisky and Hann (2003) to map FRCC using remote sensing (Ikonos 4-m resolution satellite imagery) on the 18,218 ha Mount Grant of Hawthorne Army Depot in western Nevada. Pinyon-juniper woodland and curlleaf mountain mahogany woodland were found within the historic range of variability (FRCC 1), whereas low sagebrush, mountain big sagebrush, Wyoming big sagebrush, and mixed desert shrub were moderately departed from the historic range of variability (FRCC 2). Only riparian mountain meadow was highly departed (FRCC 3). Based on fire regime departure as expressed by a continuous percentage value, FRCC assignments were borderline for low sagebrush (FRCC 2 to 1), mountain big sagebrush (FRCC 2 to 3), Wyoming big sagebrush (FRCC 2 to 3), and riparian mountain meadow (FRCC 3 to 2). For departed ecological systems, which were all range sites and the riparian mountain meadow, the common recommended action was to decrease the percentage of late-development closed and cheatgrass-dominant pixels, thus increasing the percentage of early and mid-development pixels.

Key Words: rangeland, woodland, Great Basin, state-and-transition, LANDFIRE, DOD, fire management, sagebrush, pinyon-juniper, Nevada

Introduction

Fire managers across diverse landscapes recognize the need to reduce hazardous fuel loads, restore sustainable fire regimes and ecosystems, and decrease the threat of catastrophic wildfires. The United States Department of Agriculture Forest Service recently provided national-level, coarse resolution data to address the degree and nature of departure of current vegetation and fuels from historic conditions (Hardy *et al.* 2001; Schmidt *et al.* 2002; Menakis *et al.* 2003). This coarse-scale data of the measure of departure, termed Fire Regime Condition Class (FRCC), was a significant leap forward in the integration and mapping of biophysical, vegetation, fire occurrence, and ecological community data for the purposes of gaining an ecologically-based perspective on national priorities for resource allocation for fire regime restoration, fuels treatment, and biodiversity conservation. However, while this highly anticipated and relevant coarse-scale data was not intended to be used at scales finer than regions, the lack of similarly available data at finer scales has led to misuse of the coarse data for region- and project-level prioritization and planning. Currently available FRCC data only addresses prioritization between regions and states and not projects.

Finer scale data is available for the Northern Rockies and is being developed for the Pacific Northwest, but is not consistent in methods or continuous in extent. The LANDFIRE project (www.landfire.gov) for mid scale continuous and consistent mapping of FRCC using remote sensing and gradient modeling is underway, but it is only in a prototype stage that will not lead to completion of the contiguous lower 48 states until 2006-2010 (USDA, USDI 2002). Availability of continuous spatial FRCC and associated data will help instill coordination into the tasks of restoration and fire hazard reduction across multi-ownership landscapes. Consistent, science-based measures of opportunities and risks across all land ownerships is a prerequisite for successful collaborative, multi-partner watershed-scale fire planning.

The FRCC concept is readily being adopted by the United States Congress (Healthy Forest Restoration Act 2003) and land management decision-makers as a useful landscape-scale metric to account for the success of hazardous fuels and ecosystem restoration projects. Locally, issues such as the need to develop a science-based foundation for assessment of interactions between fire regimes and invasive weeds, and conservation of species of local and regional interest (e.g. Greater Sage-grouse; *Centrocercus urophasianus*), can be favorably addressed through implementation of the FRCC mapping approach.

The objectives of this FRCC assessment were twofold: 1) fully implement for the first time the mid-scale remote-sensing method for mapping FRCC as proposed by Shlisky and Hann (2003) and 2) provide the structure and resources necessary to cooperatively develop data at appropriate scales to directly address key priorities for Hawthorne Army Depot of the United States Department of Defense in western Nevada. The mid-scale rapid assessment is expected to deliver fire regime condition class (FRCC) and associated data layers for development of an inter-agency fire management plan to prioritized fire suppression activities, protection of water resources, fuels restoration and maintenance projects, conservation area strategies for biodiversity protection, tracking success of restoration strategies, and revision and amendment of resource land management plans. In 2003, an initial conservation assessment by The Nature Conservancy of Mount Grant identified the risk of catastrophic fire due to long term fire suppression as the highest threat to the integrity of surface water quality and the viability of sagebrush shrubland, pinyon woodlands, Greater Sage-grouse habitat.

Methods

The Rapid FRCC Assessment process (Shlisky and Hann 2003) was designed to use the most recent data available. Four primary tasks were undertaken in this project approach (Fig. 1). Each of these is described below. The foundation for these methods is recent work in mapping environmental gradients (Keane *et al.* 2002), using reference ecological conditions in ecosystem management (Kaufmann *et al.* 1994; White and Walker 1997; Swetnam *et al.* 1999), and calculating departure of current from reference conditions (Hann *et al.* 2003b). Similar methods were described by Hann (2003) and McNicoll and Hann (2003) to classify FRCC at finer project scales.

