

Chapter 11

Using Historical Simulations of Vegetation to Assess Departure of Current Vegetation Conditions across Large Landscapes

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Introduction

Background

The Landscape Fire and Resource Management Planning Tools Prototype Project, or LANDFIRE Prototype Project, was conceived, in part, to identify areas across the nation where existing landscape conditions are markedly different from historical conditions (Keane and Rollins, Ch. 3). This objective arose from the recognition that over 100 years of land use and wildland fire suppression have dramatically affected wildfire characteristics and associated landscape composition, structure, and function (Turner and others 2001). Metrics were needed to describe the extent and distribution of highly departed landscapes to protect communities, ecosystems, firefighters, and public safety, as outlined in the National Fire Plan (USDA and USDI 2002; U.S. GAO 1999; <http://www.fireplan.gov>). Accordingly, the Departments of Agriculture and Interior were directed by Congress to develop a cohesive strategy for implementing the National Fire Plan (Lavery and Williams

2000), which resulted in the development of the “Fire Regime Condition Class” (FRCC) classification system for use as a key implementation measure. The FRCC classification is based on the concepts of historical ecology and is intended to represent the departure of current landscapes from the range of variability of historical conditions. Fire Regime Condition Class is defined as: a descriptor of the amount of departure from the historical natural regimes, possibly resulting in alterations of key ecosystem components such as species composition, structural stage, stand age, canopy closure, and fuel loadings (Hann and Bunnell 2001).

The U.S. GAO (2002) further recommended the development of consistent and comprehensive spatial data to identify landscapes at high risk of wildfires. Previous FRCC mapping efforts created coarse-scale (1-km) spatial data layers describing fire hazard and ecological status for the conterminous United States (Hardy and others 2001; Schmidt and others 2002; <http://www.fs.fed.us/fire/fuelman>). However, the coarse spatial resolution made these maps useful only for national-scale assessments. In addition, these maps were largely a product of expert systems, which limited the repeatability of the process for monitoring purposes. Finer-scale maps, compiled using consistent, quantitative methods, were needed for applications such as national forest plan revision and implementation and assessments related to wildland fire management plans (Rollins and others, Ch. 2). Our challenge in the LANDFIRE Prototype Project was to develop methods, applicable in a systematic and consistent manner across the U.S., which identify and

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map – at a mid-scale spatial resolution – landscapes that have diverged substantially from historical conditions.

Overview

Broad-scale changes have occurred in many landscapes of the U.S., particularly over the last century, due to land management practices and other forms of human intervention. Fire exclusion and grazing have increased tree density and fuel accumulations in many forest communities, especially those adapted to frequent surface fires (Covington and others 1994; Leenhouts 1998). These conditions favor diseases, insects, and high-intensity crown fires, which can kill old-growth trees and alter community structure (Moore and others 1999). Invasions by non-native plant species have also profoundly altered many native plant communities and ecosystems (Gurevitch and Padilla 2004). Exotic insects and pathogens have accelerated the succession cycle by killing important seral tree species, converting mid-successional stands to late-successional (Keane and others 2002). In addition, increasing emissions of atmospheric concentrations of carbon dioxide and nitrogen have altered photosynthetic processes, species richness, and ecosystem function (Farquhar 1997; Jones and others 1998; Stevens and others 2004).

We developed our methods for estimating such departure based on a set of ecological concepts used to detect changes in ecosystem properties and processes across landscapes at multiple scales. Species, ecological communities, and ecosystems vary naturally across spatial and temporal scales in response to disturbances, biotic processes, and environmental constraints (Levin 1978). These biotic and abiotic agents of pattern formation interact over time to produce a range and variability in ecological structures and processes (Morgan and others 1994; Swanson and others 1994). When the mechanisms driving ecological systems, such as disturbance, change dramatically, ecological processes and structures respond and shift that range and variability (Barnes and others 1998). Landscapes experiencing extensive changes may become altered to the point that their ecological properties are well beyond their historical range and variability, especially in their species composition and structure.

The extent of change in any particular ecosystem may be assessed by comparing current vegetation conditions to the range and variability in historical compositions and structures of vegetation communities, or simply their “natural variability.” The focus of describing natural variability is not on a single condition, but rather on a range of conditions and the variability under which

ecosystems were sustained in the past (Swetnam and others 1999). Characterization of these past ecosystems has been referred to as the “historical range of variability” (Kaufmann and others 1994) or simply “reference conditions” (Moore and others 1999). Ideally, characterization of reference conditions considers all ecosystem components (organisms, structures, biogeochemical cycles, disturbance processes, and abiotic factors) and includes the appropriate time depth and spatial scales for the ecosystem components included in the assessment (Moore and others 1999). However, many of these factors are poorly understood or are difficult to measure (Moore and others 1999). Holling (1992) suggests that a small group of “keystone” or highly interactive organisms and abiotic processes may control ecological thresholds at certain scales. The potential list of important keystone variables may still be relatively long (Aronson and others 1993; Keddy and Drummond 1996), but experience and practical considerations have led researchers to select certain variables that reflect the evolutionary environment (Moore and others 1999; Swetnam and others 1999). For example, fire and autotrophic organisms (trees, shrubs, and herbaceous plants) are used to describe ponderosa pine and sequoia ecosystems (Fulé and others 1999; Moore and others 1999; Stephenson 1999). Other considerations include identifying the historical time period for describing natural variability, including the point in time when ecological systems were considered relatively unaffected by Euro-American settlement (Hunter 1996; Schrader-Frechette and McCoy 1995). Moreover, characterization of past ecosystems should specify whether Native American influences on ecosystems are regarded as natural (Landres and others 1999).

We adopted the natural variability concept to guide our methods for estimating landscape changes from past to present. Specifically, our goal was to describe deviations of current landscape conditions from conditions between the years 1600 A.D. and 1900 A.D. and to describe them at a regional level with a mid-scale spatial resolution to help planning efforts address ecological issues (Keane and Rollins, Ch. 3). We selected this time frame for our reference conditions as the appropriate range to represent recent history because fire history reconstructions typically date back to at least 1600 and because we determined that 1900 A.D. best approximates the start of significant Euro-American influences on western U.S. landscapes (Keane and others 2002; Keane and Rollins, Ch. 3). Also, we assumed that the influence of Native Americans on landscapes was inherent in our depiction of reference conditions.

To develop methods that estimate landscape changes from this historical time period, we needed to address a number of questions. What were the historical dynamics of plant communities across the diverse ecosystems of the nation? How do we measure plant community change? At what point does the magnitude of change drive an ecosystem beyond its historical boundaries to some uncharacteristic condition and warrant ecosystem restoration? In this chapter, we outline several approaches to 1) addressing each of these questions within the ecological framework of plant community function in fire-adapted environments and 2) creating maps of ecological departure over large regions. Our chief premise for the LANDFIRE Prototype Project was that fire and other disturbances regulate succession by regeneration, reproduction, and maintenance of plant species and assemblages. That is, fires kill existing stands and set the process of regeneration in motion for the next forest; fire as a selective force elicits asexual and sexual reproduction; and periodic surface fires reduce vegetation encroachment and competition for light, soil water, and nutrition and kill understory-tolerant seedlings (Barnes and others 1998). The frequency, intensity, extent, and timing of fires (in other words, fire regimes) are characteristic of different regional and local ecosystems (Barnes and others 1998). We assumed that under each unique fire regime, plant communities approach some dynamic equilibrium in their composition and structure. When fire regime characteristics change, the character of a plant community shifts and distributions of pioneer, mid-successional, and late-successional species or assemblages become altered. The magnitude of this change can be used to prioritize, plan, and implement restorative treatments (Hann and others 2004).

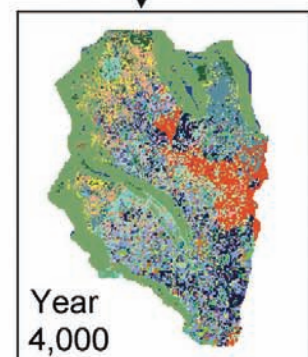
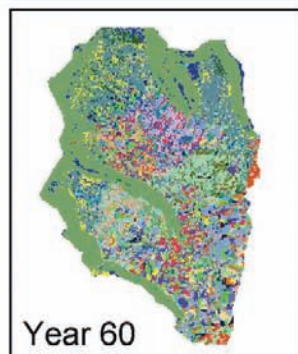
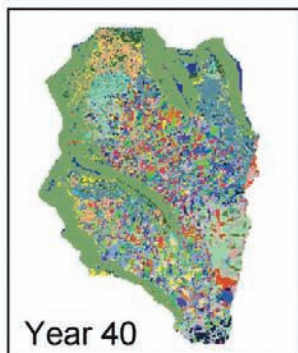
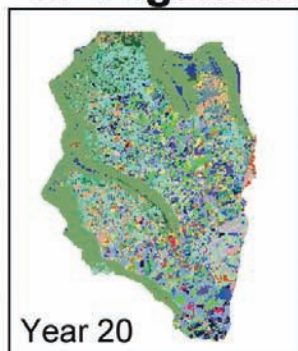
Our general approach involved developing a historical spatial database that describes the natural variability of vegetation across landscapes over time and quantitatively compares that historical distribution to the current vegetation patterns for two large study areas in the western United States. For example, the current vegetation pattern on a landscape might have changed by 70 percent from vegetation distributions observed in historical records, indicating a strong divergence (fig. 1). To quantify landscape patterns, we chose the metric of landscape composition and delineated composition by classifying landscapes according to their potential vegetation type (PVT), cover type, and structural stage (Frescino and others, Ch. 7; Zhu and others, Ch. 8). The PVT map identified areas with similar climate, landform, and geomorphic processes (biophysical settings) where distinct plant communities

are assumed to develop in the absence of disturbance (Arno and others 1985; Steele and Geier-Hayes 1989). The cover type map depicted the existing dominant plant species or assemblages, and the structural stage map approximated the stages of vegetation development for the various cover types, ranging from stand initiation to old-growth, as described by height and percent cover (Zhu and others, Ch. 8). We integrated the cover type and structural stage maps such that each unique combination described a discrete stage along succession pathways, which we call a “succession class” (Long and others, Ch. 9; see also Long and others, Ch. 6 and Zhu and others, Ch. 8 for descriptions of the cover types and structural stages used in the LANDFIRE Prototype Project). We then combined the succession class and PVT maps to describe landscape composition in a spatial context.

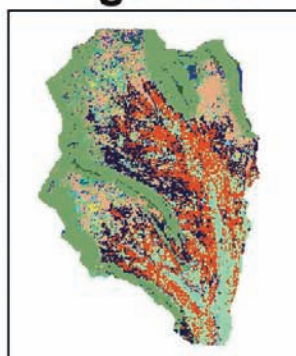
The collective area of each succession class in a PVT functions as our measure of the conditions of a landscape, which we refer to as the “vegetation composition.” We chose to use the combination of PVT and succession class as a descriptor of vegetation composition because it provided the finest classification resolution possible for evaluating landscape dynamics. That is, the PVT-succession class classification integrates the biophysical environment with existing vegetation, which discriminates between major site types. For example, we can differentiate ponderosa pine types occurring in a Douglas-fir PVT from ponderosa pines growing in a Ponderosa Pine PVT. Other landscape composition classifications are available, such as fuel models, cover types, and structural stages. However, we felt that classifying landscapes by PVT – succession class would be the most meaningful and useful depiction for the purposes of land managers, who typically use similar classification schemes for depicting landscape condition. It should be noted that landscape composition can also be described by measures other than area by vegetation class, including relative richness, diversity, dominance, and connectivity (Turner and others 2001). Similarly, landscape pattern can be described by landscape configuration instead of landscape composition using measures such as contagion, patch-based metrics, and fractals. We chose not to use these landscape metrics and measures because they are not yet widely used in management or would have required prohibitively expensive computer resources. Vegetation composition, on the other hand, was far more feasible to map, comprehend, and implement in management applications.

Comprehensive and consistent spatial estimates of historical vegetation composition were used in the LANDFIRE Prototype to identify natural variability. We

Historical Sequence of Vegetation



Current Vegetation



Departure

Change between
Historical
Sequences
& Current
Condition

Legend

Succession Classes

- Lodgepole Pine HLF
- Lodgepole Pine HHF
- Lodgepole Pine LHF
- Spruce - Fir HHF
- Spruce - Fir LHF
- Riparian Shrub HHS
- Riparian Shrub LHS
- Cool Season Grasses HLH
- Barren

0 1.5 3 6 9 12 Km

Figure 1—Example of general approach for estimating departure in a 6th hydrologic unit code (HUC). Vegetation patterns (described here by succession classes) of historical sequences are quantitatively compared to those of the current landscape to estimate departure. See table 7 for explanation of succession class codes.

relied on simulation modeling to generate a time series of data for estimating the potential range and variability of historical vegetation for our large regional areas (Keane and Rollins, Ch. 3; Pratt and others, Ch. 10). We chose to use a moderately detailed simulation model, called LANDSUMv4, because it balanced the simulation of complex ecosystem processes with computational efficiency and thereby allowed for the acquisition of time series estimating historical conditions for large regions in a timely manner (Keane and others 2003; Keane and others 2006). The justification for simulation modeling and implementation of LANDSUMv4 to develop time series representing reference conditions are described in detail by Pratt and others, Ch. 10. Results from LANDSUMv4 simulation modeling do not represent actual historical records, but they are our best approximation of how vegetation responded to fire disturbances in the past.

We developed two methods to measure the extent of change, which we refer to as “departure,” between the simulated time series estimating historical vegetation composition and the current vegetation composition on landscapes. The purpose of the first method was to implement a field-based procedure, developed by Hann and others (2004), within a digital mapping context. Hann and others’ (2004) Interagency FRCC Guidebook (<http://www.frcc.gov>) details field-based protocols by which land managers can assess the departure of current vegetation composition from that of historical conditions to meet the objectives of the National Fire Plan and Healthy Forests Restoration Act (<http://www.fireplan.gov>; <http://www.healthyforests.gov>) and also for reporting purposes, such as to the National Fire Plan Operations and Reporting System (<http://www.nfpors.gov>). Our implementation of this method, which we refer to as the “FRCC Guidebook approach,” compares the current vegetation composition to the simulated historical time series; we do not, however, compare fire frequency and fire severity, as outlined in the FRCC Guidebook field procedures (Hann and others 2004), because contemporary conditions can be difficult to define, quantify, and depict spatially.

Calculations based on vegetation composition using the FRCC Guidebook approach require that the simulated historical time series data be summarized and distilled to represent one state or observation. As such, the FRCC Guidebook approach is very limited in its ability to characterize the full range and variability of vegetation reference conditions within the simulated historical data. We determined that a more statistically sound approach was needed to comprehensively account for

patterns of temporal variation in the simulated historical landscapes (Steele and others, in preparation). Hence, we implemented a statistical method, which we refer to as the “Historical Range and Variability–Statistical” or “HRVStat” approach, to evaluate all states observed in the simulated historical time series and compares them to the current landscape to provide a complete assessment of departure. The HRVStat approach also measures the strength of evidence for the estimated departure value, which we call the “observed significance level” (Steele and others, in preparation).

Both the FRCC Guidebook and HRVStat approaches for describing vegetation change estimate departure on a continuous scale with values ranging from 0 to 100. However, the previous coarse-scale (1-km) map of FRCC (Hardy and others 2001; Schmidt and others 2002) and the FRCC Guidebook field procedures (Hann and others 2004) describe departure simply in terms of three classes, including: FRCC 1 – minimal departure from the central tendency of the natural disturbance regime, FRCC 2 – moderate departure, and FRCC 3 – high departure. Using the FRCC Guidebook and HRVStat approaches, we likewise classified our departure estimates into three categories to be consistent with the FRCC Guidebook field procedures and to facilitate comparisons with the coarse-scale map of FRCC from Schmidt and others 2002.

The development of methods for estimating departure was one of the most important objectives of the LANDFIRE Prototype Project. Documentation of these procedures is the purpose of this chapter and is presented below in detail. These procedures can serve as the foundation for estimating departure as the LANDFIRE Project is implemented across the entire United States (Keane and Rollins, Ch. 3). In the process of developing these protocols, we identified various areas in need of improvement and further research, which we outline as recommendations for developing departure indices at the national level. The methods described here may not necessarily reflect protocols followed when the LANDFIRE Project is implemented nationally, and results and specific findings may change as protocols are improved. We present results from our current methods to demonstrate their implementation and to compare procedures.

Methods

The LANDFIRE Prototype Project involved many sequential steps, intermediate products, and interdependent processes. Please see appendix 2-A in Rollins and

others, Ch. 2 for a detailed outline of the procedures followed to create the entire suite of LANDFIRE Prototype products. This chapter focuses specifically on the procedure followed in developing maps describing the departure of current from historical landscape conditions, which served as important core data products of the LANDFIRE Prototype Project.

In this chapter, we describe: 1) the key spatial layers used for estimating departure and preliminary considerations for identifying cover types for analyses; 2) the data sets for estimating departure; 3) the FRCC Guidebook approach; 4) the HRVStat approach; 5) a detailed demonstration for estimating departure using these two approaches; and 6) a comparison of departure between areas with different simulated fire return intervals. We implemented the FRCC Guidebook and HRVStat approaches across two large regions in the western United States: one in the central Utah highlands and a second in the northern Rocky Mountains of Idaho and Montana (LANDFIRE mapping zones 16 and 19, respectively; see fig. 1 in Rollins and others, Ch. 2).

Key Spatial Layers and Preliminary Considerations

Key spatial layers—Of the four maps essential for estimating departure in both the FRCC Guidebook and HRVStat approaches, three described vegetation: the PVT, existing cover type, and existing structural stage maps (Frescino and others, Ch. 7; Zhu and others, Ch. 8), and the fourth partitioned each zone into smaller map areas or “landscape reporting units” (LRUs) so that departure could be estimated for each LRU (Pratt and others, Ch. 10). The determination of appropriate units held great importance because, measurements of landscape change being scale-dependent, departure estimates vary with landscape size. (Gardner 1998).

In general, the most appropriate ecological scale for detecting change matches the scale at which key processes affecting ecosystems (such as fire and succession) interact to limit landscape dynamics at a point in time (Parker and Pickett 1998). Identifying that scale is a challenging problem (Gardner 1998) but may be accomplished by evaluating the change in variance in a landscape metric with changes in spatial extent (Levin and Buttel 1986; O'Neill and others 1991) or by using more mathematically complex methods, such as the gliding-box method (Gardner 1998). Due to time constraints, we did not conduct such analyses, but we expected that the appropriate ecological scales in Zones 16 and 19 would vary depending on the dominant landscape fire and succession processes. For example, in landscapes

subject to small, low intensity disturbances that kill vegetation in patches of only a few trees, the stand scale (about 1-10 ha) (Urban and others 1999) would likely be the most appropriate for measuring departure; however, departure may be better estimated at the landscape scale (10^3 to 10^6 ha) (Mladenoff and others 1993, 1994; Spies and others 1994) in areas subject to large, intense, stand-replacing disturbances that kill vegetation in big patches. Another consideration was the scale that would be most useful to management, which is often at a smaller spatial extent approaching the stand scale and at which subtle changes to cover type and structural stages, such as those caused by fuel treatment, can be detected (Keane and Rollins, Ch. 3).

Ultimately, we balanced our selection of LRU-scale based on both ecological and management considerations (see Pratt and others, Ch. 10 for additional details). We chose as reporting units uniform squares of 900-m by 900-m (81 ha) but coded these squares so that they could be grouped and summarized at the sub-watershed level (average area of 6,450 ha). We determined that summarizing departure to these 900-m by 900-m squares would capture stand-level processes and provide land managers with a sufficient data resolution. If a landscape-level measurement was desired, we included information that facilitates the aggregation of data over 6th level Hydrologic Unit Codes (HUCs). We are currently conducting additional analyses to systematically evaluate the appropriate reporting unit size for estimating departure.

Identifying cover types for analyses—Certain cover types would skew departure estimates and provide little useful information for conservation and restoration of landscapes. Specifically, the cover types water, barren, and ice/snow change little over time and always contribute to low departure. Conversely, agriculture and urban areas always contribute to high departure since current conditions such as these did not exist in the majority of the U.S. during the reference period. If a large proportion of any of these five cover types occur within an LRU, they can overwhelm the departure estimate and mask the condition of vegetation types present. For example, suppose that an LRU composed almost entirely of barren rock contains a small amount of vegetation that historically was perennial grasslands but is now teeming with exotic weeds. If we included the barren cover type in our departure measurements, we would calculate a very low departure, and this LRU may go unnoticed by land managers. Alternatively, consider an LRU that is predominately urbanized but contains vegetation uncharacteristic of historical conditions having missed numerous fire intervals. If we included the

urban cover type in our departure estimate, we would not know whether the high departure estimate was due to the urban or the vegetation component. Hence, land managers would have potentially ambiguous information for assessing that landscape.

The main purpose of assessing departure is to prioritize areas for management and to allow for assessments of management efforts aimed at lowering departure values. Because agriculture and urban areas typically cannot be managed nor departure in these areas reversed, we decided that it was best to exclude these land cover types from departure calculations. Similarly, since water, barren, and snow/ice types may obscure the need for management in surrounding vegetation types, these also were excluded from departure estimates. It is important to note, however, that we made these decisions after completing the Zone 16 maps. Time constraints prevented us from rectifying this error, and water, agriculture, barren, snow/ice, agriculture, and urban cover types were included in Zone 16 departure estimates. For Zone 19, on the other hand, we treated these cover types as effectively immutable and removed them from departure estimates.

Data Sets for Estimating Departure

Simulating historical reference conditions—Using the LANDSUMv4 simulation model, we created a historical reference data set to describe succession patterns continuously across broad regions and with temporal depth (Pratt and others, Ch. 10). The LANDSUMv4 model simulates disturbances (primarily fire, but also insect and disease infestations) spatially across landscapes and predicts the resulting effects of fire on vegetation using a framework of succession pathways (Keane and others 2006). The LANDSUMv4 output provided a time series describing vegetation dynamics in terms of succession classes within PVTs for all 30-m pixels in a mapping zone (see Pratt and others, Ch. 10). Specifically, the LANDSUMv4 output file described the total area (m^2) for each of the succession classes occurring within the PVTs in each LRU across a zone at every time interval over the simulation period. Details of the LANDSUMv4 simulations pertinent to departure estimates are described here, additional information can be found in Pratt and others, Ch. 10, and a detailed description of succession pathway development is available in Long and others, Ch. 9.

Ideally, one simulation would have been conducted for an entire zone; however, because of computer limitations, we partitioned the zones into smaller units of 20,000-ha and ran LANDSUMv4 separately for each of these

landscapes, which we called “simulation landscapes.” Figure 2 shows Zone 16 (6-million ha) divided into 427 simulation landscapes (20,000-ha each). Within each simulation landscape, we again partitioned the area into 256 LRUs of 81 ha each (fig. 2). LANDSUMv4 simulated succession and disturbance across the entire 20,000-ha landscape but reported only the composition of succession classes by PVTs contained within each LRU. For example, in figure 2, there are five PVTs distributed across the LRU. For each of the five PVTs and at every reporting interval, LANDSUMv4 reported the composition of succession classes summarized collectively across all stands of the same PVT.

A key requirement for measuring departure through the HRVStat approach was the acquisition of a statistically valid number of temporally uncorrelated observations from the LANDSUMv4 time series. Early testing of HRVStat indicated that a minimum of 200 observations from a LANDSUMv4 time series at reporting intervals long enough to minimize temporal autocorrelation was needed. Because fire disturbance dynamics tend to occur at longer frequencies, short annual reporting intervals result in correlated observations, but succession class distributions become less correlated with longer reporting intervals (Pratt and others, Ch. 10). Initial tests indicated that intervals of 20-years or more showed relatively little autocorrelation, and, using this interval, we executed the model for a 4,000-year simulation period to obtain 200 observations for Zone 16. Further examination, however, revealed that PVTs in Zone 16 (except Aspen, Wetland Herbaceous, Cool Herbaceous, and Alpine) showed notable autocorrelation (fig. 3a). Based on the autocorrelation in Zone 16, we extended the reporting interval to 50 years for Zone 19 and executed the model for a 10,000-year simulation period to obtain 200 observations. Although the autocorrelation in Zone 19 was not as pervasive as that for Zone 16, it was still present to some degree for most PVTs. Several PVTs, particularly forest PVTs, had moderately high correlation coefficients, even with a 50-year time lag (fig. 3b). It was logistically impractical to further increase the reporting interval and the simulation time to the length necessary to minimize autocorrelation in all PVTs because the total simulation time would become prohibitively long, given our computing resources. Further research is being conducted to study the effect of autocorrelation and succession class trends on LANDSUMv4 output and the subsequent departure calculations. It is important to note that the FRCC Guidebook approach had less rigorous requirements for representing historical conditions, requiring only one observation that describes the

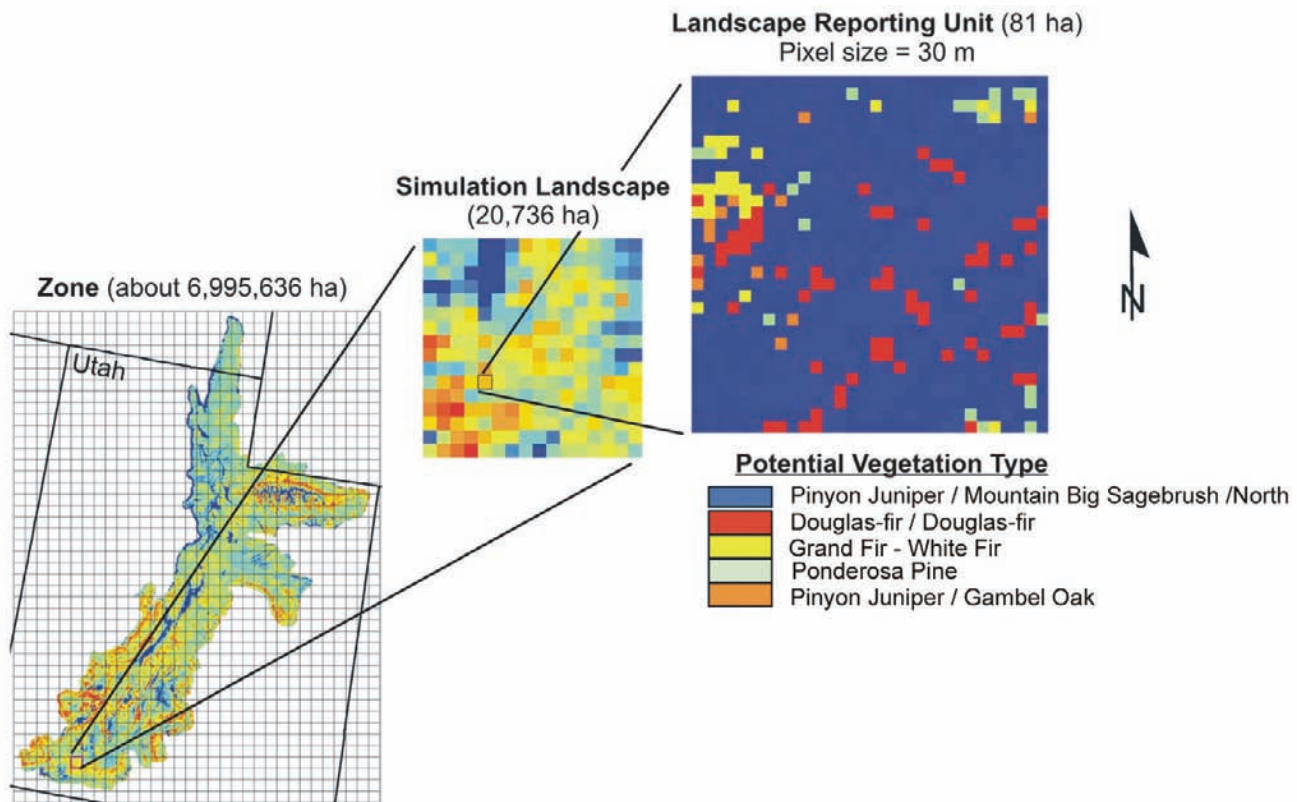


Figure 2—Example of the hierarchical configuration of spatial reporting units used to estimate reference conditions from LANDSUMv4. The broadest extent is the zone; followed by the 20,000-ha simulation landscape; and lastly, the landscape reporting unit which displays the spatial distribution of PVTs for this example in Zone 16.

central tendency of long-term natural dynamics (Hann and others 2004).

Depicting current vegetation conditions—Whereas succession class distributions by PVT were simulated by LANDSUMv4 to estimate reference conditions, current vegetation was described using existing cover type and structural stage maps derived from recent satellite imagery (Zhu and others, Ch. 8). Excepting classes with non-native or exotic cover types (Long and others, Ch. 9) established over the last (twentieth) century — which we considered a recent invasion to plant communities — we classified existing cover type and structural stage maps into the same set of succession classes used for the historical simulation modeling. The dominance of an exotic species in current succession class maps represented a distinct change from the simulated historical conditions. We then spatially combined the PVT, existing cover type, existing structural stage, and LRU layers such that all unique combinations of spatial input variables were

tabulated. The result of this process depicted the areal extent for each of the succession classes within each PVT occurring within every LRU across the zone.

Compiling the final data sets for estimating departure—We combined the data set for existing vegetation with the time series from LANDSUMv4 to develop data sets for estimating departure. That is, the departure data sets from the LANDSUMv4 output summarized the total area in each PVT-succession class combination within an LRU for the current time period and for each reporting interval (20 or 50 years, in this effort). In these data sets, current vegetation was depicted by only one instance in time for each PVT-succession class, whereas the simulated historical conditions were represented by 200 observations sampled from the LANDSUMv4 simulations for each PVT-succession class.

Departure was estimated by comparing the succession class distributions for the five PVTs contained in

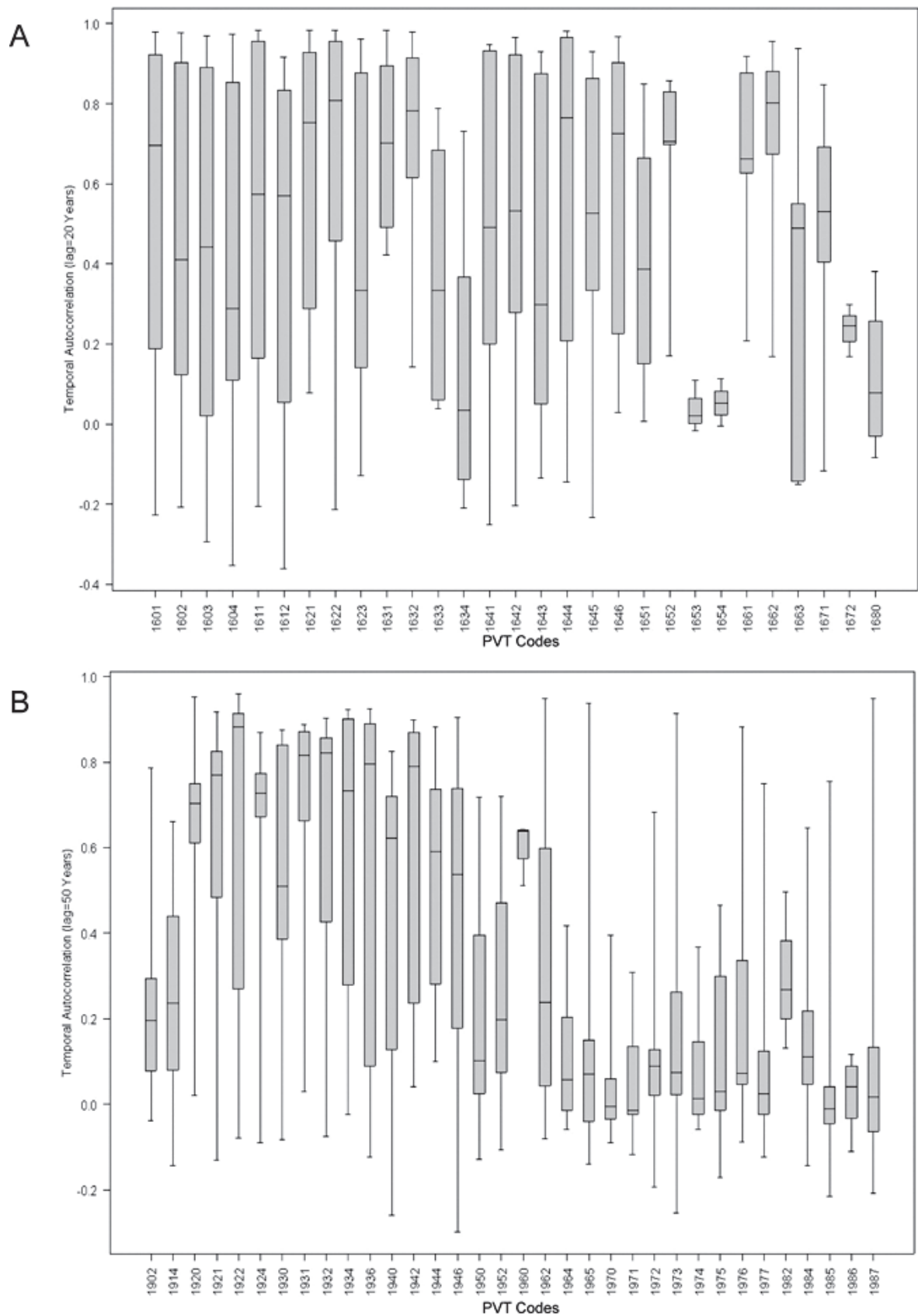


Figure 3—Box and whiskers plots showing the mean autocorrelation coefficient across PVTs in (A) Zone 16 with a 20-year lag and (B) Zone 19 with a 50-year lag. A correlation coefficient of zero represents no autocorrelation. See appendix 11-A for key to PVT codes.

the example LRU as simulated by the LANDSUMv4 model (with 200 observations possible for each unique succession class within each PVT) to succession class distributions for the same five PVTs in the current landscape (with only one observation for each PVT-succession class) (see, for example, figure 2). Put another way, the spatial arrangement of PVTs did not change between LANDSUMv4 simulations and the current landscape, but succession class distributions within PVTs did vary—and that change was the basis for measuring departure.

Implementing the FRCC Guidebook Approach

In implementing the FRCC Guidebook approach, we explored a number of options for representing reference conditions and estimating departure and applied them to Zone 16, as will be described below. Based on these and additional analyses, we developed a final method, which was applied to Zone 19.

One of the main challenges for this approach was distilling the time series of LANDSUMv4 model output with 200 observations for each PVT-succession class (within an LRU) down to a single observation for that PVT-succession class, as required by the FRCC Guidebook field procedures (Hann and others 2004). That is, the calculations of departure outlined in the FRCC Guidebook field procedures (described below) require a single value for each succession class within a PVT (within an LRU) for comparisons to the current conditions. In Zone 16, we evaluated two ways to reduce the LANDSUMv4 model output. In the first method, termed the “temporal snapshot,” we elected simply to use conditions from one reporting interval across the entire time series of the LANDSUMv4 output, and we chose year-1,000. This approach provided a “snapshot” of the simulated historical landscape. In other words, the total area that a succession class occupied within a given PVT (of a LRU) in year-1,000 of the LANDSUMv4 time series was used to represent its reference conditions.

In the second method, termed “multi-temporal,” we aimed to capture temporal variation in the simulated historical succession class distributions but with the inherent constraint of using a single value for each PVT-succession class combination (within an LRU) among the 200 values in the LANDSUMv4 time series. Various metrics were possible — such as the maximum, median, mean, and the minimum — with a succession class distribution ($n = 200$) showing values for the median and various percentiles of the percent area observed for that succession class across the simulated time series (fig. 4). Metrics emphasizing the maximum

or minimum ranges of succession class distribution can capture variability to some extent. For example, consider two succession class distributions with the same mean, but one has low variability and the other high variability. The maximum value for each of these distributions will be different, and the distribution with low variability will have a smaller maximum value than the distribution with high variability. For Zone 16, we chose to use 90 percent of the maximum area for each succession class within a PVT (within an LRU) in an effort to portray the variability in the upper end of the distributions for succession classes; for simplicity, we term this metric the “90 percent of maximum.” For Zone 19, we chose to use the 90th percentile of the area (in other words, the value that is as large as 90 percent of all values in the data set and smaller than 10 percent of all values) for each PVT-succession class (within an LRU) to, again, capture the upper range of the succession class distributions. But using the 90th percentile, we more effectively eliminated inordinately high outliers. We term this metric the “90th percentile.”

Determining the 90 percent of maximum and 90th percentiles from the LANDSUMv4 output was a straightforward process. We searched the LANDSUMv4 output and extracted the appropriate value for each PVT-succession class found in each LRU. For example, if the 90th percentile was used to represent reference conditions, the value that was as large as 90 percent of all values in the pool of LANDSUMv4 observations was chosen to represent reference conditions. The extracted values for each succession class were then converted from area to percent of the PVT that they occupied.

After choosing the metric to represent reference conditions, a second key decision involved determining the appropriate extent or spatial domain for summarizing the LANDSUMv4 time series data. Choosing the correct spatial domain was problematic because different spatial domains leads to different estimates of reference conditions for any given succession class. For example, if reference conditions were summarized across watersheds, then each PVT-succession class combination would be assigned the same reference conditions across an entire watershed, regardless of any spatial variability within that landscape.

In Zone 16, we evaluated three spatial domains for calculating reference conditions to describe the 90 percent of maximum for each PVT-succession class over the time series: 1) mapping zones (6 to 10 million ha), 2) simulation landscapes (approximately 20,000 ha), and 3) individual LRUs (81 ha) (fig. 3). For Zone 19, we evaluated only the LRU-level to focus the spatial domain

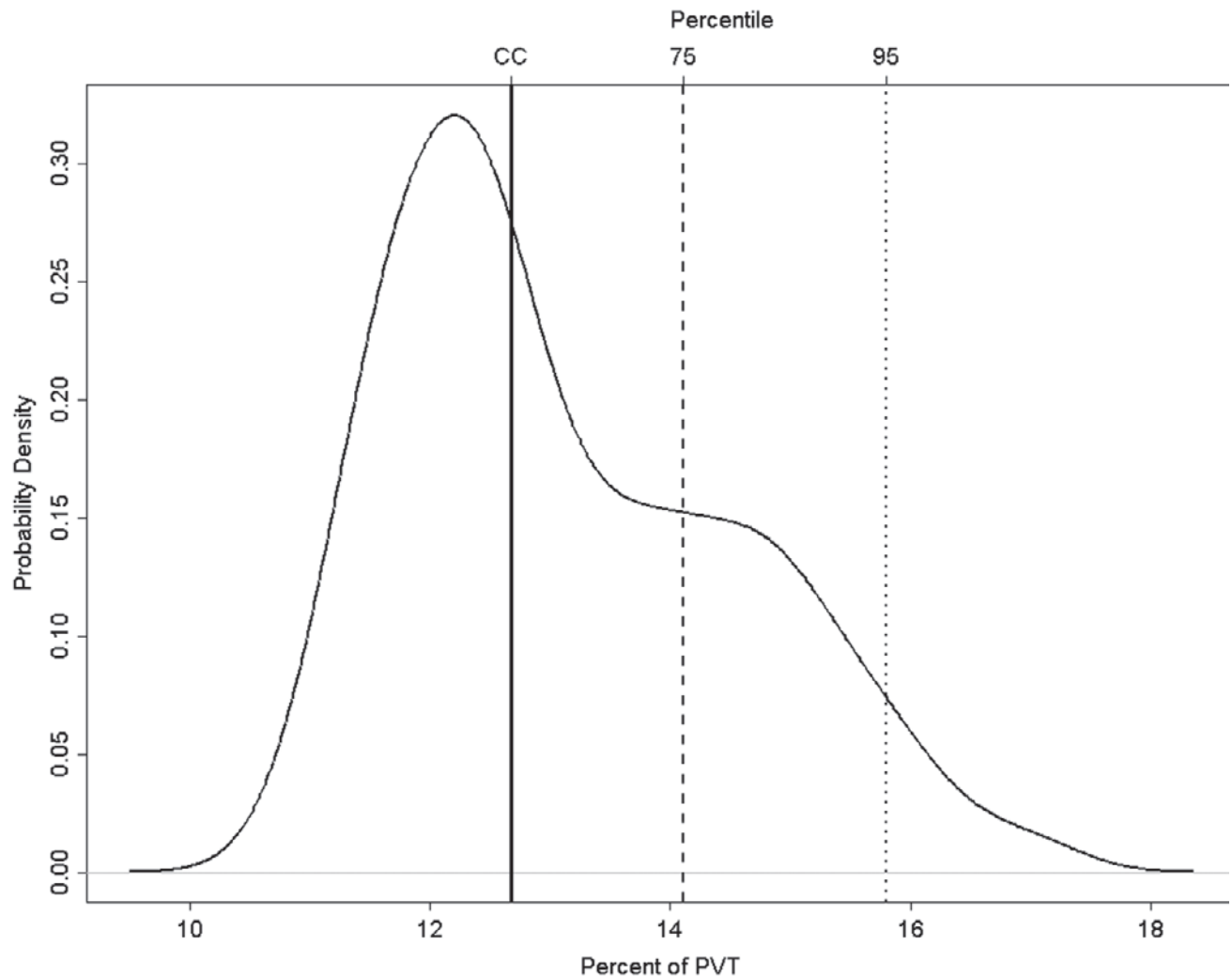


Figure 4—Empirical probability density distributions fitted to the frequency of observed percent area occupied by a slightly departed succession class (Aspen – Birch High Cover, High Height) in the LANDSUMv4 time series data ($n=200$). The 75th and 95th percentiles (in the percent area observed for that succession class across the simulated time series) occur in 14.1 percent and 15.8 percent of the PVT; the current conditions (CC) data point is at 12.7 percent and corresponds reasonably well to the median of the simulated reference conditions distribution but is relatively distant from the 75th and 95th percentile measurements. Data for each succession class was taken from a 20,000-ha spatial unit within Zone 16 dominated by the Spruce – Fir / Spruce – Fir / Lodgepole Pine PVT containing that succession class.

on local variability (and used the 90th percentile metric). The process of aggregating the LANDSUMv4 time series to the various spatial domains was a straightforward process. First the LANDSUMv4 output was examined across a given spatial domain, and all instances of a given PVT-succession class were identified. Second, for each occurrence of a PVT-succession class combination across the spatial domain, the desired reference conditions (such as the 90th percentile) were identified from the pool ($n = 200$) of LANDSUMv4 output.

Current conditions were easily calculated by converting area to the percent that a succession class occupied for each PVT across an LRU. For example, table 1 demonstrates that the PVT-succession class combination of the Pinyon-Juniper / Mountain Big Sagebrush / South PVT with the Juniper-High Cover, High Height succession class occupied 38.71 percent of the total area in the example LRU.

Comparing current to simulated historical vegetation conditions enabled the calculation of departure, which

Table 1—Example of computation of current conditions for a landscape reporting unit (LRU) showing relative distributions of succession classes expressed as the percent area occupied within each potential vegetation type (PVT) contained in the LRU. See table 7 for structural stage codes.