Study area

The Mount Grant project area (NAD 27 CONUS N 034414 E 4271143) is ~18,218 ha and contained within Hawthorne Army Depot, a 59,609 ha military installation and the Wassuk Range located in western Nevada. Mount Grant is managed and partially owned by Hawthorne Army Depot with surrounding areas in the Wassuk Range managed by the Bureau of Land Management, Carson City Field Office, US Forest Service, Humboldt-Toiyabe National Forest, or in private ownership. Much of the higher elevations are part of a 1930's public lands withdrawal where multiple uses and public access have been limited for years, including the removal of livestock grazing. As a result, the predominant terrestrial ecological systems tend to be in exemplary condition and are used for ecological baselines to measure land management practices in comparable areas throughout the Great Basin.

The Wassuk Range is a representative western Great Basin range bordered by Walker Lake Valley (1,371.6 m) on the east and the incised drainage of the East Fork Walker River on the west. The alpine summit of Mount Grant reaches 3,425.6 m in elevation. The Wassuk Range is topographically diverse and geologically complex.

Thirteen broad ecological systems occur on the slopes of Mount Grant. The nine upland types include mixed desert shrub, big sagebrush (*Artemisia tridentata*) semidesert, pinyon (*Pinus monophylla*)–juniper (*Juniperus osteosperma*) woodland (as defined by Miller et al., 1999), curlleaf mountain mahogany (*Cercocarpus ledifolius* var. *intermontanus*) woodland, mountain big sagebrush (*A. tridentata* subsp. *vaseyana*), low sagebrush (*A. arbuscula*), subalpine pine forest, and alpine (often dominated by low sagebrush). Subalpine pine forest, which are mostly limber pine (*Pinus flexilis*) and whitebark pine (*Pinus albacaulis*), occupy very small areas within the mountain big sagebrush matrix. The four mesic ecological systems include cottonwood (*Populus* spp.) forest, willow (*Salix* spp.) riparian shrubland, montane meadow, and aspen (*Populus tremuloides*) forest.

The range supports several large mammals including desert bighorn sheep, mule deer, black bear, mountain lion, bobcat, and coyote. It also hosts an unusually diverse and abundant rodent assemblage with highest diversity occuring in mid- to low-elevation side canyons with some riparian vegetation. The big sagebrush semidesert, mountain big sagebrush, and low sagebrush matrix communities are important habitats for several sagebrush obligates, including Greater Sage-grouse, which is part of a genetically distinct California population.

Initial map of potential natural vegetation types

Potential natural vegetation types (PNVT) are one type of biophysical classification based on dominant and upper-layer lifeform plant species that are indicators of the natural disturbance regime, site climate, and topo-edaphic relationships. In LANDFIRE, PNVTs are called Biophysical Settings. Biophysical characteristics that to a large extent control fire regimes and the distribution of vegetation are reflected in the distribution of PNVTs. PNVTs are the foundation for stratification of reference and vegetation-fuel conditions, the development of reference models and calculation of departures between reference and current conditions. The PNVT represents the vegetation type that would exist under the historic range of variability (HRV), with natural disturbances, including Native American pre-settlement disturbances, and in the absence of modern human interference. Thus, it is the pre-settlement vegetation, but with the current climate. HRV is defined as the distribution of structural vegetation classes (see below) and distribution of fire return intervals in the pre-settlement landscape. Because quantitative historical data are generally absent for the pre-settlement period, the HRV is modeled—hence the use of state-and-transition modeling.

PNVTs for Mount Grant were first obtained by interpreting an order III soil survey completed in the 1990s by the United States Department of Agriculture Natural Resources Conservation Service (NRCS) for Hawthorne Army Depot (No. 799; USDA SCS 1991). Order III soil surveys do not map inclusions (ecological sites <4.04 ha), therefore small ecological systems were initially imbedded into larger ecological systems. The soil survey was downloaded from the NRCS's SSURGO website (www.ftw.nrcs.usda.gov/ssur_data.html) and dominant upper-layer lifeform species matched with ecological range site polygons. All ecological range or forest sites sharing the same dominant species in the upper-layer lifeform (e.g., mountain big sagebrush) were lumped into a major vegetation type:

Refinement of PNVT map using current spatial data

Field surveys revealed that the initial map of PNVTs based on the NRCS soil survey was too coarse because it does not always separate many ecological sites based on landform position and slope; therefore, fine scale inter-digitization between low sagebrush and mountain big sagebrush were commonly observed, although these were not the only ecological systems with this limitation. The FRCC assessment process (Shlisky and Hann 2003) requires the use of available spatial data on PNVT, current land cover, and development/structural stage to refine spatial data layers to mid-scale resolutions (e.g., $30m^2$) as well as large-scale resolutions (e.g., $\leq 4m^2$).

We combined the existing NRCS soils data with a recent plant community mapping at Mount Grant (Nachlinger 1990) and current vegetative conditions identified from Ikonos satellite imagery (Fig. 2) to develop and refine a PNVT layer for Mount Grant where the scale of the NRCS data did not sufficiently resolve smaller patches of some PNVTs. For example, in many areas along the slopes and drainages of Mount Grant, narrow bands of mountain big sagebrush extended into areas identified only as low sagebrush by the NRCS data. It was determined by the 1990 mapping effort (Nachlinger 1990) and local expert ecologists that these narrow bands of mountain big sagebrush were indeed representative of the mountain big sagebrush PNVT and should be mapped as such. The resolution of the Ikonos imagery clearly identified the presence of the mountain big sagebrush. Based on the classification from the satellite imagery, the draft

NRCS-based PNVT map was revised to include the more spatially robust mountain big sagebrush characterization. Similar processes were utilized to spatially refine the infrequent-fire pinyon-juniper, low sagebrush, and mountain mahogany PNVTs.

Modeling the HRV

Prior to the availability of models and descriptions of ecological systems from LANDFIRE (www.landfire.gov), original models were developed using quantitative state-transition models for each PNVT developed with the software Vegetation Dynamics Development Tool (VDDT from ESSA Technologies, Inc.; Barrett 2001; Beukema *et al.* 2003). In the case of Mixed Desert Shrub, the model was downloaded as-is from the FRCC Guidebook (www.frcc.gov; Hann *et al.* 2003a), which is a collection of coarse-scale PNVTs classified by the Rocky Mountain Research Station Fire Modeling Institute (RMRS FMI) used as the foundation for modeling reference conditions and mapping FRCC. The original models were replaced with new LANDFIRE models from the Great Basin Region Rapid Assessment and from National-LANDFIRE detailed modeling for mapping zones 16 (Utah High Plateau), 12 (Western Great Basin), and 17 (Eastern Great Basin). LANDFIRE models were preferred because they were developed and reviewed by experts for a specific region and incorporated the most recent ecological knowledge on estimated successional transition times, fire frequency and severity, and disturbance probabilities between a relatively simple set of structural stages (PNVT classes) expected to occur historically, and representing reference conditions.

Modeled structural stages were identified as early development, mid-development open, mid-development closed, late-development open, and late-development closed, or a subset thereof (e.g., late-development wooded). The terms “seral” and “development” are used interchangeably. This simple classification is consistent with mid-scale spatial data likely to be available for structure and composition. VDDT models were parameterized with reference successional and fire disturbance probabilities and run for 500-1000 yrs, or until PNVT structural stage composition stabilized.

Classify and map development/structural stages and canopy cover

Two options were evaluated for completing the task of classifying and mapping development/structural stages and canopy cover. The options involved acquiring and utilizing different sources and resolutions of base digital satellite imagery for mapping of development/structural stages and canopy cover. The general process for manipulating the satellite imagery to discern and map the desired features of interest was essentially identical for each source of imagery. The primary difference between the two options, aside from cost, was the spatial resolution of the data and the potential scale at which the resulting data may be applied.

The first imagery option evaluated, Landsat Thematic Mapper (TM), had a spatial resolution of 30 m and was most appropriate for more regional analysis and characterization. While the concept of a minimum-mapping-unit (mmu) is not entirely applicable to mapping with raster satellite imagery, a mmu of 3-5 acres is typically what can be realized with Landsat TM-derived mapping efforts. In other words, a patch size for any given fuel type/land cover condition of 3-5 acres is necessary to be adequately resolved and mapped by the 30-m resolution satellite imagery. Patch sizes of conditions/land cover smaller than 3-5 acres will likely not be discernable from the Landsat TM imagery and therefore not indicated on the resulting maps.

The second imagery option evaluated the use of high-resolution satellite imagery from the Ikonos satellite (4-meter Multi-spectral; SpaceImaging Corporation). This high-resolution satellite image sources provided a much more site-specific characterization of the landscape than the more spatially coarse Landsat TM imagery. A minimum-mapping-unit of ¼ to ½ acre can be expected from high-resolution imagery.

Based on the desire to produce the most spatially refined characterization of Fire Regime Condition Class possible for this study area, the 4-m Ikonos imagery was selected and utilized for this mapping effort. Figure 2 show the high-resolution satellite imagery of the Mount Grant area obtained on July 10, 2004.

The 4-m Ikonos satellite imagery was processed to develop a current conditions land cover classification and development/structural stage map that coincided with classes used to model reference conditions. Classification of vegetation structure involved utilizing thematic stratification, unsupervised classification techniques, spatial modeling, and manual editing. Existing Geographic Information System (GIS) data pertaining to current development stage, size class, structure, or any other pertinent vegetation characterization was evaluated and utilized to map structure where appropriate. This primarily included existing GAP vegetation data; although usefulness of this data was quite limited. For the majority of the assessment, an unsupervised classification of the satellite imagery resulted in spectral classes were evaluated using existing GIS structural data, aerial imagery, field-based data, or any other available ancillary data to determine the relationship between the spectral reflectance characteristics from the satellite imagery and current structure/development stages. Most importantly, three full days of field data collection from July 29 – 31, 2004 was completed to visit pre-selected field sites corresponding to specific spectral classes of interest that were identified from the Ikonos imagery. At each field site, a set of digital photos was taken and specific estimations of existing vegetative cover were made to fully characterize the current vegetation type, current vegetative structure (e.g. early-, mid-, late-development) and current vegetative canopy cover (e.g. open, closed, wooded). Armed with this site specific data as well as other more subjective field notes and expert opinion, spectral classes were labeled as "early", "mid-development open", "mid-development closed", late-development open", "late-development closed", or "late-development wooded". Other ancillary GIS data such as DEM, NRCS soils, and GAP classification data was used to aid in refining the resulting classification through spatial modeling. These models included the use of elevation/aspect zones and current vegetation types to further stratify the spectral classes for more accurate labeling of structure. Also, for areas exhibiting spectral anomalies or known errors that can not be efficiently and effectively corrected through further automated image processing techniques, manual editing was employed to enhance the thematic accuracy of the final structure classification. The first draft of the *development/structural stages and canopy cover* map was groundtruthed with 61 pre-selected plots on 23 June, 21 July, and 13 October 2005.