PVT	Structural stage	Cover type	Current conditions (% of area occupied)
Pinyon – Juniper / Mountain Big Sagebrush / South	HHW	Juniper	38.71
Pinyon – Juniper / Mountain Big Sagebrush / South	LLW	Juniper	11.52
Pinyon – Juniper / Mountain Big Sagebrush / South	LHW	Juniper	1.23
Pinyon – Juniper / Mountain Big Sagebrush / South	LLW	Pinyon – Juniper	19.20
Pinyon – Juniper / Mountain Big Sagebrush / South	HHW	Pinyon – Juniper	17.05
Pinyon – Juniper / Mountain Big Sagebrush / South	LHW	Pinyon – Juniper	0.77
Pinyon – Juniper / Mountain Big Sagebrush / South	LHS	Mountain Deciduous Shrub	9.37
Pinyon – Juniper / Mountain Big Sagebrush / South	HHS	Mountain Deciduous Shrub	2.00
Pinyon – Juniper / Mountain Big Sagebrush / South	HLS	Mountain Big Sagebrush Complex	0.15
Total Percent Area			100
Pinyon – Juniper / Gambel Oak	LLW	Pinyon – Juniper	44.76
Pinyon – Juniper / Gambel Oak	HHW	Pinyon – Juniper	41.26
Pinyon – Juniper / Gambel Oak	LHS	Mountain Deciduous Shrub	7.69
Pinyon – Juniper / Gambel Oak	HLS	Mountain Deciduous Shrub	3.50
Pinyon – Juniper / Gambel Oak	HLS	Mountain Deciduous Shrub	2.80
Total Percent Area			100
Wyoming – Basin Big Sagebrush	HLS	Wyoming – Basin Big Sagebrush Complex	85.71
Wyoming – Basin Big Sagebrush	LLS	Wyoming – Basin Big Sagebrush Complex	10.71
Wyoming – Basin Big Sagebrush	LLS	Rabbitbrush	3.57
Total Percent Area			100
Pinyon – Juniper / Wyoming – Basin Big Sagebrush / South	LLW	Juniper	50.00
Pinyon – Juniper / Wyoming – Basin Big Sagebrush / South	HLS	Wyoming – Basin Big Sagebrush Complex	29.41
Pinyon – Juniper / Wyoming – Basin Big Sagebrush / South	LLS	Wyoming – Basin Big Sagebrush Complex	2.94
Pinyon – Juniper / Wyoming – Basin Big Sagebrush / South	LLW	Pinyon – Juniper	14.71
Pinyon – Juniper / Wyoming – Basin Big Sagebrush / South	HLS	Dwarf Sagebrush Complex	2.94
Total Percent Area			100
Ponderosa Pine	LLF	Ponderosa Pine	58.82
Ponderosa Pine	LHF	Ponderosa Pine	23.53
Ponderosa Pine	LLF	Juniper	5.88
Ponderosa Pine	HHF	Ponderosa Pine	5.88
Ponderosa Pine	LLF	Pinyon – Juniper	5.88
Total Percent Area			100

was then classified to represent FRCC. The measure of departure relied on the computation of “similarity,” discussed in depth by Hann and others (2004). We calculated this simple metric by comparing current and reference conditions in the same LRU for a given PVT. The percent composition of each succession class in the current condition map was compared with that of the reference conditions for each PVT within an LRU, and the lesser of the two was termed “similarity.” Across each PVT, the similarity values were totaled throughout the entire LRU. Departure was subsequently calculated for each PVT as:

$$\text{Departure} = 100 - \text{Similarity} \quad (1)$$

where Similarity is the summation of individual similarity values for each of the PVTs across an entire LRU, given as:

$$\sum_{i=0}^{SClasses} \text{Similarity}(i) \quad (2)$$

where Similarity is computed as the smaller area of either current vegetation or that of the reference conditions for each succession class encountered in a PVT. Aggregation of estimated Similarity values from individual PVTs to the LRU was performed on an area-weighted basis. We conducted this process in two steps. First, the area and departure of each PVT within a given LRU were computed (table 2). In the second step, we computed the final departure estimate by weighting each PVT-based departure by its respective area and summing these values across the entire LRU (table 3). For visual simplification and to allow for identification of areas with low, moderate, or high departure, we classified departure for Zone 16 using the following threshold values from the FRCC Guidebook field procedures (Hann and others 2004): departure < 33; 33 ≤ departure < 67; and departure ≥ 67, which correspond to FRCC 1, 2, and 3, respectively. For Zone 19, we used FRCC classification thresholds that were different from those used for Zone 16 to match values subsequently modified by managers implementing the FRCC Guidebook procedures in the field; these were: departure < 5, 5 ≤ departure < 52.5, and departure ≥ 52.5, which correspond to FRCC 1, 2, and 3, respectively (Hann, personal communication).

Implementing the HRVStat Approach

In developing and implementing the HRVStat approach, we wanted to employ a statistical test that could detect whether a single observation of current vegetation was unusual compared to a set of observations repre-

senting historical vegetation composition. That is, we wanted to consider every observation in the simulated historical record for all succession classes in a PVT and compare this set to the current conditions. This approach was fundamentally different from the FRCC Guidebook method, which measures departure using only one value to represent the time series of simulated historical conditions for any PVT-succession class combination.

To estimate departure using a range of historical conditions, Steele and others (in preparation) developed a new statistical technique based on measuring the extent that a suspected outlier (in our case, the current observation) can be estimated from the simulated historical observations. This multivariate statistical approach uses concepts from matrix algebra to compute linear approximations and measurements of approximation error (Leon 2002). Essentially, this method computes the best possible approximation of the current observation that can be formed as a linear function of the simulated historical data. Usually, there is some error in the approximation, and the square root of that error is the estimated departure value using the HRVStat method. More specifically, departure is calculated as the square root of the error sum-of-squares after normalizing the current observation vector. If the measured error (that is, departure) is small, the current observation is similar to the simulated historical data. Conversely, a current observation inconsistent with historical patterns will be poorly approximated, and the error will be relatively large, as will the estimated departure value. Steele and others (in preparation) considered other approaches to identifying whether an observation is dissimilar from other observations in a data set. Some of these methods are based on the measure of the distance of a single observation from measures of central tendency (for example, the mean), such as Mahalanobis distance. More commonly, these methods concentrate on measuring distance along particular eigenvector axes extracted from the sample variance matrix. A simulation study showed that the HRVStat approach is far better at detecting unusual observations and particularly effective for use with our highly-dimensional (in other words, having numerous categories of PVT–succession class combinations) data sets comprised of count data (Steele and others, in preparation). We adopted this new method, termed herein as the “best linear approximation,” to measure the extent to which current vegetation composition in an LRU differs from simulated historical vegetation composition – which we call the “observed departure.”

We also wanted a measure that expressed the strength of evidence for a given observed departure estimate, or

Table 2—First step in computing departure in example LRU using the FRCC Guidebook method. This LRU has 12 PVTs, but only 5 are shown here for brevity. See table 7 for structural stage codes. Note: current conditions are also shown in table 1.

PVT	Structural stage	Cover type	Current conditions	Reference conditions	Similarity	Sum of similarity	Departure
Pinyon – Juniper / Mt. Big Sagebrush / South	HHW	Juniper	38.71	0.04	0.04	18.52	81.48
Pinyon – Juniper / Mt. Big Sagebrush / South	LLW	Pinyon – Juniper	19.20	10.00	10.00		
Pinyon – Juniper / Mt. Big Sagebrush / South	HHW	Pinyon – Juniper	17.05	0.11	0.11		
Pinyon – Juniper / Mt. Big Sagebrush / South	LLW	Juniper	11.52	2.51	2.51		
Pinyon – Juniper / Mt. Big Sagebrush / South	LHS	Mt. Deciduous Shrub	9.37	2.31	2.31		
Pinyon – Juniper / Mt. Big Sagebrush / South	HHS	Mt. Deciduous Shrub	2.00	4.71	2.00		
Pinyon – Juniper / Mt. Big Sagebrush / South	LHW	Juniper	1.23	0.62	0.62		
Pinyon – Juniper / Mt. Big Sagebrush / South	LHW	Pinyon – Juniper	0.77	2.47	0.77		
Pinyon – Juniper / Mt. Big Sagebrush / South	HLS	Mtn. Big Sagebrush Complex	0.15	25.30	0.15		
Pinyon – Juniper / Mt. Big Sagebrush / South	LLW	Pinyon – Juniper	44.76	7.12	7.12	21.55	78.45
Pinyon – Juniper / Gambel Oak	HHW	Pinyon – Juniper	41.26	0.44	0.44		
Pinyon – Juniper / Gambel Oak	LHS	Mt. Deciduous Shrub	7.69	16.70	7.69		
Pinyon – Juniper / Gambel Oak	HHS	Mt. Deciduous Shrub	3.50	40.20	3.50		
Pinyon – Juniper / Gambel Oak	HLS	Mt. Deciduous Shrub	2.80	7.61	2.80		
Wyoming – Basin Big Sagebrush	HLS	Wy.–Basin Big Sagebrush Complex	85.71	6.98	6.98	21.02	78.98
Wyoming – Basin Big Sagebrush	LLS	Wy.–Basin Big Sagebrush Complex	10.71	17.60	10.70		
Wyoming – Basin Big Sagebrush	LLS	Rabbitbrush	3.57	3.33	3.33		
Pinyon – Juniper / Wy.–Basin Big Sagebrush / S	LLW	Juniper	50.00	1.12	1.12	25.70	74.30
Pinyon – Juniper / Wy.–Basin Big Sagebrush / S	HLS	Wy.–Basin Big Sagebrush Complex	29.41	14.60	14.60		
Pinyon – Juniper / Wy.–Basin Big Sagebrush / S	LLW	Pinyon – Juniper	14.71	4.60	4.60		
Pinyon – Juniper / Wy.–Basin Big Sagebrush / S	HLS	Dwarf Sagebrush Complex	2.94	2.39	2.39		
Pinyon – Juniper / Wy.–Basin Big Sagebrush / S	LLS	Wy.–Basin Big Sagebrush Complex	2.94	16.70	2.94		
Ponderosa Pine	LLF	Ponderosa Pine	58.82	2.24	2.24	32.51	67.49
Ponderosa Pine	LHF	Ponderosa Pine	23.53	37.60	23.50		
Ponderosa Pine	LLW	Juniper	5.88	0.50	0.50		
Ponderosa Pine	LLW	Pinyon – Juniper	5.88	0.36	0.36		
Ponderosa Pine	HHF	Ponderosa Pine	5.88	23.00	5.88		

Table 3—Second step in computing departure for example landscape reporting unit using the FRCC Guidebook method. Departure is calculated as $100 - \text{similarity}$. The final estimate of departure is computed by weighting the departure for the 12 PVTs across the entire landscape reporting unit (LRU) by their respective areas. All 12 PVTs are shown here.

PVT	Sum of similarity for PVT	Departure for PVT	Area of PVT	Weighted departure
Douglas-fir / Douglas-fir	14.20	85.80	1.44	1.24
Grand Fir – White Fir	16.72	83.28	0.67	0.56
Grand Fir – White fir / Maple	0.82	99.18	0.11	0.11
Mountain Big Sagebrush	13.86	86.14	0.11	0.10
Pinyon – Juniper / Gambel Oak	21.55	78.45	15.89	12.47
Pinyon – Juniper / Mountain Big Sagebrush / South	18.52	81.48	72.33	58.94
Pinyon – Juniper / Mountain Mahogany	1.12	98.88	0.22	0.22
Pinyon – Juniper / Wy.– Basin Big Sagebrush / South	25.70	74.30	3.78	2.81
Ponderosa Pine	32.51	67.49	1.89	1.27
Riparian Hardwood	20.57	79.43	0.22	0.18
Spruce – Fir / Blue Spruce / Lodgepole Pine	5.94	94.06	0.22	0.21
Wyoming – Basin Big Sagebrush	21.02	78.98	3.11	2.46
Departure for entire LRU				80.55

an “observed significance level.” The observed significance level is similar to a p-value measurement, which estimates the probability that a type I error (rejecting a true null hypothesis) occurred. However, this formal interpretation requires independent observations from LANDSUMv4 simulations within an LRU – a condition which could not necessarily be met due to possible autocorrelation across time and space. As previously discussed, we observed evidence of temporal autocorrelation using a 20-year reporting interval and, to some extent, a 50-year reporting interval. LRUs may also be spatially correlated because areas close in space tend to have similar vegetation and fire disturbances. Moreover, if we conducted formal tests for each of the tens of thousands of LRUs across a mapping zone, we may obtain a significant result by chance alone, and adjustments would be needed to avoid such type I errors. Hence, the observed significance values reported here are used only to provide a quantitative measure of the evidence of departure for comparisons between LRUs, and not for formal testing (Steele and others, in preparation).

To determine the observed significance level of a departure estimate, we first constructed an empirical distribution using the current and simulated historical observations for each LRU (Steele and others, in preparation). That is, after calculating the observed departure, as described above, we next calculated the departure for each observation *within* the simulated historical data of an LRU, using the best linear approximation calculations. We used the term “divergence” to describe the best linear approximations of the simulated historical time series – to avoid confusion with the “observed

departure” term used to estimate differences between the current and simulated historical time series. We calculated divergence within the simulated historical data set by removing each observation from the data set and computing its divergence from the remaining data (for example, we measured the divergence between year-20 and years 40 to 4,000 in the LANDSUMv4 data set for Zone 16). We then combined the divergence estimates ($n = 200$) with the observed departure ($n = 1$) to produce the empirical distribution for each LRU. Finally, we computed the observed significance level by calculating the proportion of divergence values in the distribution that are at least as large as the observed departure (Steele and others, in preparation).

To help illustrate the statistical procedures in the HRVStat approach, we provide a simplified example in figure 5. Consider two LRUs that contain only one PVT with one succession class, the same mean area over time for reference conditions (percent of the area is 0.2 in fig. 5A), and the same observed area for current conditions (percent of the area is 0.8 in fig. 5A). However, LRU-A has lower variability in the percent areas of the succession class than LRU-B. In figure 5B, we show the distribution of the divergence estimates and the observed departure. The divergence estimates similarly show that LRU-A has less variability for divergence estimates and a lower mean divergence than LRU-B, whereas observed departures are the same for both LRUs (fig. 5B). In figure 5C’s empirical distributions of the divergence, we show the observed significance level for each LRU as the proportion of values greater than or equal to the

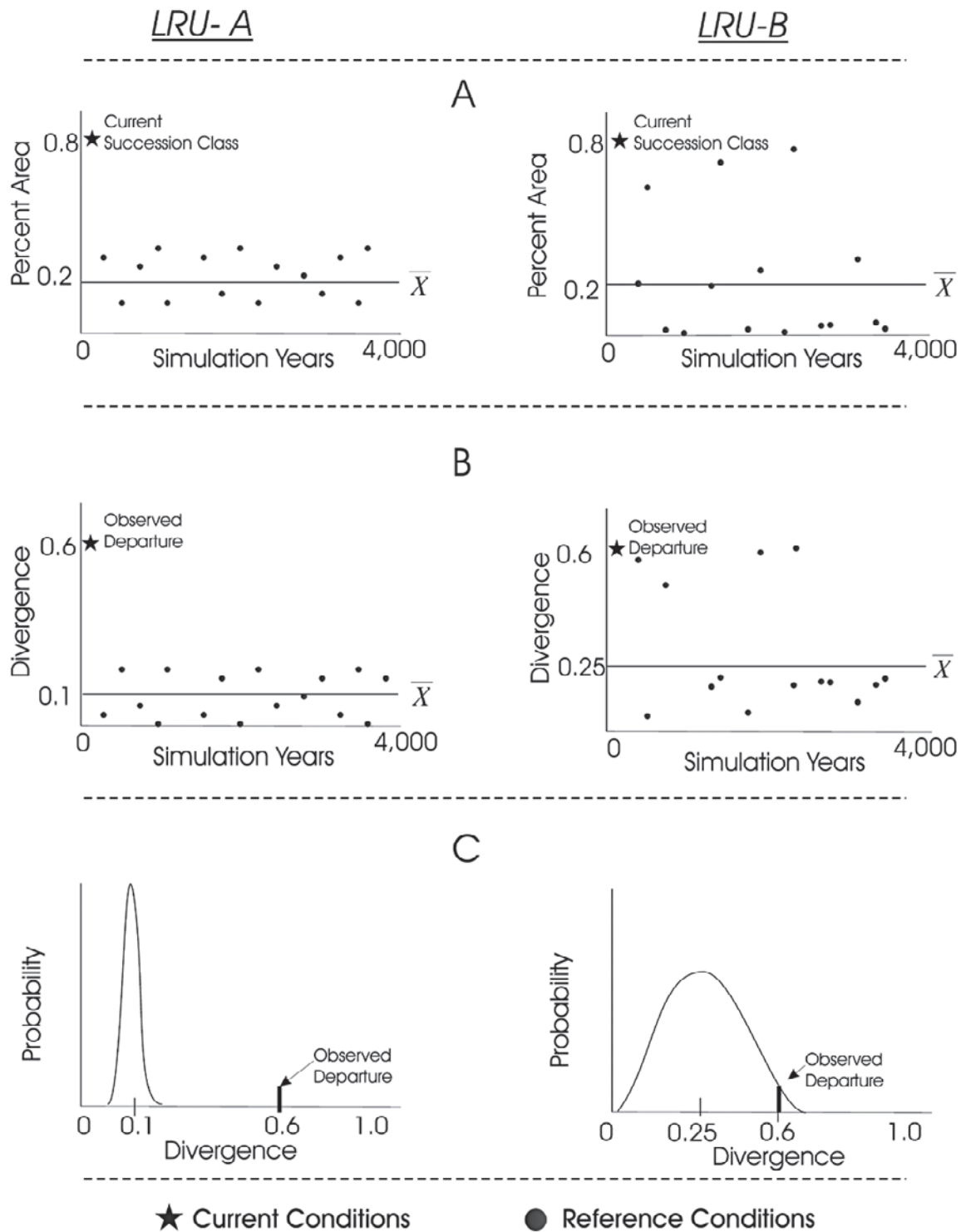


Figure 5—Hypothetical, simplified example demonstrating HRVStat for two landscape reporting units (LRU-A and LRU-B) that contain only one PVT with one succession class under current and reference conditions. Set A shows that LRU-A and LRU-B have the same current percent area for that succession class (current succession class) and that the reference conditions have similar mean percent areas ($\bar{X}$), but LRU-A has less variability than LRU-B. Set B shows estimates for observed departure from and divergence within reference conditions. LRU-A and LRU-B have identical observed departures, but LRU-A has a lower mean divergence ($\bar{X}$) and variability than LRU-B for reference conditions. Set C shows the probability distributions of divergence, where the area under the curve above the observed departure represents the observed significance level. Observed significance level is less in LRU-A than LRU-B because LRU-A has less variability in the reference conditions.

observed departure, where the observed significance value is higher in LRU-B than LRU-A. In summary, we have the same estimate of observed departure for LRU-A and LRU-B, but evidence for that observed departure is greater in LRU-A because of less variability in the distribution of the succession class in the historical time series. In reality, calculations in an actual LRU from Zone 16 or Zone 19 would be far more intensive because of the large number of PVT-succession class combinations (up to 220).

Creating maps for comparing departure estimates—Our last task was classifying HRVStat results to make comparisons with the 1-km coarse-scale FRCC maps (Schmidt and others 2002) and the FRCC Guidebook approach maps, which classify departure as low (FRCC 1), moderate (FRCC 2) and high departure (FRCC 3). We determined that the most informative classification scheme integrates both the departure and observed significance level estimates from HRVStat to describe not only the degree of departure in a landscape but also the evidence supporting the departure estimate.

Both departure and observed significance level values ranged from 0 to 1.0. We classified these parameters into three groupings by choosing two thresholds for partitioning values (table 4). For observed significance

level, we chose thresholds of 0.01 and 0.1 to describe high, moderate, and low observed significance within our departure estimate, based on value limits commonly used in statistics to assess significance. To partition departure into classes, we chose threshold values of 0.33 and 0.67, as recommended in the FRCC Guidebook field methods (Hann and others 2004) and also used in the FRCC Guidebook approach for Zone 16. We call the three classes “classified HRVStat departure” estimates, instead of FRCC, to avoid confusion with the classified departure values from the FRCC Guidebook approach. Accordingly, the classified HRVStat departure values of Class 1, Class 2, and Class 3 correspond to the categories of FRCC 1, FRCC 2, and FRCC 3. We determined that managers would be most interested in areas where the strength of evidence (observed significance) for a departure estimate was highest, and we assigned those areas relatively higher classification values. For example, an LRU may have a relatively low departure estimate (less than 0.33), but if the observed significance value was less than <0.01, we assigned a Class 2 value to the unit. Conversely, we gave lower classification values to areas where evidence in the departure estimate was low; for example, an LRU with a high departure estimate (≥ 0.67) and a high observed significance (≥ 0.1) would be assigned a Class 1 value.

Table 4—Classified HRVStat departure as assigned to each departure/observed significance grouping and the percent of each zone in these categories for zones 16 and 19.

	obs. sign. < 0.01	0.01 ≤ obs. sign. < 0.1	obs. sign. ≥ 0.1
Classified HRVStat departure:			
$d < 0.33$	2	1	1
$0.33 \leq d < 0.67$	3	2	1
$d \geq 0.67$	3	3	2
Percent area of zone:			
Zone 16			
$d < 0.33$	60.34%	22.27%	9.96%
$0.33 \leq d < 0.67$	5.69%	0.01%	0
$d \geq 0.67$	1.73%	0	0
Zone 19			
$d < 0.33$	61.42%	6.88%	6.12%
$0.33 \leq d < 0.67$	12.67%	0.03%	0.00%
$d \geq 0.67$	11.99%	0.90%	0.00%

Operational process for HRVStat—The steps for developing the departure, observed significance level, and classified HRVStat departure map layers were three-fold (fig. 6). First, we extracted the relevant fields from the LANDSUMv4 database, including reporting interval, LRU, PVT, succession class, and area, and combined these data with the associated current landscape data to create the input file. Next, we ran the HRVStat program using GAUSS software (Aptech Systems, Inc. 2004) in addition to an independent platform of the HRVStat program. The HRVStat program produced output files containing departure, observed significance level, and classified HRVStat departure values for each LRU. We then linked the HRVStat output files to the LRU map, and created maps of departure, observed significance level, and classified HRVStat departure.