Calculate and map departure in vegetation/fuels and fire frequency/severity.

The departure in vegetation/fuels and fire frequency/severity was calculated by comparing reference development/structural stage compositions and fire frequency/severity by PNVT to current conditions. The general methodology utilized is described by Hann *et al.* (2003a) and can be applied at any spatial scale.

Percent area coverage of each structure/density class (e.g., early development, mid-development closed, mid-development open, late-development closed, late-development open, or late-development wooded) for each PNVT was computed from the final structure/density map. These percentages indicate the cover of the current vegetative conditions within each PNVT. The current vegetative condition cover percentages were then directly compared to the historic range of variability (HRV) percentages calculated through VDDT modeling for each PNVT. By summing the lowest of the two area coverage percentages between the HRV and current conditions for each structure/density combination, a measure of "similarity" is obtained. Correspondingly, subtracting this similarity measure from "100" renders a measure of "dissimilarity" between the HRV and current conditions. Dissimilarity measures (i.e., combined vegetation and fire regime departures) ranging from 0-33% are classified as "intact" or unaltered (FRCC 1). Departures ranging from 34-66% and 67-100% are classified as "moderate" (FRCC 2) or "high" (FRCC 3) departure, respectively. By cross-walking dissimilarity measures with the corresponding FRCC class value, a measure of FRCC is derived for each PNVT.

Action data

In addition to the calculation of FRCC across the Mount Grant study area, an additional derivative data was produced from the comparisons of current condition structural/density cover values and HRV values. For every 4-m pixel in this map, an attribute of "Decrease", "Increase", or "Maintain" was developed based on the following relationship between current conditions and HRV:

Current Condition %	>	HRV %	→ Decrease
Current Condition %	<	HRV %	→ Increase
Current Condition %	= (+/- 5%)	HRV %	→ Maintain

This data, referred to as the *Action Map* when mapped, provides the user with a spatial representation of a more sensitive measure of the ecological relationship/conformity between each current structural/density stage and its corresponding HRV estimation for each PNVT. It is important to understand that the terms "decrease", "maintain", and "increase" do not apply to fuels loadings, but the percentage of the development class in the landscape. The Action Map used in conjunction with the FRCC map provides a strong spatial characterization of ecological condition of the study area, as defined by FRCC criteria, and potentially indicates alternative areas needing management, such as fuels reduction.

Results

Mapping PNVTs

Seven PNVTs were obtain from the interpretation of the NRCS soil survey: mixed desert shrub, Wyoming big sagebrush (*A. tridentata* spp. *wyomingenss*) with pinyon-juniper, infrequent-fire pinyon-juniper, mountain mahogany (curlleaf), low sagebrush, mountain big sagebrush, riparian mountain meadow. These major vegetation types became the first draft of PNVTs, which also modeled and described by LANDFIRE (Table 1).

The draft map of PNVTs was refined with current imagery to separate those that might belong to difference landforms and slopes. The result of this process provided a large-scale characterization of PNVTs throughout the Mount Grant study area that more closely and appropriately matched the spatial resolution of the 4-m Ikonos satellite imagery (Fig. 3). It is very important to note the significance of utilizing input data for the FRCC process (e.g., PNVT, satellite imagery, etc.) that are of comparable scale. Incorporating data of varying incomparable scales greatly limits the applicability of the FRCC mapping results. If one utilizes very high-resolution satellite imagery to characterize existing conditions and structural stages in conjunction with more coarsely defined PNVT data, for instance, the results are only applicable at the scale of the smallest scale data used in the process. For this reason, it was imperative that the scales/resolution of all input data be comparable for this FRCC mapping effort. Otherwise, it would have been unnecessary and a waste of resources to utilize the more costly high-resolution Ikonos satellite imagery along with the more coarsely defined PNVT data. Another critical point is the use of current vegetation imagery to refine historic vegetation types should only be done for PNVTs that are edaphically controlled and not subject to range expansion or contraction caused by modern human interference. For example, low sagebrush is the only sagebrush that survives on a claypan that perches the water table for extended periods during the spring. Therefore, the presence of low sagebrush today is an excellent predictor of this species dominance during the long process of soil formation and made the separation of low and mountain big sagebrush relatively easy. Curlleaf mountain mahogany is similarly dependent of a few soil types.

Modeling the HRV

Table 2 contains the modeled HRV values based on vegetation structure and composition. Because the overlap between the original and LANDFIRE models was high, we only needed to crosswalk the structural vegetation classes (crosswalking was necessary to preserve the original coding for the imagery without incurring huge expenses). The least direct crosswalk, which required interpretation, was between the riparian mountain meadow PNVT and the Rocky Mountain riparian herbaceous ecological system (Table 2). The crosswalk for the Wyoming big sagebrush with pinyon-juniper was direct but the original class names, although preserved for mapping, were not needed (Table 2).

The description of each PNVT is provided in seven PDF documents downloadable from www.landfire.gov or can be obtained from the first author. These LANDFIRE descriptions include sections on the range, bio-physical setting, vegetation composition, disturbance regimes, comments by experts, structural classes (i.e., early, mid-closed, mid-open, late-open, and late-closed) and their dynamics, and the mean Fire Return Interval for surface, mixed severity, and replacement fire. The VDDT model files that produced the HRV values and mean Fire Return Intervals, including the definition files needed to code the simulations, can be downloaded from www.landfire.gov or requested from the first author. The VDDT software is Public Domain software that can be downloaded free from www.essa.com. In order to understand and run the models, the reader should follow instructions by downloading the modeling manual (PDF) from http://www.landfire.gov/Workshops/.

Classify and map development/structural stages and canopy cover

The processed 4-m Ikonos satellite imagery resulted in a current conditions land cover classification (Fig. 4) and development/structural stage maps (Fig. 5) that coincided with classes used to model reference conditions (Table 2). Groundtruthing resulted in reinterpretation of common spectral signatures for pinyon-juniper, low sagebrush, and mountain big sagebrush development stages, and increased the detectability of uncharacteristic cheatgrass cover where the non-native species (*Bromus tectorum*) was dominant. Figure 5 represents the final draft.

Calculate and map departure in vegetation/fuels and fire frequency/severity.
Infrequent-fire pinyon-juniper and mountain mahogany had FRCCs of 1, whereas low sagebrush, mountain big sagebrush, Wyoming big sagebrush, and mixed desert shrub were at FRCC 2 (Table 3; Fig. 6). Only riparian mountain meadow was highly departed (FRCC 3). The fire regime departure as expressed by a continuous percentage value was borderline between different FRCCs for many PNVTs (Table 3). Low sagebrush and mountain big sagebrush, respectively, were within 1-2 percentage points from being in FRCC 1 and 3, whereas Wyoming big sagebrush and riparian mountain meadow were within 4 percentages points from FRCC 3 and 2, respectively.

Action data

For all range sites and the riparian mountain meadow, the common recommended action was to decrease mostly the percentage of late-development closed pixels and cheatgrass (in Wyoming big sagebrush) and increase the percentage of early and mid-development pixels (Table 2 versus Table 3; Table 4). In other words, late-development stages are too abundant. For woodlands sites, which are infrequent-fire pinyon-juniper and curlleaf mountain mahogany, the recommended action was primarily to increase the percentage of late-development stages. But since these woodland types are in FRCC 1, simply waiting for tree growth is the primary option.

Discussion

We mapped FRCC as a first step of data acquisition for Hawthorne Army Depot to write an Interagency Fire Management Plan to address the practical need of attacking wildfire incidents within and outside its ownership, and to manage its fuels for protection of surface water and conservation of natural resources. Currently, Hawthorne Army Depot has no Fire Management Plan for Mount Grant, full fire suppression is the default policy, and the Depot does not have a fuels crew to implement prescribed burns and other fuels reduction operations. Because Shlisky and Hann (2003) had just published the methodology, but never implemented it, this project, therefore, was the first ever implementation of the mid-scale remote sensing FRCC mapping in the USA, including the recommended three field verifications. Moreover, implementation used high-resolution imagery.

FRCC versus Action Map

Much attention is placed on FRCC maps because the FRCC value per PNVT for a project area is required by law to obtained National Fire Plan funds for wildland fuels management (Healthy Forest Restoration Act 2003). For fuels management project planning, however, FRCC maps are perhaps less interesting than a PNVT-specific Action Map that shows departure per pixel. FRCC is a landscape-scale metric with true meaning at large scale, whereas the Action Map localizes the concept of FRCC. Fuels management projects are designed from the wide canvas offered by the Action Map by applying constraints and decision rules to it, such as Wilderness Areas restrictions, military restrictions, inaccessible landforms, degree of departure, availability of methods to treat a fuel type, and so on. In the case of Hawthorne Army depot, the next step would be to use the FRCC map and Action data to identify restoration projects meeting mission driven goals.

Local FRCC results

FRCC results were counter-intuitive for Mount Grant and suggest management activities different than initially anticipated. For example, we assumed that pinyon-juniper woodlands would resemble typical stands in the Great Basin that have experience increasing numbers of young trees and increasing tree density (densification) and require active management, especially to prevent sedimentation into perennial water corridors. Although there is an indication of more cover of mid-development classes than predicted by the HRV (Table 4), departure was within the range of FRCC 1. We also had assumed that the riparian mountain meadow PNVT should be protected from fire to maintain surface water quality, but both the FRCC Map and Action data identified a need for urgent management attention, perhaps in the form of prescribed burning of shrub-dominant cover to increase the herbaceous component described in the NRCS soil survey. Greater grass content, perhaps as basin wildrye (*Elymus cinereus*), would actually form a barrier to sedimentation coming from canyon slopes supporting pinyon-juniper woodlands. Also, we did not expect low sagebrush to be moderately departed from the HRV because this PNVT, which is found mostly at higher elevation, experiences only infrequent fire. Granted that low sagebrush saddles FRCCs 1 and 2 (Table 3), the combination of encroachment of mostly pinyon into high-elevation shrublands and over-representation of late-development stage compared to the HRV suggest thinning of trees and mosaic prescribed burning of mountain big sagebrush, which is needed, to spread fire to low sagebrush. Moreover, low shrub cover values for low sagebrush rendered separation of the mid- and late-development classes more difficult, thus may be a source of misclassification between these classes. The FRCC 2 for the mountain big sagebrush PNVT was perhaps the least unexpected result. Early field surveys revealed the predominance of late-development closed shrub cover. In retrospect, this is not surprising given that low sagebrush might be acting as a fire barrier around the many elongated patches of mountain big sagebrush (Fig 3). Small scale and dispersed prescribed burning to minimize fire size and detrimental effects to Greater sage-grouse (Connelly *et al.* 2000) is required to prevent the PNVT from becoming highly departed.