Detailed Demonstration of Departure Estimates using the HRVStat and FRCC Guidebook Approaches

For illustration purposes, we provide a detailed demonstration of departure calculations for a selection of LRUs using both the FRCC Guidebook and HRVStat approaches. We chose three LRUs in Zone 16 with classified HRVStat departure and FRCC estimates of 1, 2 and 3. To demonstrate the FRCC Guidebook approach, we present a detailed description of estimation procedures for only one LRU (FRCC 3) because we determined one example was sufficient, given the simplicity of the calculations. Because the HRVStat approach is less easily comprehended, we provide examples for all three LRUs. Specifically, we present the distributions of succession

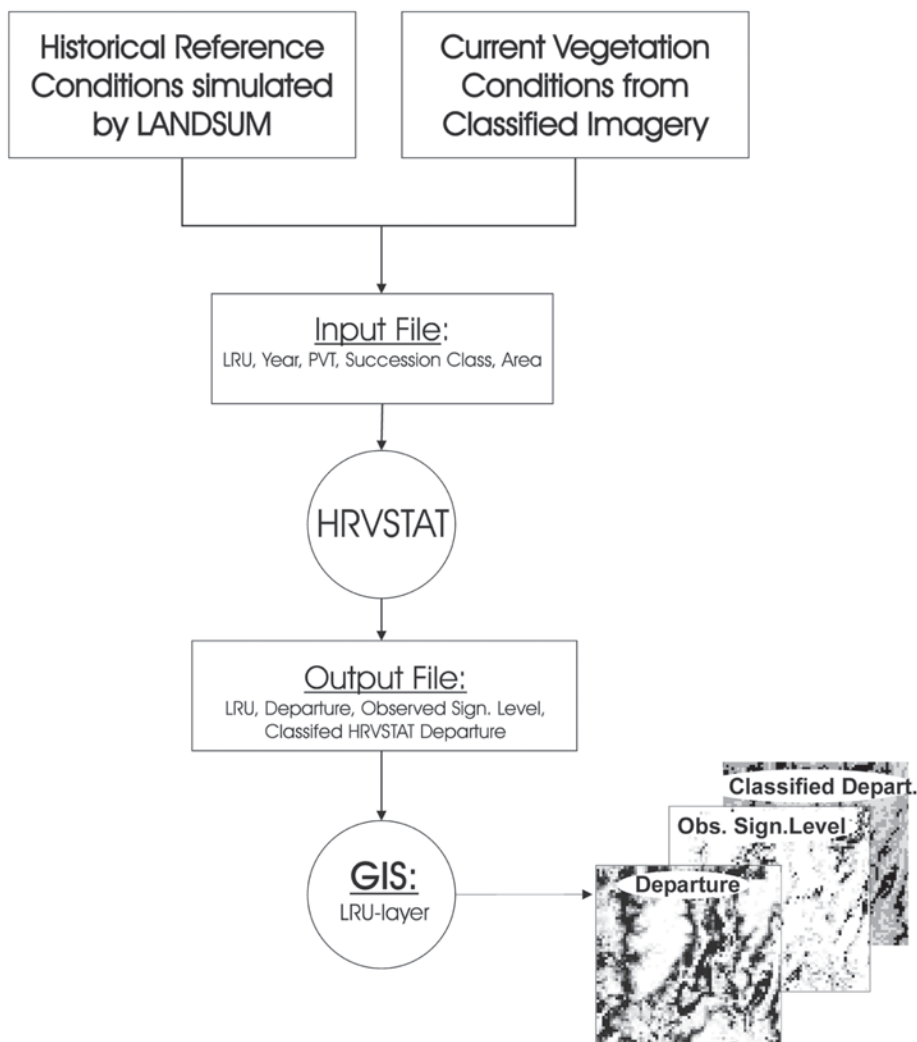


Figure 6—The flow diagram for developing the departure, observed significance level, and classified HRVStat departure maps using the HRVStat method. Data from LANDSUMv4 simulations are combined with current landscape data to build input files containing the attributes of landscape reporting unit (LRU), PVT, succession class, and area (m^2). HRVStat calculates departure statistics for each LRU and produces an output file with departure, observed significance, and classified HRVStat departure estimates for each LRU. Departure statistics are linked to the LRU spatial layer to build maps of departure, observed significance level, and classified HRVStat departure.

classes by PVT and qualitatively describe the succession classes contributing most to departure for individual LRUs. We also present the empirical distributions of divergence and observed departure estimates, from which observed significance values are derived.

Departure Estimates by Fire Return Intervals

The national coarse-scale project evaluated the relationship of estimated FRCCs on current landscapes to estimates of historical fire return intervals (Schmidt and others 2002), and the LANDFIRE Prototype Project conducted similar analyses for comparison. One of the map layers created by the LANDSUMv4 model described fire return intervals (the number of years between successive fires for each pixel in the mapping zone), which was classified into four categories to be compatible with the fire regime maps developed for the national coarse-scale project, including: 0-35 year frequency, 36-100 year frequency, 101-200 year frequency, and 201+ year frequency (Pratt and others, Ch. 10). We compared the departure indices estimated by the FRCC Guidebook and HRVStat approaches to the classified fire return interval layer to evaluate whether departure becomes higher in areas where more fire is observed under simulated historical conditions.

Results

We present maps and other results from the exploratory stages in our method development for Zone 16; for Zone 19, we present our resultant recommended method for estimating departure. However, even for Zone 19, results reflect a work in progress, and more analysis and research is needed to further improve the FRCC Guidebook and HRVStat approaches. Hence, the specific findings presented here should be considered primarily as a demonstration of method development and as a comparison of approaches to estimating departure. Maps and computed values for departure statistics may change as these procedures are refined for the national implementation of the LANDFIRE Project.

FRCC Guidebook Approach

A comparison of the temporal snapshot and multi-temporal methods for deriving reference conditions revealed that the snapshot approach produced the highest zone-wide estimates of departure, with a zonal mean of 73 (fig. 7A) compared to means ranging from 23 to 63 using the multi-temporal method (fig. 7B-7D). We expected this

result because many of the currently present succession classes did not exist in the year-1,000 LANDSUMv4 output. Simply stated, if reference conditions for a succession class are 0 (the succession class, by chance, did not occur in year-1,000 LANDSUMv4 output) then there would be no similarity and thus, complete departure. Once we recognized the ineffectiveness of the snapshot method for deriving reference conditions, we focused our efforts on the multi-temporal approach.

Using the multi-temporal approach for deriving reference conditions, we discovered that for Zone 16, each progressively smaller spatial domain (fig. 2) produced noticeably lower estimates of departure (fig. 7B-7D), with a zonal mean of 63 using the zone as the spatial domain, 45 using the simulation landscape, and 23 using the LRU as the spatial domain; furthermore, the proportions of the zone belonging to FRCC 3 were highest using the zonal-spatial domain (41 percent) and lowest using the LRU-spatial domain (1 percent) (table 5). For all three spatial domains, departure and FRCC were higher in the area surrounding the Uinta Mountains and in the southern portions of the mapping zone (figs. 7B-7D and 8). Examining the LRU-spatial domain alone, the departure estimates for Zone 16 ranged from 0 to 96 with a mode of 11 (fig. 9A). For Zone 19, we evaluated only the LRU-spatial domain to derive reference conditions and observed a zonal departure mean of 42, mode of 43, and a range of 0 to 100 (fig. 9B); in addition, most (74 percent) of Zone 19 belonged to FRCC 2 (table 5). Departure and FRCC were generally higher in the northern portions of the zone and in scattered clusters in the central and eastern portions of the zone (fig. 10).

To assess how the various vegetation types contributed to departure, we also evaluated the mean departures for each PVT across the mapping zones by constructing simple spatial overlays of departure and PVT maps for each zone (appendices 11-B and 11-C). For Zone 16, using all three spatial domains for computing reference conditions, the highest departure was estimated to occur in the Douglas-fir / Timberline Pine PVT (appendix 11-B), but this PVT occupied only a small fraction (0.47 percent) of the zone. The Pinyon-Juniper / Mountain Big Sagebrush / South PVT had the second highest estimate of departure across all three spatial domains (appendix 11-B) and was the most abundant PVT (17 percent) in the zone. In Zone 19, the Bluebunch Wheatgrass PVT had the highest estimated departure (62), followed by the Dry Shrub PVT (58) (appendix 11-C), but they occupied relatively small portions of the zone (six and one percent, respectively). The most abundant PVTs were Wyoming – Basin Big Sagebrush Complex (15 percent

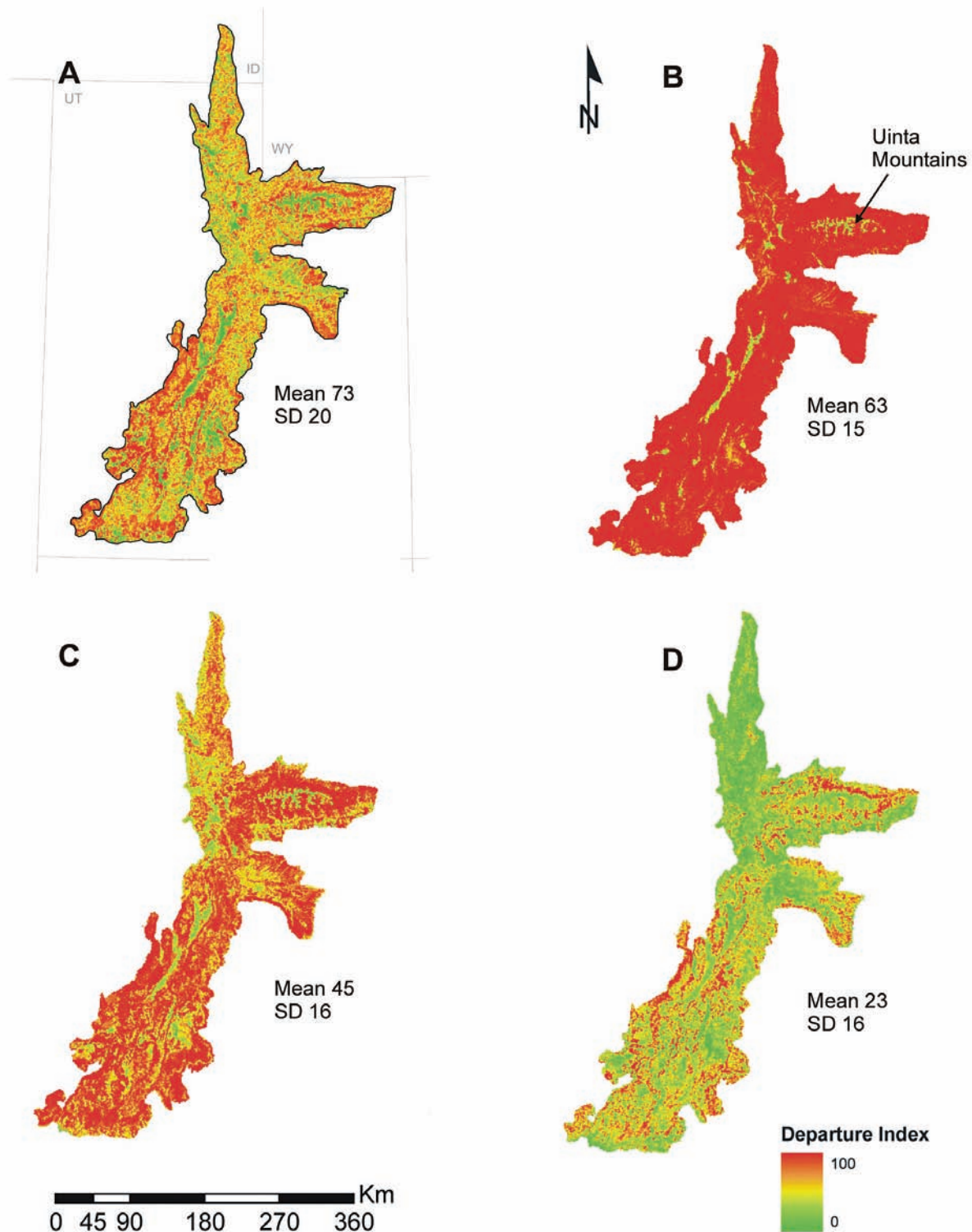


Figure 7—Departure estimates using FRCC Guidebook approach for Zone 16 based on reference conditions derived from: (A) LANDSUMv4 output at simulation year-1000 and 90 percent of the maximum percent area observed for each succession class in a PVT across the simulated time series for three spatial domains (the areal extent for summarizing the LANDSUMv4 time series data) including: (B) the entire zone, (C) individual simulation landscapes, and (D) individual landscape reporting units.

Table 5—Proportion of each mapping zone in the three classes describing (1) classified HRVStat departure, (2) FRCC using the FRCC Guidebook approach for each of the three spatial domains of mapping zone, simulation landscape (SL), and landscape reporting unit (LRU) in Zone 16 and for the LRU spatial domain only in Zone 19, and (3) FRCC from Schmidt and others 2002.

Class	Classified HRVStat departure	FRCC Guidebook approach using zonal spatial domain	FRCC Guidebook approach using SL spatial domain	FRCC Guidebook approach using LRU spatial domain	Schmidt and others 2002
Zone 16					
1	32%	5%	24%	77%	62%
2	60%	54%	67%	22%	34%
3	8%	41%	9%	1%	4%
Zone 19					
1	13%	n/a	n/a	1%	37%
2	70%	n/a	n/a	74%	40%
3	17%	n/a	n/a	25%	23%

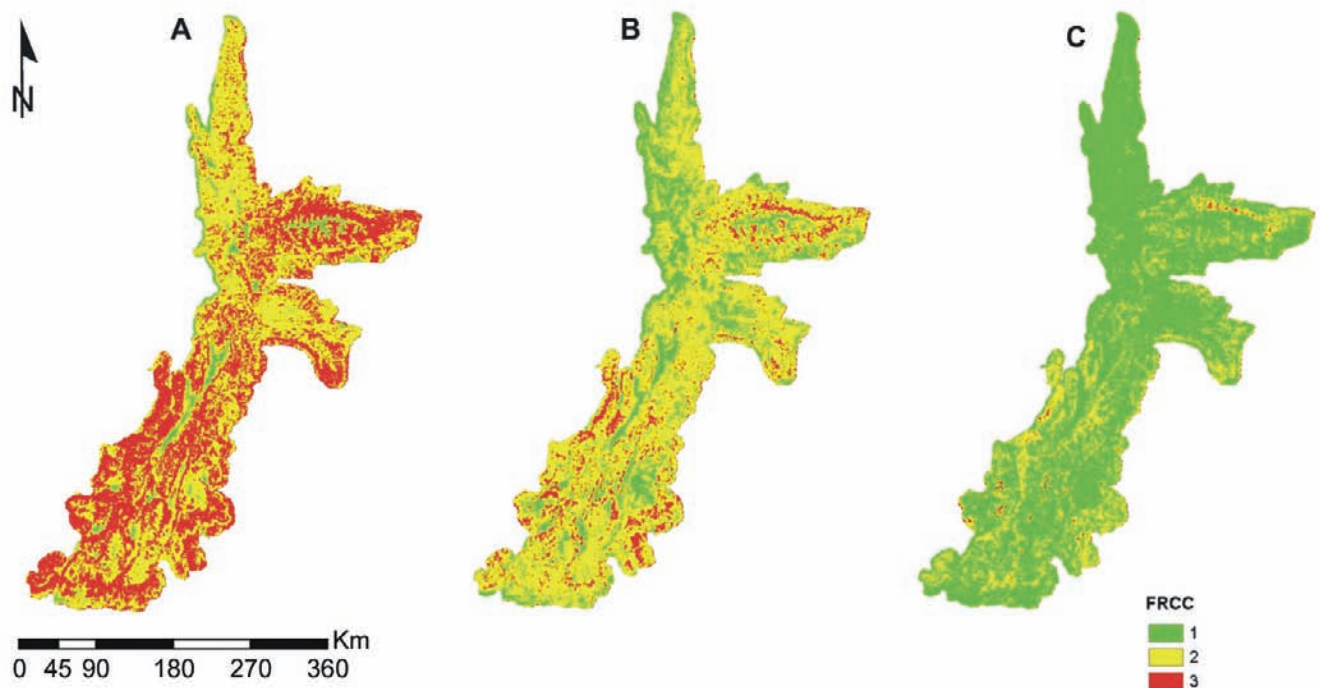


Figure 8—Fire regime condition class (FRCC) for Zone 16 using the FRCC Guidebook approach and based on reference conditions derived from 90 percent of the maximum percent area observed for each succession class in a PVT across the simulated time series for three spatial domains (the areal extent for summarizing the LANDSUMv4 time series data) including: (A) the entire zone, (B) individual simulation landscapes, and (C) individual landscape reporting units.

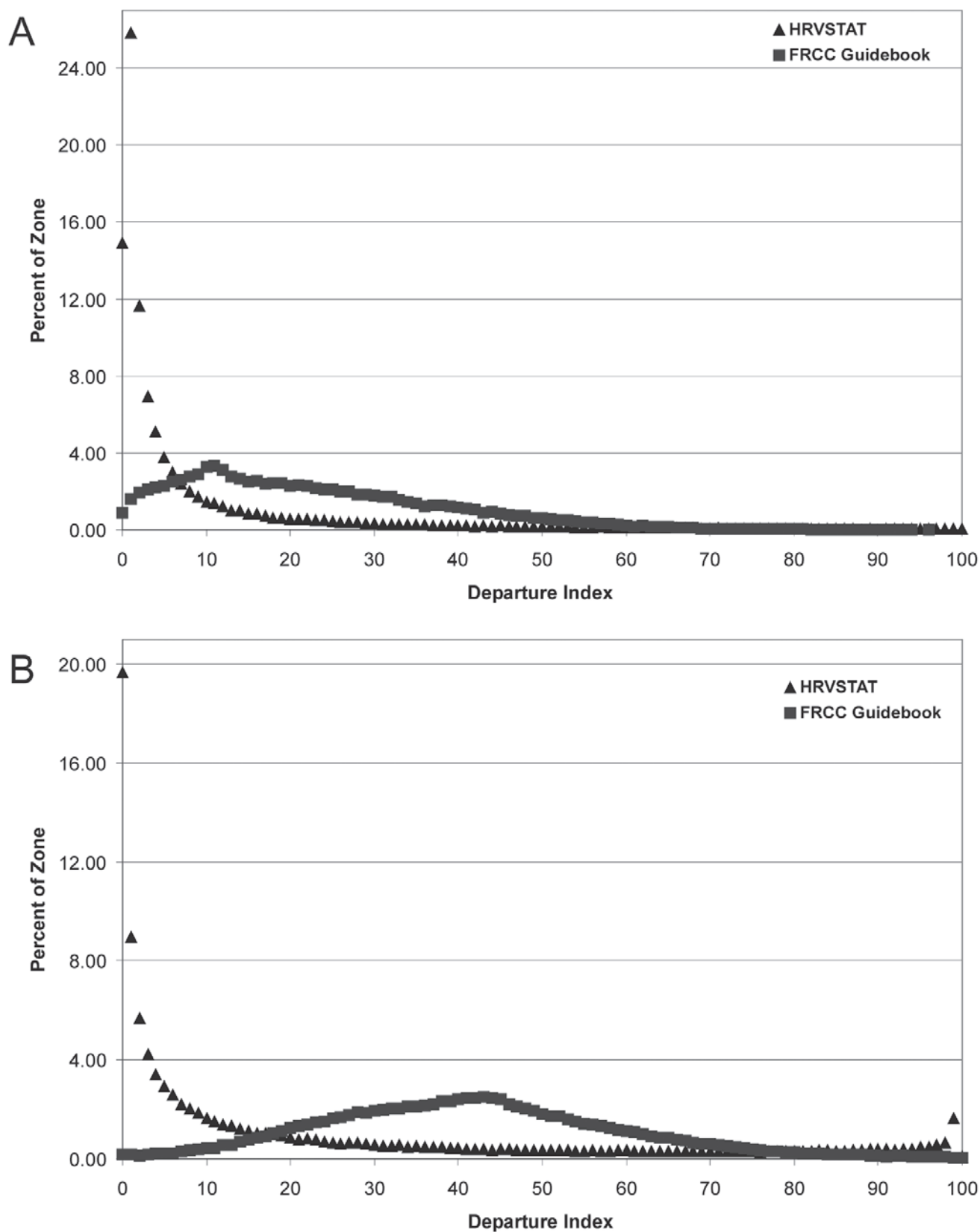


Figure 9—Frequency distribution of departure estimates using the HRVStat and FRCC Guidebook approaches for (A) Zone 16 and (B) Zone 19. Departure values from HRVStat were rescaled from 0-1.0 to 0-100 to match the scale of the FRCC Guidebook values. FRCC Guidebook estimates use the LRU as the spatial domain.