In the landscape of Mount Grant within the boundary of Hawthorne Army Depot, the sizes of Wyoming big sagebrush and mixed desert shrub PNVTs were perhaps too small to accurately estimate FRCC. These systems are extensive outside of the project area, but the artificial ownership boundary forced us to assess small portions of these systems. Regardless of the FRCC 2 for these PNVTs, the main problem for Hawthorne Army Depot is extensive cheatgrass invasion, especially in former burns at lower elevations.

Spatial scale

Summarizing current condition structure/density values, and therefore, deriving FRCC value, can be accomplished at a variety of scales. For instance, in this project, current condition percentages and FRCC were calculated by PNVT for the entire study area as a whole—that is, the FRCC value calculated for mountain big sagebrush is the same throughout the study area wherever mountain big sagebrush was mapped to currently exist. Another option would have been to summarize current condition structure/density cover percentages and calculate FRCC values using some smaller spatial stratification (e.g., sub-watershed, 1st order hydrologic units, etc.). An approach of this sort would have rendered a more spatially robust characterization of FRCC. One could calculate FRCC utilizing a smaller spatial stratification and using the same current conditions structure/density maps and calculated HRV values that were developed and utilized during this mapping effort.

Lessons learned

Three lessons were learned in this project and all affect greatly FRCC calculations. 1) Perhaps the most important lesson, which will be of no surprise to remote sensing specialists, is to groundtruth repeatedly interpreted spectral signatures at different stages of the project. We conducted three field surveys to a) broadly define large landforms and PNVT types, b) define/quantify development/cover classes, and c) verify interpreted development stages. As a result of the third field verification of common spectral signatures, the FRCC of four PNVT changed substantially and we were able to more cleanly identify the spectral signature of cheatgrass dominant pixels.

2) Soil surveys from the USDA NRCS, which are generally not or partially available for USDA Forest Service lands, are the best first draft approximation of PNVT and are invaluable for mapping FRCC. Because soils take centuries to form as an interaction of climate, geology, and vegetation, they approximate the pre-settlement based on the best available science for soil-vegetation interactions. We found that order III soil surveys will need to be resolved with existing imagery because NRCS mapping units commonly contain multiple soils per mapping unit (polygons) that primarily depend on landform position and slope.

3) In addition to modeling PNVTs and producing HRV, ecologists must fully describe the PNVT and, especially, the cover values, vegetation height, dominant and upper-layer lifeforms, and dominant signature species. Without these descriptions, the remote sensing specialist does not have enough information to separate vegetation development stages in the absence of an ecologist who created the models for the PNVT. At the onset of the project in 2004, we did not have descriptions and this caused confusion later on. The descriptions of PNVT from LANDFIRE's Rapid Assessment (PNVT) or National-LANDFIRE (Biophysical Settings) provide comprehensive PNVT descriptions that can be locally modified.

Acknowledgments

Research was funded by The Nature Conservancy's Fire Learning Network award to L.P. (National Fire Plan prime award *Restoring Fire Adapted Ecosystems*) and the Department of Defense Legacy II funding. Brian McMenamy and Mike Polly provided GIS assistance, and Ayn Shlisky supplied riparian VDDT models. We are especially grateful to John Peterson from Hawthorne Army Depot for his support, logistic help, and participation. Mention of a proprietary product does not constitute a guarantee or warranty of the product by the Department of Defense or the authors and does not imply its approval to the exclusion of the other products that also may be suitable.

Literature Cited

Barrett TM (2001) 'Models of vegetation change for landscape planning: a comparison of FETM, LANDSUM, SIMPPLLE, and VDDT.' USDA Forest Service, Rocky

Mountain Research Station Gen. Tech. Rep. RMRS-GTR-76-WWW. (Ogden, UT) 14 pp.

Beukema SJ, Kurz WA, Pinkham CB, Milosheva K, Frid L (2003) 'Vegetation Dynamics Development Tool, User's Guide, Version 4.4c.' Prepared by ESSA Technologies Ltd.. Vancouver, BC, Canada, 239 p.

Connelly JW, Schroeder MA, Sands AR, Braun CE (2000) Guidelines to manage sage grouse populations and their habitats. *Wildlife Society Bulletin* 28, 967-985.

Hann WJ (2003) Mapping fire regime condition class: a method for watershed and project scale analysis. In 'Fire in Temperate, Boreal and Montane Ecosystems', 22nd Tall Timbers Fire Ecology Conference, Tall Timbers Research Station, Tallahassee, FL.

Hann WJ, Havlina D, Shlisky A, Barrett S, Pohl K (2003a) 'Project scale fire regime and condition class guidebook.' USDA Forest Service, US Department of the Interior, The Nature Conservancy, and Systems for Environmental Management. http://frcc.gov.

Hann WJ, Wisdom MJ, Rowland MM (2003b) Disturbance departure and fragmentation of natural systems in the interior Columbia basin. USDA Forest Service, Pacific Northwest Research Station Res. Pap. PNW-RP-545. (Portland, OR) 19 pp.

Hardy CC, Schmidt KM, Menakis JP, Samson RN (2001) Spatial data for national fire planning and fuel management. *International Journal of Wildland Fire* 10, 353-372.

Kaufmann MR, Graham RT, Boyce Jr DA, Moir WH, Perry L, Reynolds RT, Bassett RL, Mehlhop P, Edminster CB, Block WM, Corn PS (1994) An ecological basis for ecosystem management. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station Gen. Tech. Rep. RM-246. (Fort Collins, CO) 22 pp.

Keane RE, Rollins MG, McNicoll CH, Parsons RA (2002) Integrating ecosystem sampling, gradient modeling, remote sensing, and ecosystem simulation to create spatially explicit landscape inventories. USDA Forest Service, Rocky Mountain Research Station RMRS-GTR-92. (Fort Collins, CO) 61 pp.

McNicoll CH, Hann WJ (2003) Multi-scale planning and implementation to restore fire adapted ecosystems, and reduce risk to the urban/wildland interface in the Box Creek watershed. In 'Fire in Temperate, Boreal and Montane Ecosystems', 22nd Tall Timbers Fire Ecology Conference, Tall Timbers Research Station, Tallahassee, FL.

Menakis JP, Osborne D, Miller M (2003) Mapping the cheatgrass-caused departure from historical natural fire regimes in the Great Basin. In 'Conference on fire, fuel treatments and ecological restoration: proper place, appropriate time.' US Department of Agriculture, Forest Service, Rocky Mountain Research Station RMRS-P-29. (Ft Collins, CO) 281-288 pp.

Nachlinger J (1990) 'Ecological survey of Mount Grant, Wassuk Range, Mineral County, Nevada.' Unpublished report to Bureau of Land Management, Carson City District. The Nature Conservancy (Reno, NV) 33 pp.

Schmidt KM, Menakis JP, Hardy CC, Hann WJ, Bunnell DL (2002) Development of coarse-scale spatial data for wildland fire and fuel management. USDA Forest Service, Rocky Mountain Research Station Gen. Tech. Rep. RMRS-GTR-87. (Fort Collins, CO) 41 p. + CD.

Shlisky AJ, Hann WJ (2003) Rapid scientific assessment of mid-scale fire regime conditions in the western US. In 'Proceedings of 3rd International Wildland Fire Conference.' (Sydney, Australia).

Swetnam TW, Allen CD, Betancourt J (1999) Applied historical ecology: using the past to manage for the future. *Ecological Applications* 9, 1189-1206.

USDA Soil Conservation Service (1991) 'Soil survey of Hawthorne Army Ammunition Plant, Nevada, part of Mineral County.' Unpublished report by USDA SCS in cooperation with US Department of Army. 418 pp.

USDA, USDI. (2002) 'LANDFIRE study plan.:Technical advisory team review copy.' USDA, Forest Service Rocky Mountain Research Station, Fire Science Laboratory, and US Department of the Interior, Geological Survey, EROS Data Center. Available from RMRS Fire Laboratory, Missoula, MT. ,88 pp.

White PS, Walker JL (1997) Approximating nature's variation: selecting and using reference information in restoration ecology. *Restoration Ecology* 5, 338-349.

Table 1. Potential natural vegetation types (PNVT) of Mount Grant and equivalent LANDFIRE ecological systems used to obtain the historic range of variability (HRV).

PNVT	LANDFIRE Ecological System and Code
Infrequent Fire Pinyon-Juniper	Juniper Steppe and Pinyon-Juniper Steppe Woodland (infrequent fire) = R2PIJU[&]
Low Sagebrush	Inter-Mountain Basins Montane Sagebrush Steppe (low); mapping zone 16 = 1126low*
Curlleaf Mountain Mahogany	Inter-Mountain Basins Mountain Mahogany Woodland and Shrubland; mapping zones 12 and 17 = 1062*
Mountain Big Sagebrush (no tree invasion)	Inter-Mountain Basins Montane Sagebrush Steppe = R2SBMT[&]
Wyoming Big Sagebrush with potential for pinyon-juniper invasion	Inter-Mountain Basins Big Sagebrush Shrubland; mapping zones 16, 12, and 17 = 1080*
Riparian Mountain Meadow	Rocky Mountain Riparian Herbaceous (mapping zone 16; crosswalk requires interpretation and compromise with old PNVG) = 1164*
Mixed Desert Shrub	Intermountain Basins Semi-Desert Shrub Steppe (mapping zone 16) = 1127*

[&]: From LANDFIRE's Rapid Assessment modeling for the Great Basin Region.

*: From National-LANDFIRE models developed for the Great Basin Region Mapping Zones 12, 16, and 17.