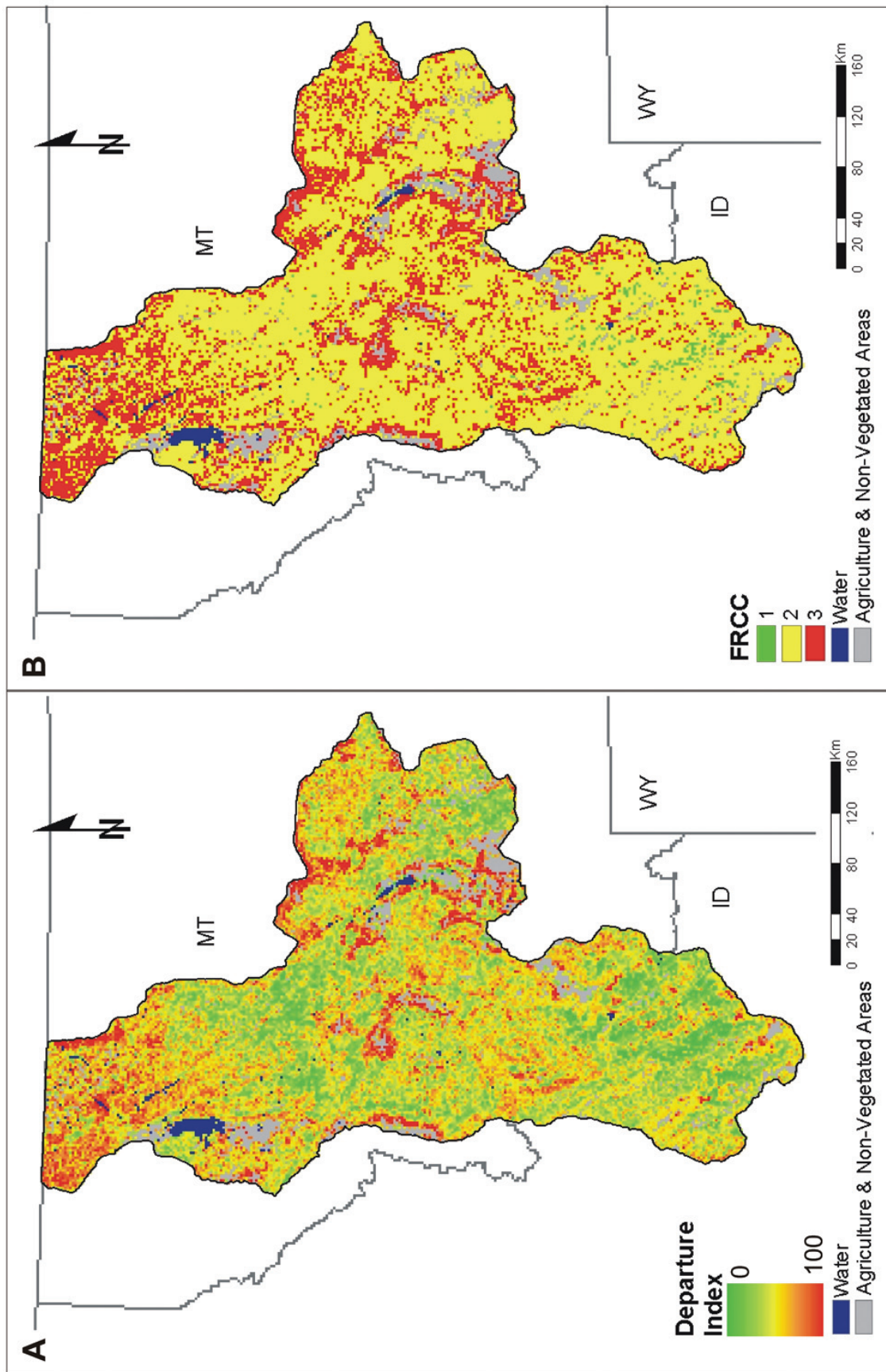


Figure 10—FRCC Guidebook approach results for (A) departure and (B) FRCC for Zone 19 based on reference conditions derived from the 90th percentile of percent area observed for each succession class in PVTs across the simulated time series using the landscape reporting unit as the spatial domain (the areal extent for summarizing the LANDSUMv4 time series data).

of zone) and Douglas-fir / Douglas-fir (11 percent), and they had relatively low departures of 39 and 34, respectively.

It should be recognized that these results do not precisely estimate the degree to which each vegetation class contributed to departure. That is, the results presented were produced through simple overlays (for example, a departure layer overlaid on a PVT layer), and the amount that any of these vegetation classes contributed to the measured departure within LRUs could not be precisely measured. For example, an LRU with a high departure estimate may be composed of 90 percent Douglas-fir PVT and 10 percent Cool Herbaceous PVT. In these simple spatial overlays, both PVTs would be reported as having high departure. However, the Douglas-fir PVT would likely be the dominant contributor to the high departure estimate. The Cool Herbaceous PVT may be only slightly departed, but we would not observe its true value given our overlay methods. More extensive programming and analysis are needed to more precisely describe departure by vegetation class.

HRVStat Approach

The final products using the HRVStat method were sets of three maps representing departure, observed significance level, and classified HRVStat departure (figs. 11 and 12). In Zone 16, departure estimates were generally higher in the southern portion of the mapping zone, and correspondingly, most occurrences of high classified HRVStat departure (Class 3) were in the southern area, as well. Departure and classified HRVStat departure in Zone 19 were generally higher in the central and eastern portions of the zone. Overall, estimates of departure were lower in Zone 16 (0.086) than in Zone 19 (0.285), but observed significance values were similar (0.039 and 0.014 in zones 16 and 19, respectively). Most departure estimates for individual LRUs were less than 0.1 in Zone 16 and less than 0.3 in Zone 19 (fig. 9), and observed significance levels for individual LRUs were generally less than 0.1 in both zones. The proportions of each mapping zone belonging to the three classified HRVStat departure categories were similar between zones, with the majority (60-70 percent) belonging to Class 2 (table 5).

To obtain an overall sense of the extent to which each of the vegetation classes contributed to estimated departure, we also evaluated departure estimates by PVT using simple spatial overlays of departure, observed significance, and classified HRVStat departure layers with the PVT layer (appendices 11-D and 11-E). The highest departure (mean values greater than 0.1) observed in Zone

16 occurred primarily in non-forest PVTs (pinyon-juniper types and the Salt Desert Shrub PVT), had relatively low observed significance (mean values of 0.01 to 0.03), and comprised 28 percent of the mapping zone; some forest PVTs (Ponderosa Pine, Douglas-fir / Timberline Pine, and Douglas-fir / Douglas-fir) had similarly high departure and low observed significance and comprised 6 percent of the mapping zone (appendix 11-D). Results for the distributions of classified HRVStat departure by PVT were similar. Of those areas in Zone 16 categorized as Class 3, the most prevalent were non-forest PVTs, including: Pinyon – Juniper / Mountain Big Sagebrush / South PVT (comprising approximately 26 percent of the zone), Pinyon – Juniper / Wyoming – Basin Big Sagebrush / South (24 percent), and Salt Desert Shrub (9 percent).

In Zone 19, the PVTs with the relatively highest departure estimates (>0.5) and low observed significance (<0.01) were also non-forest (bluebunch wheatgrass types, the Dry Shrub PVT, and Fescue Grasslands PVT) and encompassed about 10 percent of the mapping zone. PVTs with relatively moderate departure (<0.5 and >0.3) were a mixture of forest and non-forest types and comprised approximately 6 percent of the zone (appendix 11-E). The lowest departure (<0.3) observed in the mapping zone occurred mainly in forest PVTs (about 55 percent of the zone) but also occurred in sagebrush-related PVTs (about 20 percent). It should be noted that approximately 10 percent of Zone 19 was composed of water, agriculture, and non-vegetated areas, which were omitted from departure estimates. Of the areas in Zone 19 categorized as Class 3, the most abundant PVTs were a mixture of grass, shrub, and forest: Bluebunch Wheatgrass (14 percent of the mapping zone), Wyoming – Basin Big Sagebrush Complex (19 percent), and Douglas-fir / Douglas-fir (8 percent).

When evaluating the extent to which a landscape has diverged from simulated historical conditions, we can also examine which current succession classes within a given PVT contribute the most to departure. A complete presentation of departure estimates by all PVTs and succession classes for each mapping zone is beyond the scope of this report; however, we present an example from Zone 16 for illustration purposes (table 6). Succession classes within the Pinyon – Juniper / Mountain Big Sagebrush / South PVT with the highest mean departure indices across Zone 16 were Juniper High Cover, High Height (0.45) and Pinyon – Juniper High Cover, High Height (0.37) (table 6). Both of these succession classes are late-seral classes that were less prevalent under reference conditions perhaps because

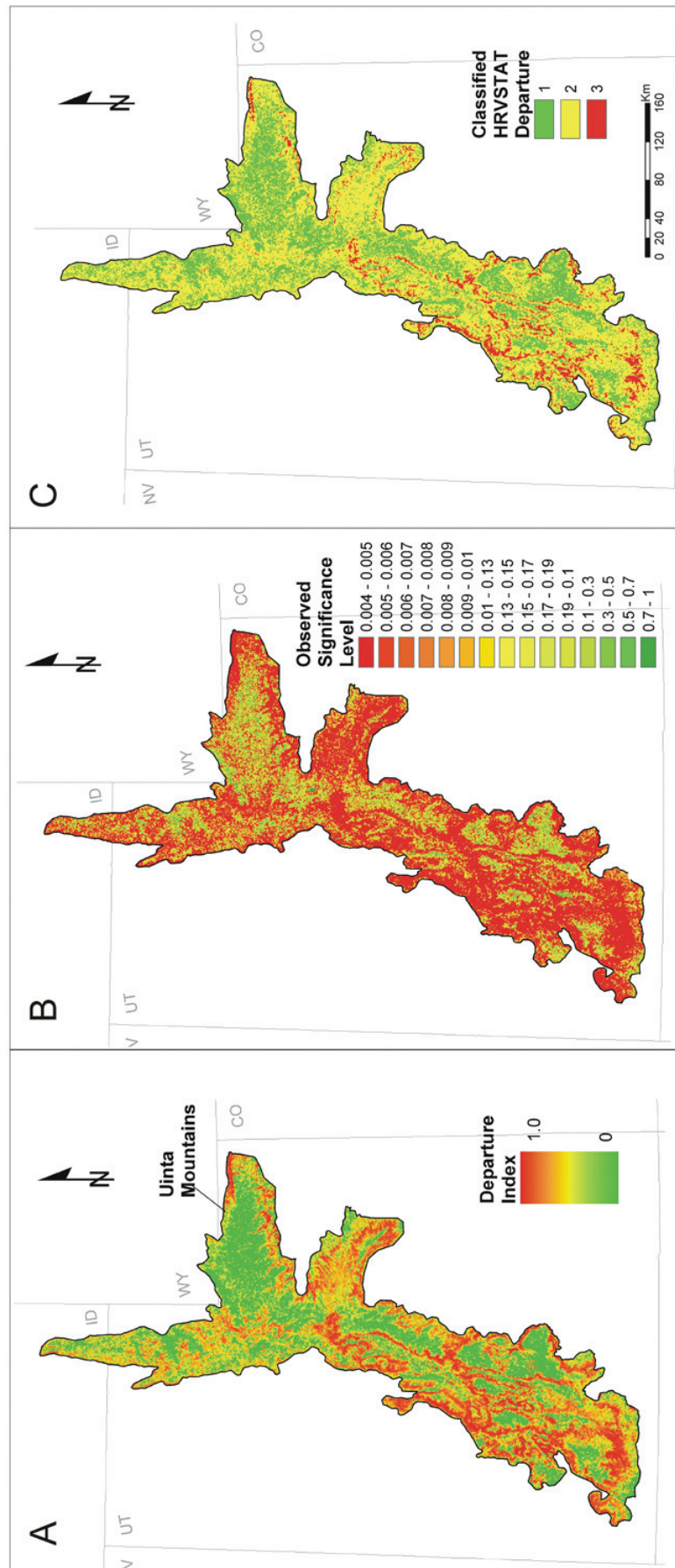


Figure 11—Zone 16 HRVStat results for (A) departure, (B) observed significance level, and (C) classified HRVStat departure, as categorized from departure and observed significance level.

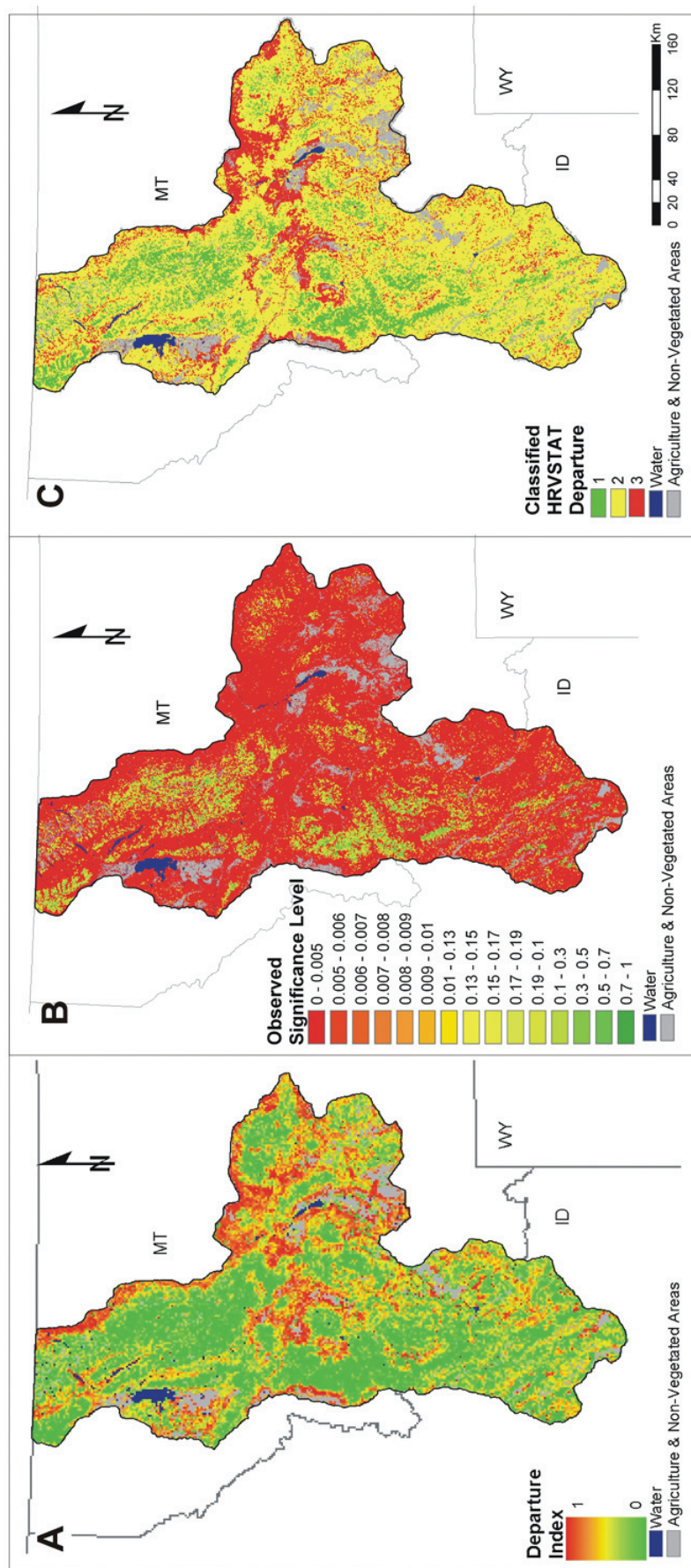


Figure 12—Zone 19 HRVStat results for (A) departure, (B) observed significance level, and (C) classified HRVStat departure, as categorized from departure and observed significance level.

Table 6—Mean departure estimates and observed significance, using HRVStat methods, for each succession class in the Pinyon – Juniper / Mountain Big Sagebrush / South PVT, as well as the percent by area of each succession class for the PVT in Zone 16. See table 5 for definitions of structural stage codes in succession class names.

Succession class	Mean departure	Mean observed significance	Percent of PVT in zone
Juniper HHW	0.45	0.004	14.27%
Pinyon – Juniper HHW	0.37	0.004	12.74%
Juniper LHW	0.33	0.004	1.68%
Pinyon – Juniper LHW	0.31	0.005	1.03%
Juniper LLW	0.26	0.006	26.92%
Mountain Deciduous Shrub LHW	0.26	0.006	9.15%
Pinyon – Juniper LLW	0.22	0.006	24.42%
Cool Season Grasses HLH	0.21	0.006	0.08%
Dry Deciduous Shrub HLS	0.19	0.007	0.16%
Mountain Deciduous Shrub HHS	0.18	0.008	5.84%
Exotic Forbs HLH	0.17	0.006	0.01%
Mountain Big Sagebrush Complex HLS	0.14	0.010	3.06%
Mountain Big Sagebrush Complex LLS	0.12	0.012	0.53%
Dry Deciduous Shrub LLS	0.07	0.019	0.12%

fires were simulated with higher frequencies than occurs in current landscapes. Exotic Forbs (High Cover, Low Height) within this PVT also had relatively high mean departure estimates (0.17) (table 6). Users of the spatial data layers can easily perform similar analyses with the HRVStat data sets for estimating departure.

Detailed Demonstration of Departure Estimates using the HRVStat and FRCC Guidebook Approaches

We demonstrate the process for computing FRCC through the FRCC Guidebook method using an LRU with an estimated FRCC of 3 that was located in the southern portion of Zone 16 (tables 2 and 3; fig. 13). We provide just one example because it is a simple calculation relative to that required using the HRVStat approach. We estimated departure for the example LRU in two steps. First, we computed the departure for each PVT within the LRU of interest (table 2). Although there are 12 PVTs in the LRU examined in table 2, for brevity, we present only the calculations for the five most dominant PVTs in the LRU (table 10). Note that there is one overall departure calculation for a given PVT, but each succession class within a PVT also has a unique departure value. This reflects the fact that the similarity values for each succession class are summed across the PVT in which they reside. Once the overall departure is calculated for each PVT, the first step is complete. In

the second step, we computed the area of each PVT in the LRU (table 3). These data were then used to scale departure measures for every PVT on an area-weighted basis (table 3). This process is accomplished by multiplying the proportion of each PVT within an LRU by its respective departure estimate and summing these values for the entire LRU. In our example calculation (tables 2 and 3), the Pinyon – Juniper / Mountain Big Sagebrush / South PVT had the highest departure (81.48). This high departure greatly affected the final departure estimate for the entire LRU because the Pinyon – Juniper / Mountain Big Sagebrush / South PVT also occupied the largest area (72%).

To demonstrate the characteristics of LRUs with departure estimates derived through the HRVStat approach, we present three examples of LRUs with classified HRVStat departures of 1, 2, and 3. Our example of a Class 3 LRU was composed primarily of two PVTs: the Pinyon – Juniper / Mountain Big Sagebrush / South PVT (72 percent) and the Pinyon – Juniper / Gambel Oak PVT (16 percent) (fig. 13). For the Pinyon – Juniper / Mountain Big Sagebrush / South PVT, current distributions of succession classes were very different from those of simulated historical conditions, which lead to a high departure estimate. The dominant succession classes under simulated historical conditions were low shrub and grassland types, whereas the pinyon and juniper succession classes dominated the current vegetation (fig. 14A; table 7). The second and more minor component of this LRU was the

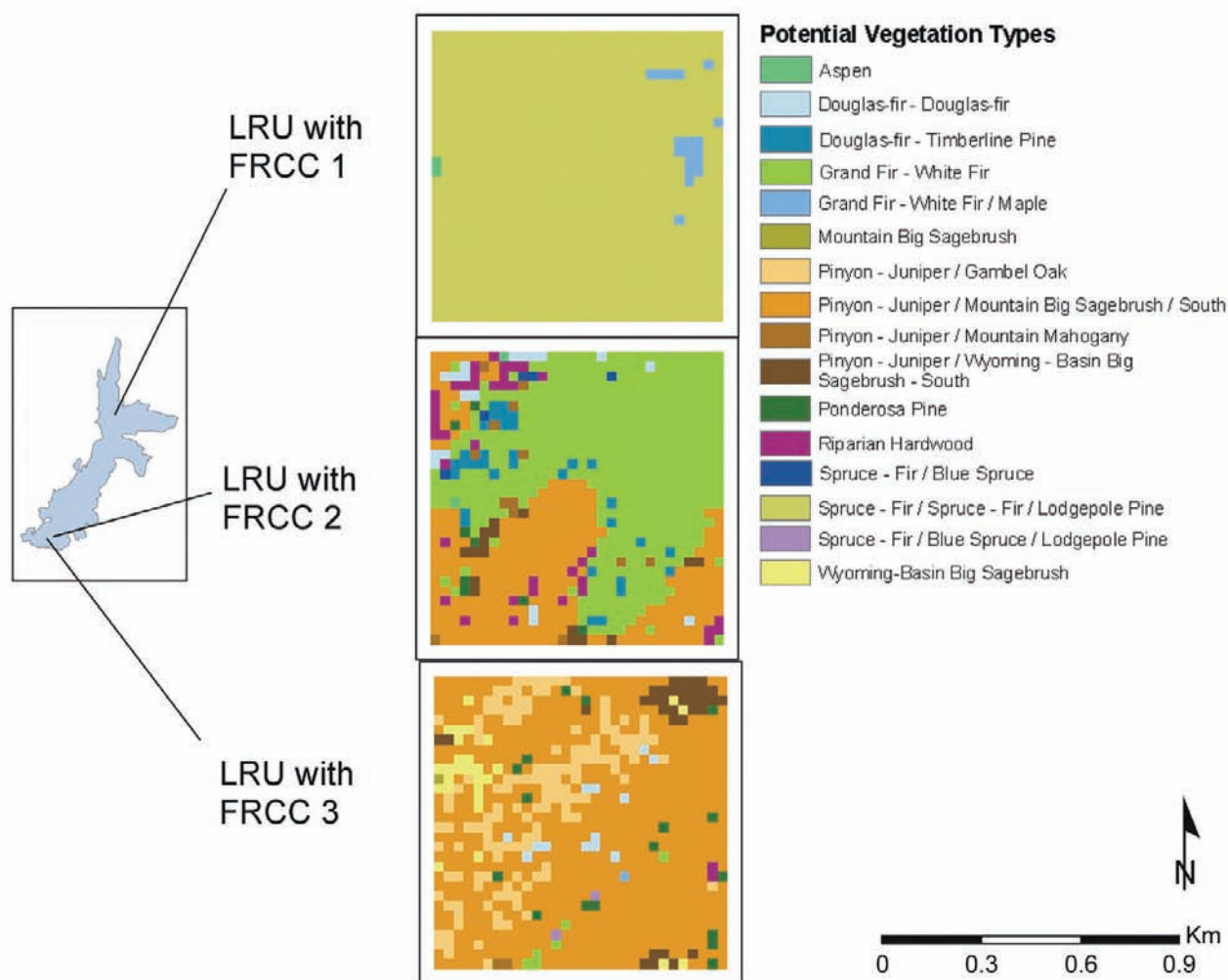


Figure 13—Three LRUs in Zone 16 assigned by the FRCC Guidebook and HRVStat methods to three classes (described here as FRCC 1, 2, and 3) and the spatial distribution of PVTs within each of these LRUs.

Pinyon – Juniper / Gambel Oak PVT, which also showed considerable differences between historical and current succession class distributions. Under simulated historical conditions, this PVT was composed mainly of low shrub and grassland-related succession classes, whereas the current landscape contains mainly pinyon and juniper type succession classes (fig. 14B; table 7). Figure 15 shows that the observed departure estimate (0.74) is much greater than the distribution of divergence estimates, resulting from the dissimilarities in succession class distributions between current and reference conditions; moreover, these dissimilarities lead to a low estimate for the observed significance level (0.005).

To illustrate the characteristics of a Class 2 LRU derived using the HRVStat approach, we chose a unit with an estimated moderately low departure index (0.25)

but high observed significance value (0.005) (table 4). The LRU contained mostly the Grand Fir – White Fir PVT (53 percent) but also a substantial amount of the Pinyon – Juniper / Mountain Big Sagebrush / South PVT (32 percent) (fig. 13). For the more abundant Grand Fir – White Fir PVT, succession class distributions were only moderately dissimilar between current and simulated historical conditions, contributing to a relatively low departure estimate. Simulated historical conditions contained numerous succession classes (27), which consisted primarily of the Douglas-fir and Aspen-Birch types. The current landscape also contains a substantial amount of Aspen-Birch in addition to a dominant Grand Fir succession class and various others (fig. 16A, table 7). The second PVT revealed greater differences in succession class distributions between current and

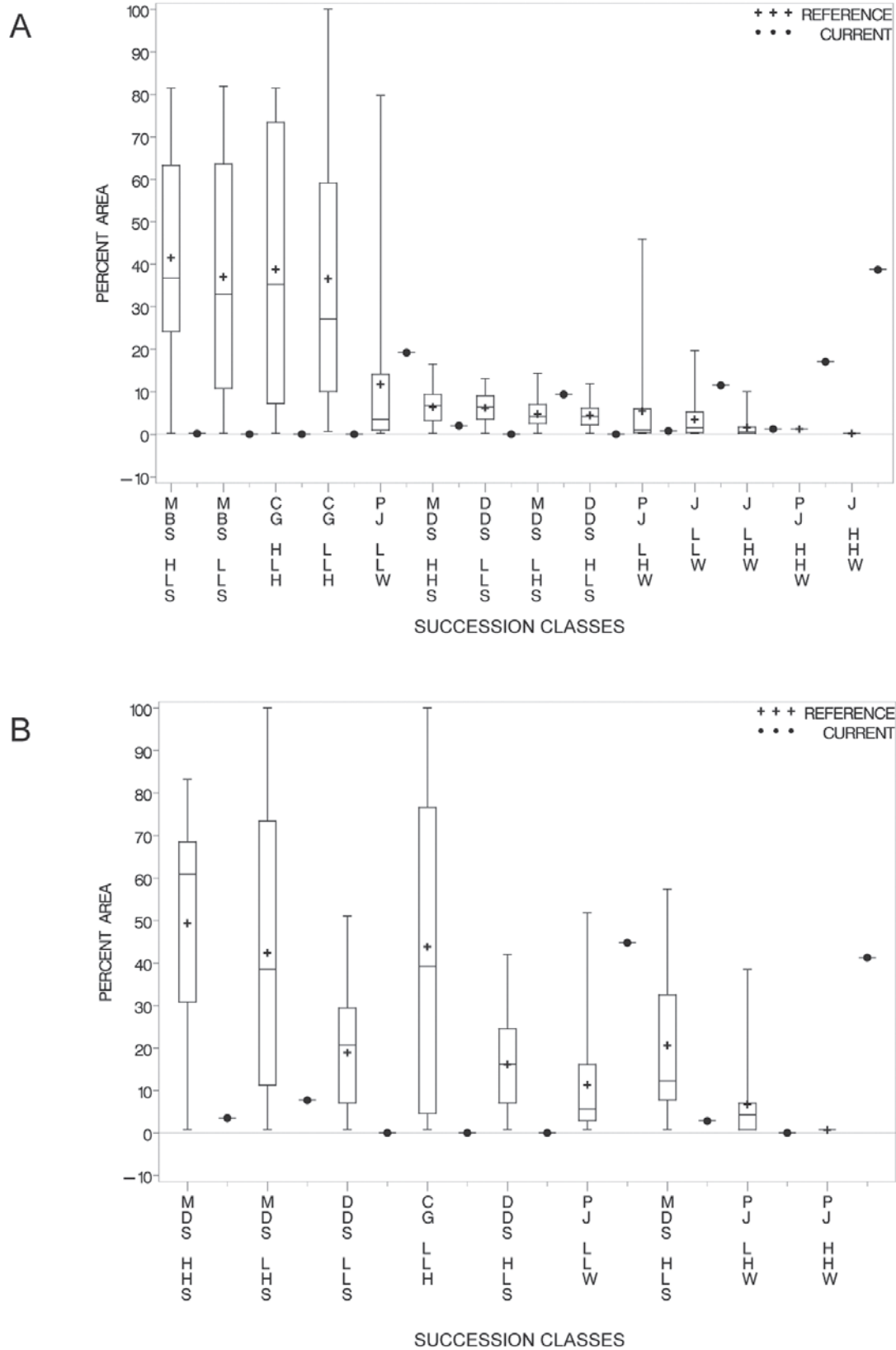


Figure 14—Distribution of succession classes in the two dominant PVTs, for reference and current conditions, in a landscape reporting unit with a classified HRVStat departure of 3 (departure index = 0.74 and observed significance level = 0.005) in Zone 16: (A) Pinyon – Juniper / Mountain Big Sagebrush / South covers 72 percent of the landscape reporting unit and (B) Pinyon – Juniper / Gambel Oak covers 16 percent of the landscape reporting units. See table 7 for explanation of succession class codes.

Table 7—Succession classes for PVTs in landscape reporting units demonstrating classified HRVStat departure in figures 14, 16, 18 and 22 – using the HRVStat approach. Codes defining succession class are described first by cover type and then by structural stage.

Cover type code	Cover type
Forest types	
AB	Aspen – Birch
DF	Douglas-fir
GF	Grand Fir–White Fir
LP	Lodgepole Pine
PP	Ponderosa Pine
SF	Spruce – Fir
TP	Timberline Pines
WH	Western Hemlock
Woodland types	
J	Juniper
PJ	Pinyon – Juniper
Shrub & Grassland types	
CG	Cool Season Grasses
DDS	Dry Deciduous Shrub
ES	Montane Evergreen Shrubs
MBS	Mountain Big Sagebrush Complex
MDS	Mountain Deciduous Shrub
NF	Native Forbs
Structural stage code	Structural stage
LLF	Low Cover, Low Height Forest
HLF	High Cover, Low Height Forest
LHF	Low Cover, High Height Forest
HHF	High Cover, High Height Forest
LHW	Low Cover, High Height Woodland
HHW	High Cover, High Height Woodland
LHW	Low Cover, High Height Woodland
LLS	Low Cover, Low Height Shrubland
HLS	High Cover, Low Height Shrubland
LHS	Low Cover, High Height Shrubland
HHS	High Cover, High Height Shrubland
LLH	Low Cover, Low Height Herbaceous
HLH	High Cover, Low Height Herbaceous

simulated historical conditions. Specifically, the most frequent succession classes under simulated historical conditions were rare to absent under current conditions, and vice versa (fig. 16B). Figure 17 demonstrates that the observed departure estimate (0.25) is greater than the distribution of divergence estimates for the simulated historical conditions, resulting in a low observed significance value (0.005).

The unit chosen to demonstrate the characteristics of a Class 1 LRU had a low departure estimate (0.002),

a relatively high observed significance (0.2475), and was composed almost entirely of one PVT: 99 percent Spruce-Fir / Spruce-Fir / Lodgepole Pine (fig. 13). Most of the succession classes were relatively rare in the simulated historical data sets (fig. 18; table 7), and the current conditions' dominant class of Aspen-Birch Low Cover / High Height was relatively abundant in the historical data. Figure 19 shows that the observed departure estimate (0.002) was similar to the median (0.001) of the divergence estimates from the simulated

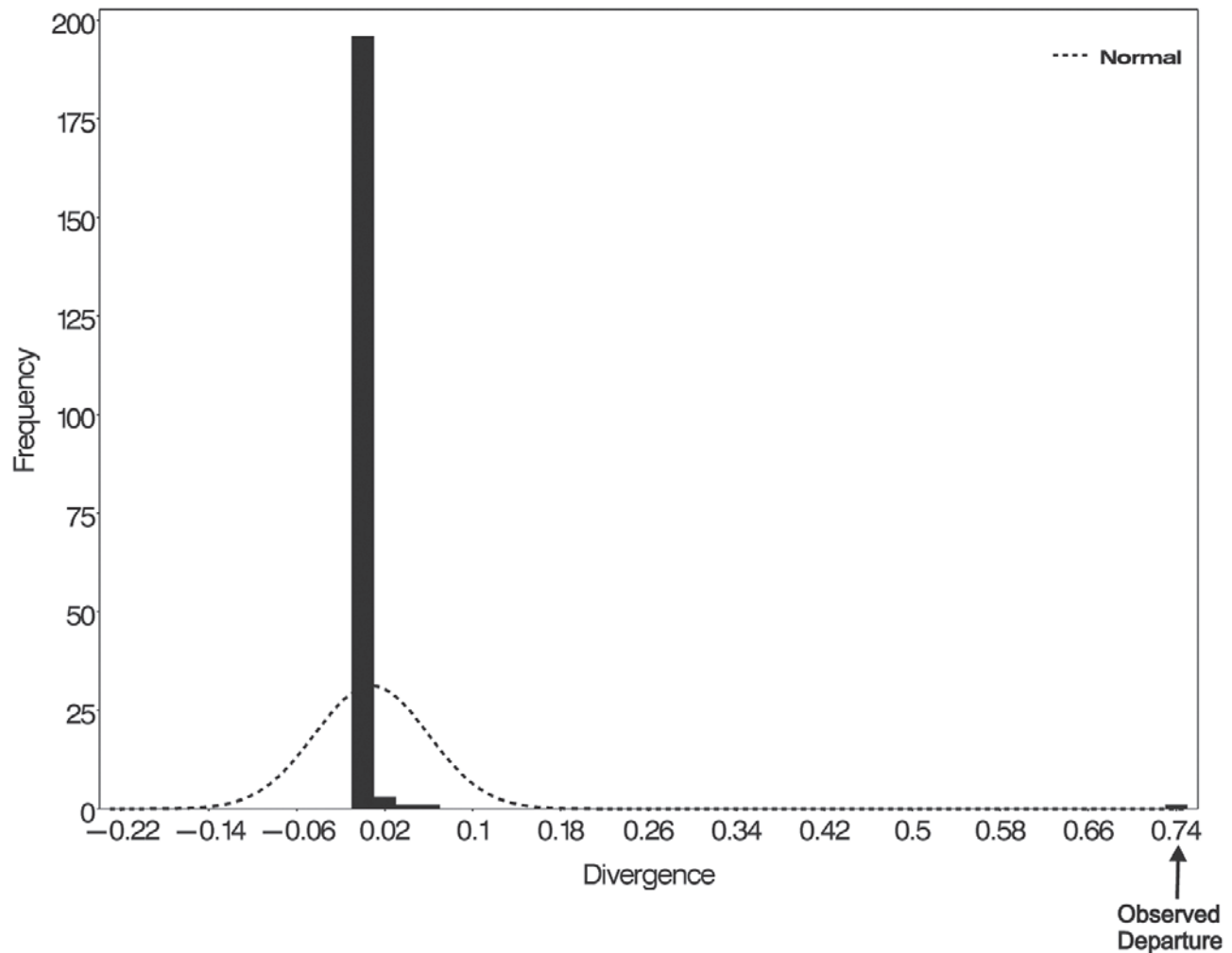


Figure 15—Frequency distributions for divergence estimates in the example landscape reporting unit with a classified HRVStat departure of -3, the normalized probability distribution (dashed line), and an observed departure for current conditions of 0.74. The proportion of area under the probability distribution above the observed departure is 0.005, which is the estimated observed significance level.

historical data set, leading to a relatively high observed significance (0.2475).

Departure Estimates by Fire Return Interval

Evaluation of departure results by fire return interval classes suggested that, under simulated historical conditions, areas with short simulated fire return intervals tended to have higher departure estimates (table 8). In Zone 16, HRVStat departure estimates were highest (9.42 on a scale of 1 to 100) in areas with short fire return intervals (0-35 years) under reference conditions.

In contrast, areas with long fire return intervals (201+ years) had the lowest departures (3.16 on a scale of 1 to 100) under reference conditions. The FRCC Guidebook departure estimates showed a less clear but somewhat similar trend, with higher departure (mean value of 35.22) in areas with short simulated fire return intervals (0-35 years) and somewhat lower departure (mean value of 27.27) in areas where long fire return intervals (201+ years) were simulated (table 8).

Results from Zone 19 showed similar patterns (table 8). HRVStat departure estimates were highest (mean value of 38.13 on a scale of 1 to 100) in areas with short fire

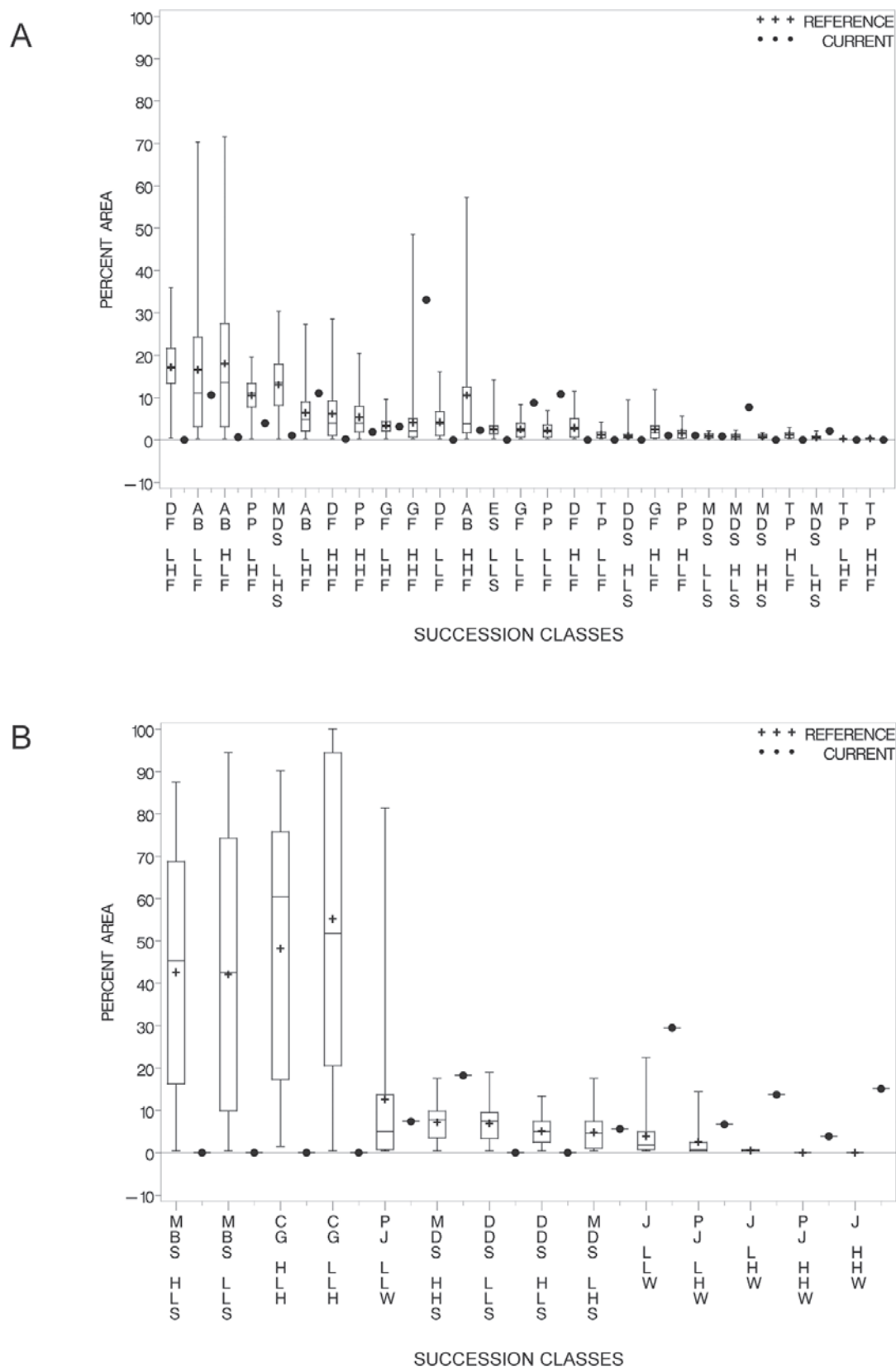


Figure 16—Distribution of succession classes in the two dominant PVTs, for reference and current conditions, in a landscape reporting unit with a classified HRVStat departure of -2 (departure index = 0.25 and observed significance level = 0.005) in Zone 16: (A) Grand Fir – White Fir covers 53 percent of this landscape reporting unit and (B) Pinyon – Juniper / Mountain Big Sagebrush / South covers 32 percent of the landscape reporting units. See table 7 for explanation of succession class codes.

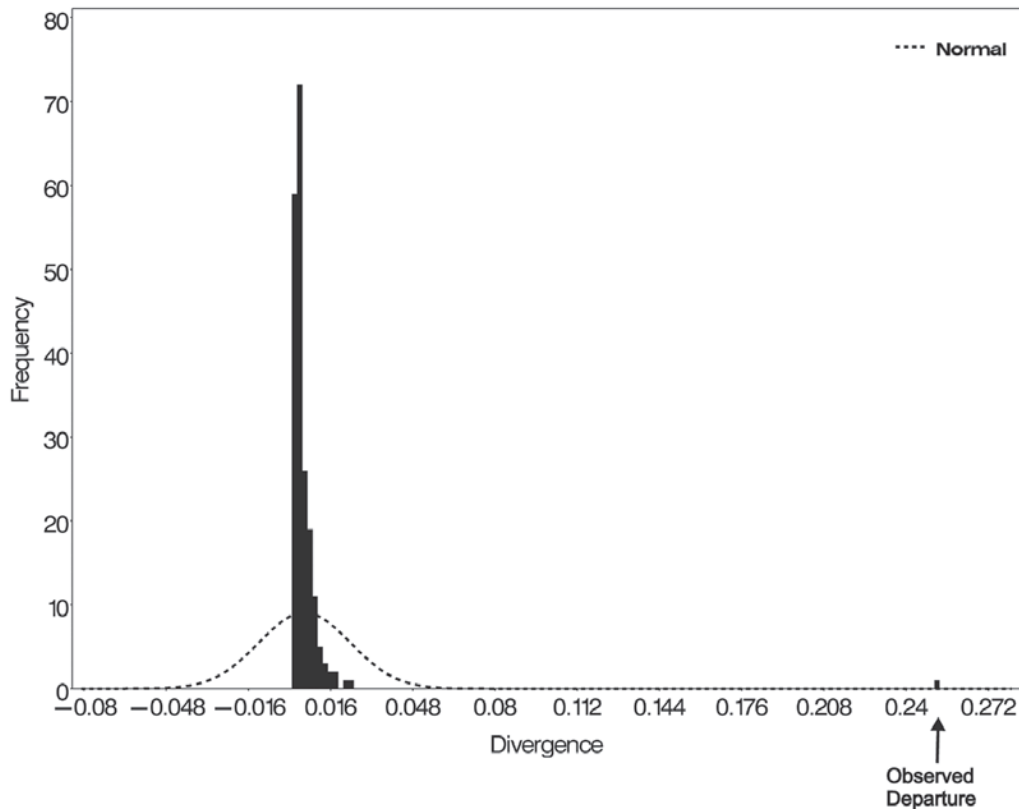


Figure 17—Frequency distributions for divergence estimates in the example landscape reporting unit with a classified HRVStat departure of -2, the normalized probability distribution (dashed line), and an observed departure for current conditions of 0.25. The proportion of area under the probability distribution above the observed departure is 0.005, which is the estimated observed significance level.

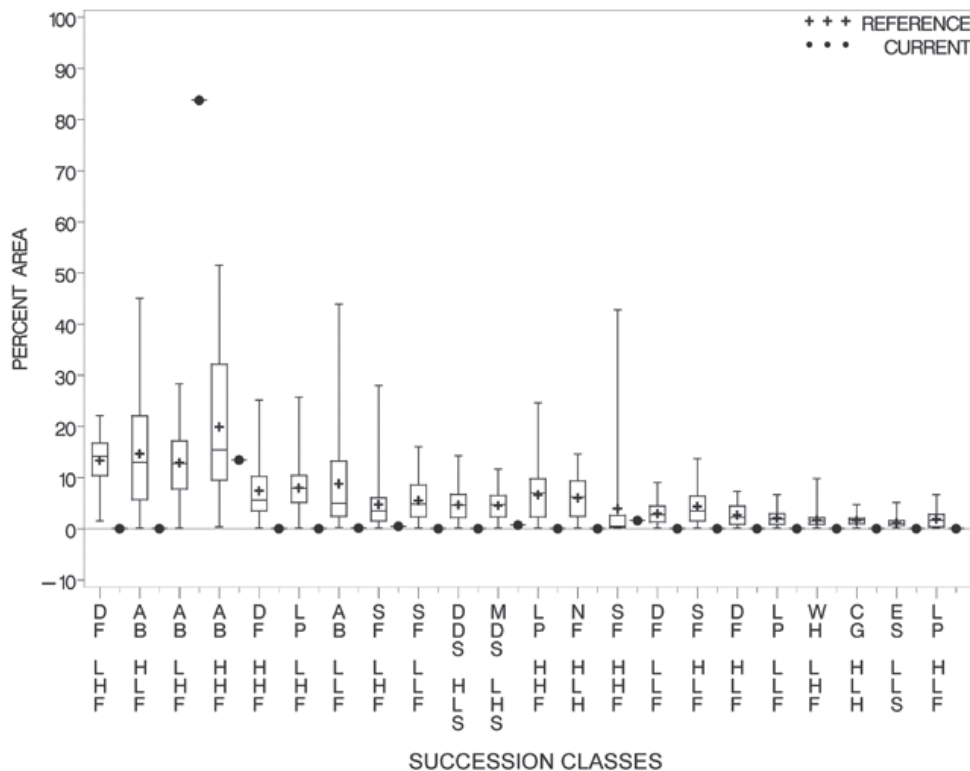


Figure 18—Distribution of succession classes by percent area, under reference and current conditions, for the Spruce – Fir / Spruce – Fir / Lodgepole Pine PVT that dominates a landscape reporting unit with a classified HRVStat departure of -1 (departure index = 0.002 and observed significance level = 0.25) in Zone 16. See table 7 for explanation of succession class codes.