Table 2. Before and after crosswalking potential natural vegetation types (PNVT) to match the LANDFIRE historic range of variability (HRV) with the original satellite coding.

Class	**HRV Before Crosswalk (%)**	**HRV After Crosswalk (%)**
	INFREQUENT FIRE PINYON-JUNIPER	
Early	5	5
Mid Closed	5	5
Mid Open	15	15
Late Open	35	35
Late Closed	40	40
	LOW SAGEBRUSH	
Early	10	10
Mid Closed	N/A	N/A
Mid Open	35	35
Late Open	N/A	N/A
Late Closed	55	55
	MOUNTAIN MAHOGANY	
Early	10	10
Mid Closed	15	15
Mid Open	10	10
Late Open	20	20
Late Closed	45	45
	MOUNTAIN BIG SAGEBRUSH	
Early	20	20
Mid Closed	N/A	35
Mid Open	45	45
Late Open	N/A	N/A
Late Closed	35	0
	WYOMING BIG SAGEBRUSH WITH PJ	
Early	15	15
Mid Closed	25	25
Mid Open	50	50
Late Open	5	N/A

Late Closed	5	5
Late Wooded	N/A	5
	RIPARIAN MOUNTAIN MEADOW	
Early	5	5
Mid Closed	N/A	70[1]
Mid Open	80[1]	10[1]
Late Open	13[2]	N/A
Late Closed	2[2]	15[2]
	MIXED DESERT SHRUB	
Early	10	10
Mid Closed	40	40
Mid Open	N/A	50
Late Open	50	N/A
Late Closed	N/A	N/A

[1] The 80% class representation for Mid Open was split into classes Mid Closed and Mid Open according to the original PNVG model.

[2] Classes Late Open and Late Closed represent a shrub-dominated condition. Thus, they were combined into the Late Closed class.

Table 3. Actual current condition structure/density and cover percentages for each potential natural vegetation type (PNVT) at Mount Grant. Fire regime condition class is given in bottom line where 1 represents intact condition, 2 is moderate departure condition, and 3 is high departure condition.

	Infrequent Fire PJ	**Low Sagebrush**	**Mountain Mahogany**	**Mountain Big Sagebrush**	**Wyoming w/PJ**	**Riparian Mountain Meadow**	**Mixed Desert Shrub**
Early	3.0	0.8	11.4	0.6	0.2	0.2	2.0
Mid Closed	22.0	N/A	21.3	54.5	8.7	11.2	2.9
Mid Open	24.0	11.0	21.2	0.1	20.5	2.7	41.2
Late Open	24.0	N/A	25.3	N/A	N/A	N/A	26.3
Late Closed	26.0	82.6	20.8	35.3	32.8	85.9	12.0
Late Wooded (for Wyoming/PJ invasion)	N/A	N/A	N/A	N/A	3.3	N/A	
Late –					0.1		

Uncharacteristic							
Early – Uncharacteristic	1.0				34.4		15.6
PJ Invaded – Uncharacteristic		5.6		9.5			
Sum of Lower %s (SIMILARITY)[1]	73.0	66.8	75.8	35.7	39.4	29.1	46.1
DISSIMILARITY	27.0	33.2	24.2	64.3	60.6	70.9	53.9
FRCC	**1**	**2**	**1**	**2**	**2**	**3**	**2**

[1]: Similarity was based on differences between reference values from Table 2 and actual current values provided here and calculated using index from Shlisky and Hann (2003).

Table 4. Recommended actions resulting from comparison of current condition structure/density and historic range of variability (HRV) for each potential natural vegetation type (PNVT) at Mount Grant.

	Infrequent Fire PJ	Low Sagebrush	Mountain Mahogany	Mountain Big Sagebrush	Wyoming w/PJ	Riparian Mountain Meadow	Mixed Desert Shrub
Early	increase	increase	maintain	increase	increase	maintain	increase
Mid Closed	maintain	n/a	maintain	decrease	increase	increase	increase
Mid Open	maintain	increase	decrease	increase	increase	increase	increase
Late Open	increase	n/a	increase	n/a	n/a	n/a	decrease
Late Closed	decrease	decrease	maintain	decrease	decrease	decrease	decrease
Late Wooded (for Wyoming/PJ invasion)	n/a	n/a	n/a	n/a	maintain	n/a	

Late - Uncharacteristic			decrease
Early - Uncharacteristic			decrease
PJ Invaded – Uncharacteristic	decrease	decrease	

Legend of Figures

Fig. 1. Rapid Fire Regime Condition Class (FRCC) Assessment process (Shlisky and Hann 2003).

Fig. 2. Ikonos satellite imagery of Mount Grant study area (R,G,B) 4,2,1.

Fig. 3. Potential Natural Vegetation Type (PNVT) map developed from NRCS soils data, TNC plant community classification mapping, and Ikonos satellite imagery.

Fig. 4. Current Land Cover Classification developed from Ikonos satellite imagery.

Fig. 5. Current Structure/Density Classification developed from Ikonos satellite imagery.

Fig. 6. Fire Regime Condition Class (FRCC) Map for Mount Grant. FRCC 1 is considered intact, while FRCC 2 and FRCC 3 are interpreted as moderate and high departure from historic range of variability, respectively.