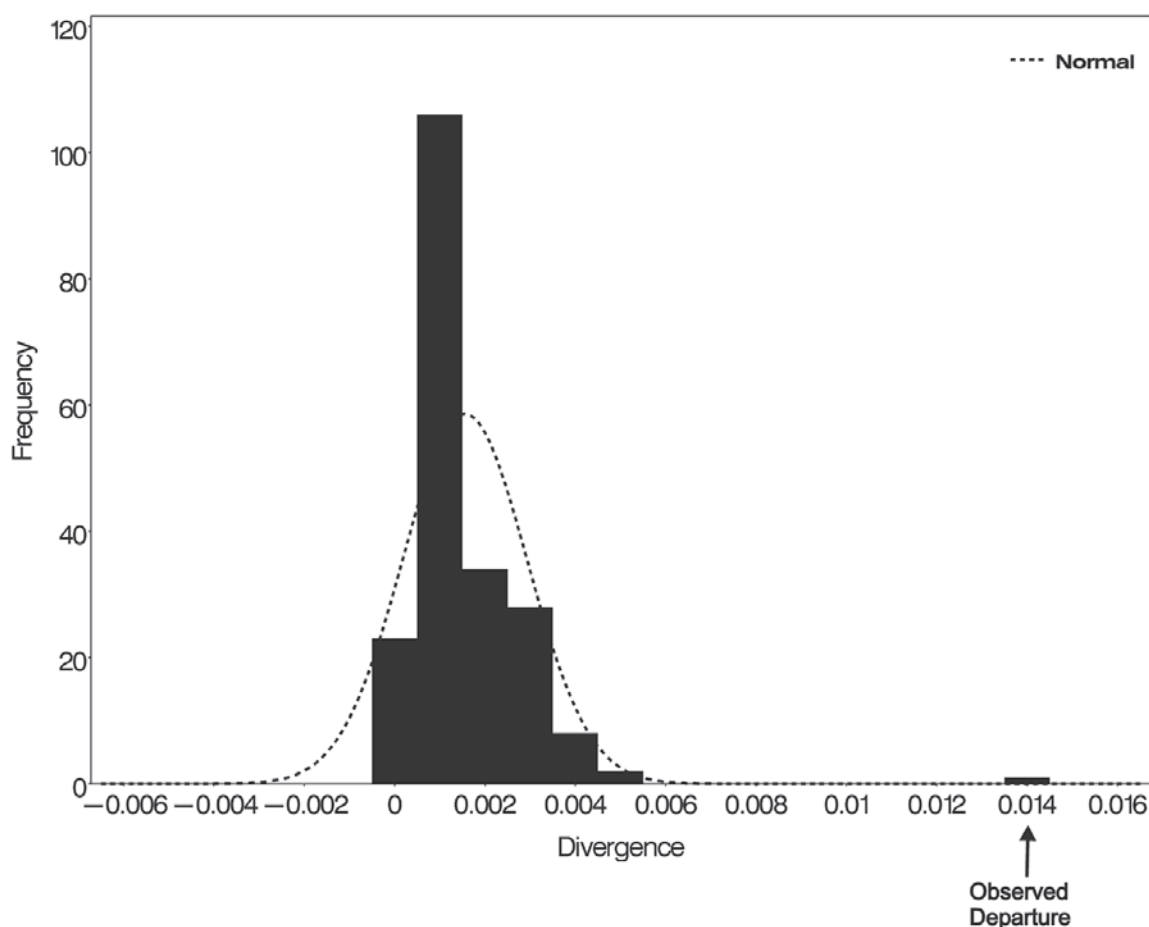


Figure 19—Frequency distributions for divergence estimates in the example landscape reporting unit with a classified HRVStat departure of -1, the normalized probability distribution (dashed line), and an observed departure index for current conditions of 0.002. The proportion of area under the probability distribution above the observed departure index is 0.2475, which is the estimated observed significance level.

Table 8—Summary of departure estimates (area weighted mean) by historical fire return interval classes using the HRVStat and FRCC Guidebook methods. In the FRCC Guidebook method, the spatial domains were the individual landscape reporting units. Note: the HRVStat departure index was rescaled from 0-1 to 0-100 to match the FRCC Guidebook departure range.

Fire frequency class	Departure using HRVStat approach	Departure using FRCC Guidebook approach
Zone 16		
1 - 35 years	9.42	35.22
36 – 100 years	7.78	31.50
101 - 200 years	7.92	22.92
201+ years	3.16	27.27
Zone 19		
1 - 35 years	38.13	20.15
36 – 100 years	16.08	16.59
101 - 200 years	4.37	16.41
201+ years	14.77	17.06

return intervals (0–35 years) under reference conditions. Average departure decreased as fire return intervals increased (with a mean value of 16.08 for the 36 to 100 year group and 4.37 for the 101–200 year group); however, in areas with the longest fire return intervals (201+ years), the mean departure estimate was intermediate (14.77). The FRCC Guidebook departure indices in Zone 19 showed the most departure (20.15) in areas with short simulated fire return intervals (0–35 years) and somewhat lower departure in the areas with longer return intervals (17.06 for 201+ years).

Discussion

We developed two methods for creating maps describing the departure of current landscape conditions from simulated historical conditions. Both methods are standardized, both can be applied across large, continuous landscapes, and both can be automated to produce maps efficiently. The methods were designed for different applications: the FRCC Guidebook approach was intended to implement field-based procedures in a GIS environment, whereas the HRVStat approach was intended for use in the development of a statistically rigorous method that incorporates the temporal variability in a complex, spatial database describing historical conditions. Correspondingly, each method produced divergent results in the maps of departure and their classifications (figs. 7, 8, 10, 11 and 12; table 5). To interpret these disparities and ranges, we need to recognize the strengths and weaknesses of each approach and understand their differences and commonalities.

Strengths and Limitations of the FRCC Guidebook Approach

The FRCC Guidebook method is simple, flexible, and designed to be easily understood by managers. This approach does not require advanced statistical techniques or large data sets, and the metrics used to represent the simulated historical conditions in the departure calculation can be easily changed. For Zone 16, we used the 90 percent of the maximum percent area observed for each succession class in a PVT as the metric through which to summarize the reference conditions' time-series; for Zone 19, we used the 90th percentile of the percent area observed for each succession class in a PVT. However, median, mean, minimum, or other metrics characterizing the reference conditions data set could also be substituted. The FRCC Guidebook approach does not require the simulated historical data set to have a minimum temporal depth (as does the HRVStat approach) and can use a data

set describing PVT-succession class distributions that is limited to one observation, such as is demonstrated in figure 7A where only one reporting interval was used. Since the departure estimate is based on a procedure currently being applied by federal managers to characterize ecosystems with regard to hazardous fuel accumulation (Hann and others 2004), many managers should already be familiar with the calculations and readily understand the process by which spatial data are produced using the FRCC Guidebook approach.

Despite these merits, the FRCC Guidebook approach fails to provide a consistent and comprehensive measure of departure. Specifically, this approach requires that reference conditions are represented by a single observation, but departure estimates are very sensitive to the metric chosen to represent that point statistic. To compare the PVT-succession class distributions of current and reference conditions, we must choose a metric to reduce the 200 observations from the simulated time series to one observation. However, the choice of vegetation metric (median, mean, minimum, 90 percent of maximum, or 90th percentile) for summarizing reference conditions cannot aptly represent all cases of vegetation composition distributions, and the chosen metric will bias departure estimates in different ways, depending on the composition of an LRU. This shortcoming is illustrated in table 9 where departure ranged from 0 using the 90 percent of maximum and 90th percentile metrics to 32 using the median as the metric.

We chose metrics for describing reference conditions (90 percent of maximum and 90th percentile) that would be more sensitive to variation on the upper end of succession class distributions (Hann, personal communication). We used the 90 percent of maximum metric for estimating reference conditions in Zone 16, but determined that the metric over-emphasized the upper end of distributions and consequently over-predicted departure—particularly in cases where an extreme, rare event triggers large but brief fluctuations in vegetation composition. In other words, departure would be measured only by evaluating the reference conditions for a PVT-succession class combination at its widest ranges, even though the remaining time series may be primarily in a narrower range. The 90th percentile metric proved more suitable because it filtered the rare, large oscillations in vegetation conditions and better represented the upper range of variation in vegetation classes. However, the 90th percentile metric represented the simulated time series poorly towards the median and lower end of succession class distributions. For example, the current vegetation composition may be very similar to the dominant vegetation composition

Table 9—Example departure calculations using three vegetation metrics to characterize reference conditions. Note that, using the logic of the FRCC Guidebook field procedures (Hann and others 2004), reference conditions are non-orthogonal (the summation of their area exceeds 100 percent) with respect to the total area that the succession classes occupy within a PVT. See table 7 for codes to structural stages within succession class categories.

PVT	Succession class	Reference condition	Current condition	Similarity	Sum of similarity
		90th percentile			
Ponderosa Pine	Ponderosa Pine / LLF	60	15	15	100
Ponderosa Pine	Ponderosa Pine / LHF	90	85	85	
Pinyon – Juniper / Mountain Big Sagebrush / South	Juniper / HHW	85	65	65	100
Pinyon – Juniper / Mountain Big Sagebrush / South	Pinyon-Juniper / LLW	75	35	30	
Pinyon – Juniper / Mountain Big Sagebrush / South	Pinyon-Juniper / HHW	35	0	0	
Departure estimate					0
		90 % of max.			
Ponderosa Pine	Ponderosa Pine / LLF	70	15	15	100
Ponderosa Pine	Ponderosa Pine / LHF	95	85	85	
Pinyon – Juniper / Mountain Big Sagebrush / South	Juniper / HHW	90	65	65	100
Pinyon – Juniper / Mountain Big Sagebrush / South	Pinyon-Juniper / LLW	85	35	35	
Pinyon – Juniper / Mountain Big Sagebrush / South	Pinyon-Juniper / HHW	45	0	0	
Departure Estimate					0
		Mean			
Ponderosa Pine	Ponderosa Pine / LLF	3	15	3	56
Ponderosa Pine	Ponderosa Pine / LHF	53	85	53	
Pinyon – Juniper / Mountain Big Sagebrush / South	Juniper / HHW	45	65	45	80
Pinyon – Juniper / Mountain Big Sagebrush / South	Pinyon-Juniper / LLW	53	35	35	
Pinyon – Juniper / Mountain Big Sagebrush / South	Pinyon-Juniper / HHW	28	0	0	
Departure estimate					32

observed in the simulated time series, as shown in figure 4, with an Aspen – Birch High Cover, High Height succession class in a Spruce-Fir / Spruce-Fir / Lodgepole Pine PVT. Using the 90th percentile for our metric, we would estimate a relatively high departure – a seemingly incongruous result since current conditions are similar to the historical conditions.

We avoided using metrics that evaluate central tendencies (in other words the mean or median) because they can overlook or understate variation. For example, succession classes may have the same mean occurrence in the simulated historical record regardless of whether variability around the mean was low or high, and the resulting departure estimates would also be the same—even though the succession class occurrence for the current conditions might fall well within the simulated historical range when the data contain high variability. In short, the similarity calculation in the FRCC Guidebook approach is very sensitive to the metric used to represent reference condition time series data, and we expect that departure estimates for Zones 16 and 19 would look very different if other metrics were used.

An additional limitation to spatial application of the FRCC Guidebook approach is that illogical calculations can result. Specifically, we must select a single value to represent the percent of each succession class occupying a PVT across a time series. Because these selected values are not likely to occur at the same time interval (as in the temporal snapshot approach illustrated in fig. 7A), the sum of the area for all succession classes in a PVT will not equal 100 percent. In a simple hypothetical example, an LRU consists entirely of one PVT with three succession classes occurring across the simulated time series such that their 90th percentiles are: 65 for succession class A in year 150; 40 for class B in year 4,550; and 20 for class C in year 7,050. The total percent area for the reference conditions sums to 125 percent — an area greater than the possible size of an LRU. Table 9 also demonstrates that, for a given PVT, the sum of the succession class areas does not necessarily total 100 percent, such as in the case of the Ponderosa Pine PVT where, using the 90th percentile as the reference condition metric, the sum of the succession classes totals 150 percent. Such nonsensical results in the total summed area occur regardless of the metric used. For example, in table 9, the sum of succession classes for the Ponderosa Pine PVT, using the mean as the reference condition, was 56 percent. These incongruities do not occur in the field implementation of the FRCC Guidebook field procedures (Hann and others 2004) because reference conditions are estimated for a discrete point in time. In

the simulation environment, however, we encountered the problem because we applied the FRCC field-based procedures to a time series of data. Despite the illogical calculations in our FRCC Guidebook implementation, departure estimates were constrained to values from 0 to 100 because the calculation does not rely on total area, but instead uses the value for the least abundant succession (the smaller of reference or current conditions) to determine similarity and ultimately the departure estimate.

Another problem — stemming from the requirement of using a point statistic to represent reference conditions — is that departure estimates are sensitive to stochasticity in the LANDSUMv4 simulations. Because the LANDSUMv4 model includes stochastic processes in the simulation of fire and vegetation processes, the likelihood of a rare event increases with greater simulation time. Consequently, departure estimates could be inconsistent between LANDSUMv4 runs and, potentially, substantially different, depending on simulation length. For example, a catastrophic fire may not occur during a 4,000-year simulation but is more likely to occur during a 5,000-year simulation. Use of the 90th percentile to represent reference conditions for Zone 19 helped minimize the potential effects of rare disturbances on the upper range of succession class distributions. Because point statistics cannot completely represent the full range and variability of a data set, the other possible metrics (median, mean, 90th percentile, etc.) would also be limited in their ability to moderate the effects of extreme stochastic events and would only impose different biases.

A final limitation of the FRCC Guidebook approach relates to the fact that the number of succession classes in a PVT affected the calculation of the departure index. That is, greater complexity in the succession models used to model reference conditions for each PVT led to an increase in the FRCC departure index. As the succession pathway complexity increased in the simulated historical data, the percent area occupied by any one succession class became dispersed across more classes, leading to a lower percent area for each individual class over the simulation period. Lower area values for each succession class leads to lower similarity indices when comparing reference conditions to the current, and consequently higher, departure estimates (see table 2 for examples of similarity and departure calculations). The effect of PVT succession pathway complexity on departure estimates is also demonstrated in the departure maps for Zone 16, in which the three spatial domains of mapping zone, simulation landscapes, and LRUs

were explored (figs. 7B-7D). The number of succession classes per PVT in the reference conditions was highest in the zonal spatial domain, followed by the simulation landscapes domain, and lowest in the LRU domain; correspondingly, the departure estimates were highest in the largest spatial domain (zone) and lowest in the smallest (LRU). The effect of PVT succession pathway complexity on departure estimates highlights the need to identify ways to standardize succession pathways across all areas of consideration.

Strengths and Limitations of the HRVStat Approach

The HRVStat approach statistically compares current succession class distributions to simulated historical distributions, integrating every observation of PVT and succession class as they fluctuate across landscapes in the time-series. The data sets for these analyses were complex: the number of PVTs and succession classes occurring within any one LRU ranged from 1 to approximately 220, and each of these classes varied in percent area for each landscape reporting interval across the time series. HRVStat was able to incorporate the variance structure within the entire time-series of this highly dimensional data set to produce a measure of departure using the best linear approximation approach and estimate an observed significance for measuring the evidence for departure estimates (Steele and others, in preparation).

One limitation of this approach was the requirement by HRVStat for certain characteristics in the simulated historical data set. As discussed above, an adequate reference time series for HRVStat requires minimal temporal autocorrelation, stationary processes in vegetation class distributions, and a sufficiently long record. These requirements led to longer simulation times, larger data sets, and higher computational demands. However, the overall quality of the resulting data sets was enhanced, enabling the HRVStat approach to provide results with reasonable statistical rigor (Steele and others, in preparation).

In turn, statistics for HRVStat were developed that were specific to the simulated historical data set and that explicitly recognized the stochasticity that was intrinsic to LANDSUMv4. As discussed above, the LANDSUMv4 model simulates disturbance stochastically such that the resulting vegetation composition in a landscape will vary somewhat between repeated simulations and with longer simulation periods as the likelihood increases for rare and extreme disturbance events (such as a catastrophically large fire). The HRVStat departure statistic accommodates such stochasticity because it incorporates

every observation in the historical record. Specifically, stochastic differences between simulation runs will produce different vegetation distributions, possibly including unusual vegetation compositions resulting from extreme disturbances. However, because the departure statistic emphasizes dominant patterns by integrating all observations, departure estimates should be relatively robust to rare, extreme disturbance events.

We suspect a limitation in the statistical calculations of HRVStat because the number of PVT and succession class combinations within any LRU affects departure estimates – a problem also apparent with the FRCC Guidebook approach but with opposite effects. As the number of PVT-succession class combinations increased within LRUs, estimates of departure by HRVStat tended to decrease. This observation is based on a cursory examination of an assortment of LRUs and a general comparison of forested versus non-forested areas. In evaluating various LRUs in zones 16 and 19, we generally found lower departure in LRUs with few PVTs and simple succession pathways, as opposed to the higher departure found in LRUs with more complex vegetation composition. Comparisons of forested to non-forested areas showed that forest PVTs, which generally had more classes in their succession pathways, also had lower departure estimates. However, the lower departure estimates in forest PVTs may also be attributed to the generally longer fire return intervals because the effects of fire exclusion would be less evident since fewer intervals would have been missed over the last century and the process of departure from historical vegetation composition would be slower than in those PVTs with more rapid succession and disturbance processes. Alternatively, we may simply be better able to model forested systems than non-forested systems because more information exists describing vegetation and disturbance (particularly fire) processes in forests (Long and others, Ch. 9). As with the FRCC Guidebook approach, the influence of succession pathway complexity on HRVStat departure estimates warrants further evaluation and should include exploration of techniques to standardize the succession pathways or parameters in the multivariate statistics of the HRVStat approach.

Comparison of Approaches

We categorized our FRCC and HRVStat departure estimates into three classes to compare results with the earlier nationwide coarse-scale (1-km) mapping project (Hardy and others 2001; Schmidt and others 2002). For Zone 16, the HRVStat map showed little correspondence to the coarse-scale map, both in terms of patterns

observed and relative area in each class (fig. 20; table 5). Among the three FRCC Guidebook maps produced for Zone 16, the FRCC map based on the LRU spatial domain corresponded best to the coarse-scale map and showed similar patterns of low and moderate departures (FRCC 1 and 2) throughout the zone (figs. 7D and 20). For Zone 19, overall patterns of both the HRVStat and FRCC Guidebook maps were relatively different from those of the coarse-scale map (fig. 21). However, some correspondences existed between the coarse-scale and FRCC Guidebook maps, with high departure observed in the northern region of Zone 19. We did not compare these maps in any quantitative detail because the coarse-scale map was intended for use at the regional level. Furthermore, the accuracy in any of the maps was not known, and an extensive field campaign would be needed to evaluate the accuracy of maps such as these. Moreover, the thresholds used to categorize departure estimates into three classes are arbitrary, and if different thresholds were used, completely different patterns in the maps of FRCC and classified HRVStat departure would result.

To avoid the classes imposed by the FRCC Guidebook method, we examined the unclassified departure maps produced by the HRVStat and FRCC Guidebook methods and compared the distributions of continuous departure estimates. Figure 9 shows frequency distributions of departure estimates using the HRVStat and FRCC Guidebook methods (with LRUs as the spatial domain), and figures 7, 10A, 11A and 12A show maps of departure for Zones 16 and 19. Generally speaking, compared to the HRVStat approach, distributions of departure estimates for each zone were dominated by higher values using the FRCC Guidebook approach (fig. 9). In terms of spatial pattern, some similarities were apparent in the southerly portions of Zone 16 (figs. 7D AND 11A). Zone 19 showed more spatial pattern correspondences in that higher departure estimates were observed in the northern portions of the zone (in the North Fork Flathead River Valley and along the Rocky Mountains' eastern front) and in the central part of the zone (in the Clark Fork River Valley and eastern prairie of Montana) (figs. 10A and 12A). We suspect that the greater correspondence in Zone 19 resulted from using the 90th percentile metric instead of 90 percent of maximum to represent reference conditions in the FRCC Guidebook approach. As in the case of the FRCC / classified HRVStat departure maps, we do not have field validation data with which to assess which departure index is most effective. At best, we can qualitatively look for consistency between map results to obtain an overall picture of vegetation conditions across broad regions.

Consistent evidence of ecosystem change from these two departure maps can serve to highlight landscapes that have potentially undergone extensive ecological change. Additional information, such as site-specific field data and expert opinions, could supplement the departure estimates to evaluate how to best manage an ecological system (Landres and others 1999). It is important to note, however, that similar measures from the different approaches could also signify that the measures are simply both equally erroneous.

Dissimilarity between results from the two departure methods reveals potential weaknesses in both approaches. For example, departure estimates were different in Zone 16's Uinta Mountains in areas dominated by the Spruce-Fir / Spruce-Fir / Lodgepole Pine PVT – a PVT with a complex succession pathway. Figure 22 shows succession class distributions in an LRU dominated by that PVT, which is typical for this area of the Uintas. In the reference conditions, LRUs were occupied by as many as 22 succession classes, whereas only a few classes dominated the landscape under current conditions. The HRVStat method tended to produce low departure estimates for LRUs in the Uintas, resulting potentially from the abundance of succession classes in the reference conditions. Conversely, the FRCC Guidebook approach tended to produce high departure estimates in these LRUs because the percent area in any one succession class of these complex PVTs was reduced since the total area was spread across many succession classes. As previously mentioned, both methods require further refinement to ensure that departure estimates are not biased by the complexity of the succession class pathways.

Departure Estimates by Fire Return Intervals

We compared departure estimates by fire return interval classes in a manner similar to that used in the evaluations conducted in the coarse-scale project (Schmidt and others 2002). For both zones 16 and 19, we found that departure estimates were higher in areas with shorter fire return intervals. Similarly, Schmidt and others (2002) generally found that landscapes with estimated historical fire return intervals of 100-years or less had higher proportions of landscapes categorized as FRCC 3 (analogous to classified HRVStat departure-3), whereas areas with fire return intervals of 200-years or more had the least proportion of highly departed landscapes. We expect that the impacts of fire exclusion during the past 100 years are more evident in areas that historically had more frequent fires because such ecosystems have missed more fire return intervals

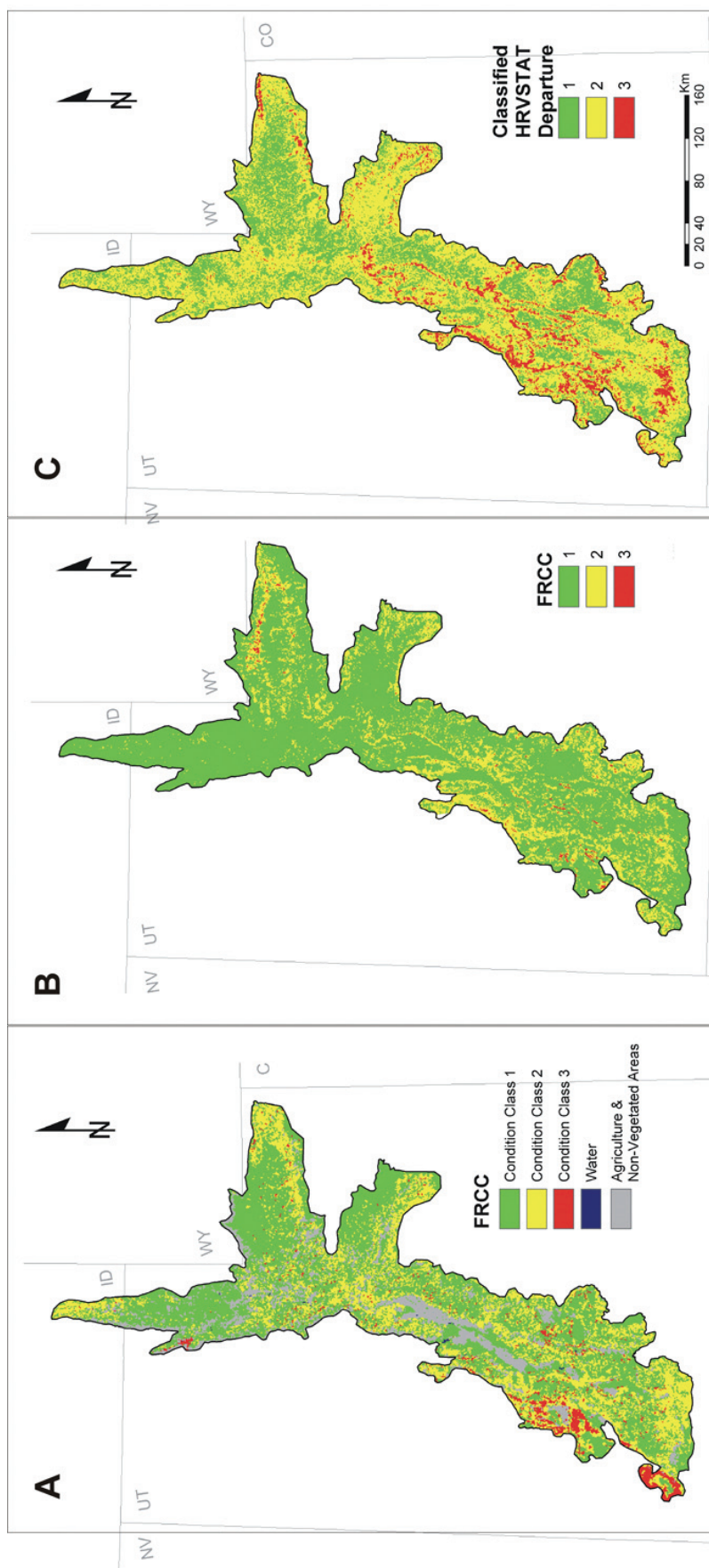


Figure 20—Comparisons between (A) FRCC estimated by Schmidt and others 2002, (B) FRCC calculated using the FRCC Guidebook method, and (C) classified HRVStat departure for Zone 16.

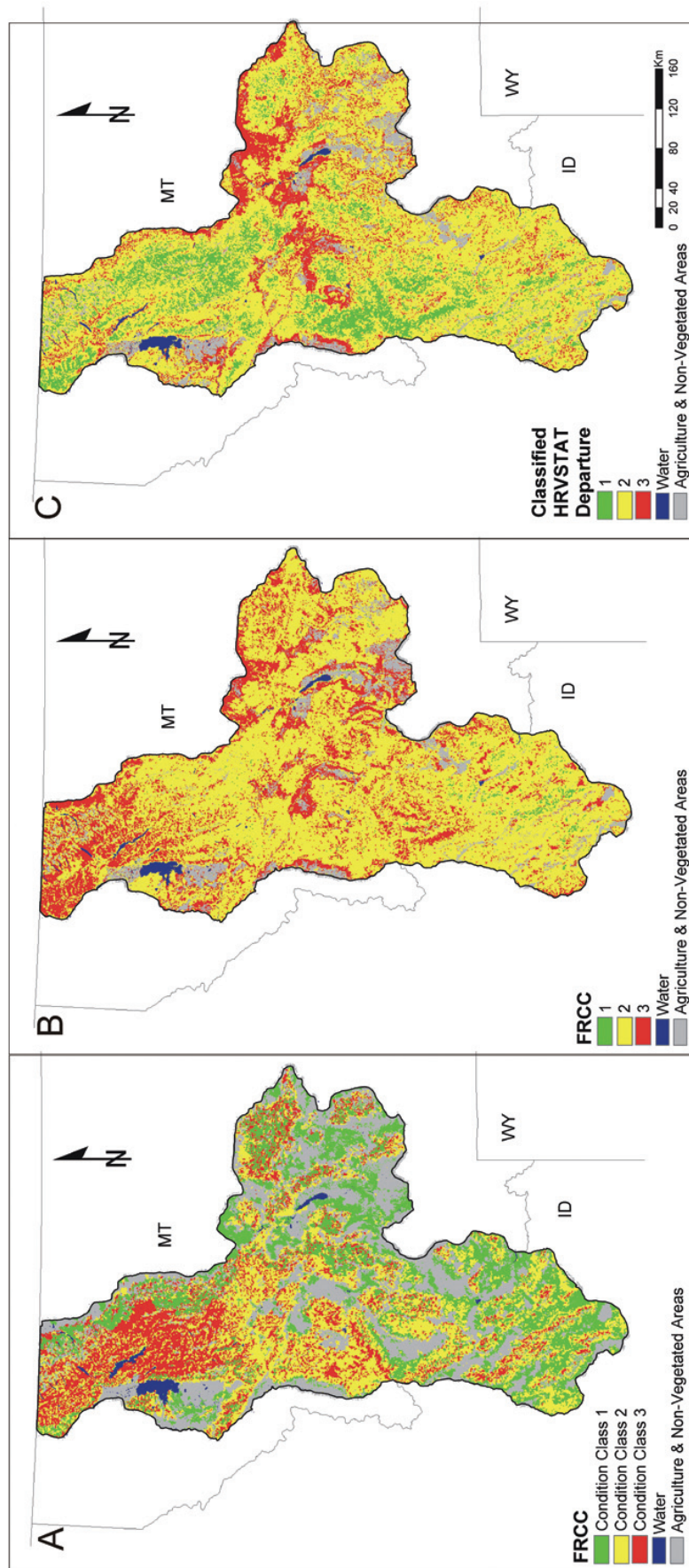


Figure 21—Comparisons between (A) FRCC estimated by Schmidt and others 2002, (B) FRCC calculated using the FRCC Guidebook method, and (C) classified HRVStat departure for Zone 19.

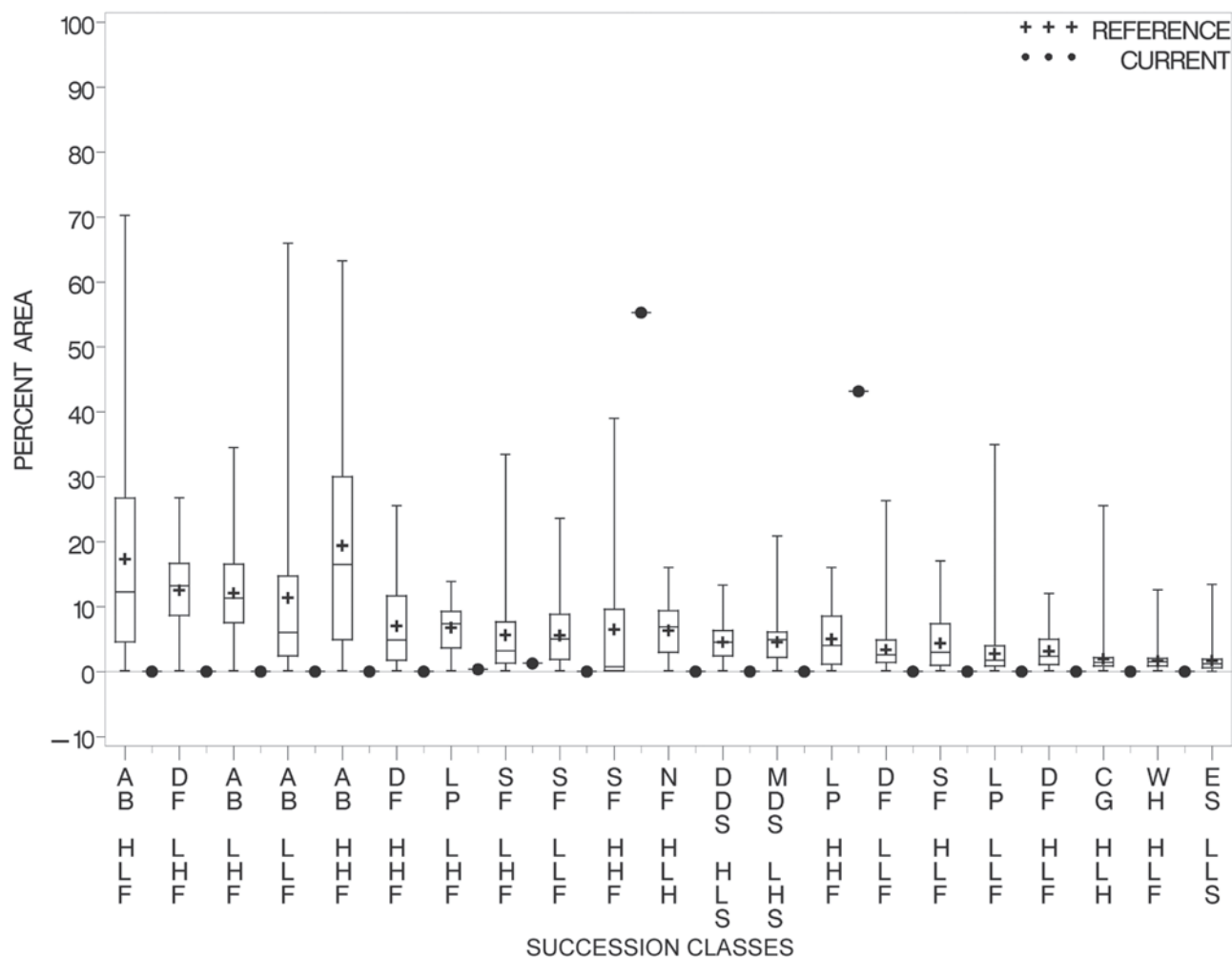


Figure 22 – Distribution of succession classes by percent area under reference and current vegetation conditions for the Spruce – Fir / Spruce – Fir / Lodgepole Pine PVT that dominates a landscape reporting unit in the Uinta Mountain Range of Zone 16. See table 7 for explanation of succession class codes.

and, as a result, have become more highly departed in their vegetation composition than systems with longer fire return intervals.

However, this assessment is predicated on the assumption that our understanding and simulation of historical fire return intervals is reasonably accurate. Indeed, fire history in different vegetation types may be poorly understood, and considerable uncertainty may exist for describing fire frequencies in some ecosystems (Baker and Ehle 2001; Baker and Shinneman 2004). For example, pinyon-juniper woodlands have been described by some as having a frequent, low severity fire regime (Brown and others 2001; Gottfried and others 1995; West 1999;), while others identify the vegetation type

as having a high-severity (Floyd and others 2000) and less frequent fire regime (Baker and Shinneman 2004). Another example can be found in ponderosa pine forests, where fire return intervals were typically reported as 2-25 years, but recent work suggests that return intervals may range between 22 and 308 years (Baker and Ehle 2001). Such uncertainty in fire history information emphasizes the need for thorough evaluations of the best available data to determine the appropriate data for inclusion in LANDSUMv4 simulations. If we assume that fire return intervals that are shorter than their actual intervals, we are likely to overestimate departure; conversely, if the assumed fire return intervals are longer than the actual, departure will likely be underestimated.

Recommendations for National Implementation

Before departure indices are computed for the national implementation of the LANDFIRE Project, the limitations of each approach need to be addressed, or at least recognized. Specifically, the effect of succession pathway complexity on departure estimates in both approaches should be evaluated. To ensure consistency across the nation, we propose using a simple, standardized model with a limited number of succession stages (for example, only five succession classes per PVT). Such a set structure may more closely characterize information on vegetation structure and fire regimes available across the nation. Also, limitations inherent to the FRCC Guidebook approach need to be addressed; these include: 1) the inability to capture the range and variability across all succession classes, 2) inconsistencies in area comparisons between current and reference landscapes, and 3) potential inconsistencies in departure estimates with longer or repeated LANDSUMv4 simulations. Additionally, if multiple departure maps are developed using different approaches, instructions must be provided for the interpretation and application of the maps both on a nationwide basis and at the local level. Furthermore, prior to national implementation, a policy decision must be made regarding the treatment of certain land cover types for modeling reference conditions and estimating departure. As discussed above, inclusion of immutable land cover types (urban, agriculture, water, barren, and snow/ice) in departure estimates can mask ground conditions and conceal the need to restore departed landscapes or to conserve healthy landscapes.

Another consideration for national implementation is the use of other ways to measure landscape condition that describe landscape configuration instead of landscape composition. Landscape configuration depicts the physical distribution or spatial character of patches within the landscape (McGarigal and Marks 1995). Such patch-based metrics can be used to identify landscapes that have become highly fragmented and possibly beyond their historical distributions of patches within landscapes (Spies and others 1994; Wallin and others 1996), and these metrics include patch size, shape, density, and relative location (Farina 2000). We did not use these metrics in the LANDFIRE Prototype Project because they are computationally intensive, but if better computer resources become available for national implementation, such metrics may be informative and preferable.

Research Recommendations

In developing methods for the LANDFIRE Prototype, a number of questions emerged that require further research before implementing LANDFIRE across the nation. We first describe recommended research pertaining to the HRVStat approach and then propose a series of other lines of research.

Adequate simulation of historical reference conditions is a key factor in developing HRVStat statistics. Two main factors determine the adequacy of the LANDSUMv4 simulations for generating historical reference conditions: (1) sufficient number of sampling observations and (2) adequate spatial representation. Prior to executing LANDSUMv4 simulations for zones 16 and 19, we conducted analyses to address these two factors. We focused on developing the best data sets of simulated historical reference conditions, given our time constraints and computer resources. Other alternatives for producing simulated historical data sets should be explored as described below.

Our initial evaluations of sample size found that 200 observations from LANDSUMv4 simulations would adequately describe simulated historical landscape dynamics. However, it is important to ensure that enough sampling observations are reported to estimate the effects of periodic rare and large fire events. For example, infrequent catastrophic fires maintained large patches of old-growth ponderosa pine in a non-equilibrium state in the Black Hills of South Dakota and Wyoming (Shinneman and Baker 1997). If we under-sample LANDSUMv4 simulations with such fire regimes, we may observe only one dominant vegetation condition and miss a different state that was an important component of historical conditions. If that unobserved state is now the current condition of the landscape, we would overestimate departure and underestimate the observed significance level (that is, describe evidence for departure as higher than its true value). We suggest further analysis that examines the sensitivity of departure statistics to the number of sampling observations, given a fixed current landscape.

An additional issue related to sample size involves the way observations are sampled in simulations and the influence on temporal autocorrelation. We sampled data within one simulation at reporting intervals that were determined long enough to minimize temporal autocorrelation. An alternative approach is to run multiple simulations at shorter time periods, sampling only once from each simulation. These separate executions

with different random number streams would ensure independence in sampling observations and eliminate any chance of temporal autocorrelation. We recommend comparing departure statistics from one long simulation to many shorter simulations (for example, a 10,000-year simulation with 50-year reporting intervals versus 200 simulations of 1,000-year length) to evaluate the influence of temporal autocorrelation. We anticipate that any differences detected would primarily affect the observed significance level. That is, the observed significance from one long simulation would be smaller than that produced from many shorter simulations because the number of independent observations and therefore degrees of freedom will be less where autocorrelation exists. If temporal autocorrelation within reporting intervals does substantially influence observed significance level estimates, we suggest exploring additional statistical techniques to minimize the effects before implementing the approach of multiple simulations. Multiple simulations, although potentially preferable, would prove costly because of the need for substantially longer simulation periods and could therefore be prohibitive to national implementation of the LANDFIRE Project.

Temporal autocorrelation may also affect departure statistics for landscapes that express a periodicity in their vegetation characteristics matching the reporting interval. For example, if a PVT alternates between two succession classes at 50-year intervals and we sample at 50-year intervals, we may only observe one of those two succession classes. In this case, the observed departure would be underestimated and observed significance level would be overestimated. We suspect that the likelihood of coinciding vegetation and reporting intervals is low, but recommend exploring the use of a restricted randomization scheme to avoid this possibility. For example, we might choose random numbers between 50 and 10 to sample the simulation data and generate reporting intervals such as 50, 75, 90, and so on.

Besides the adequacy of sampling observations, satisfactory spatial representation of vegetation composition is vital to estimating departure and is influenced by two main components: 1) LANDSUMv4 simulations and 2) the spatial grain of LRUs. In simulating historical vegetation conditions using LANDSUMv4, the main concern regarding spatial representation is simulating the full distribution of succession classes within a PVT on the landscape and, specifically, ensuring detection of all states that may currently exist on the landscape. Some of the primary LANDSUMv4 input components are fire regime parameters, fire size, and landscape

simulation size (Pratt and others, Ch. 10). Accordingly, a given fire regime and fire size will have an optimum landscape simulation size for simulating fire spread and the corresponding effects on succession. Sensitivity analyses on the scale of LRUs are needed to identify the appropriate sizes for estimating departure. As the size of LRUs decreases, temporal variability may increase in fire and vegetation characteristics. If LRUs are too small, we may observe a limited and highly variable distribution of succession classes within a stand than would be expected at the optimal size for describing its vegetation characteristics. Conversely, if LRUs are too large, important components within LRUs needing restoration or conservation could be missed. In performing these various sensitivity analyses, we expect to identify thresholds at a relatively narrow range of sizes, which will give the most effective estimates of departure. We also expect that these optimal sizes will vary from ecosystem to ecosystem, especially if fire regimes are very different, and this source of variation should be included in sensitivity analyses.

Other kinds of research are also critically needed to fully investigate the implications of calculating departure and determining FRCC. One line of research should focus on the implications of calculating departure from an array of possible methods, including the two presented here (FRCC Guidebook and HRVStat). Numerous limitations were noted, particularly in the FRCC Guidebook approach, in the methods for computing ecological departure, prompting the exploration of other departure methods. We have developed a computer program, called DEPART, that computes various other ecological indices of similarity, including Sorenson's Index, Jaccard's Index, and Similarity Ratio (Mueller-Dombois and Ellenberg 1974). Departure estimates determined from all these indices should be evaluated and compared for their sensitivity to and consistency in detecting vegetation change. A second line of research should pursue the development of field methods that can be used to validate the departure and FRCC maps created by the LANDFIRE Project. A final research track should investigate the implications of collapsing departure measures into an ordinal classification, as with the FRCC and classified HRVStat departure groupings. Specifically, identification of appropriate breakpoints should be based on standardized methods to best represent departure estimates and avoid arbitrary classifications, which may skew assessments of landscapes.

Conclusion

Spatial data describing historical and existing conditions were successfully implemented in both the Inter-agency FRCC Guidebook approach and the HRVStat approach to quantify ecological departure across two large western study areas. Each method for quantifying ecological departure had strengths and limitations. The FRCC Guidebook approach proved relatively easy to use, but was not statistically rigorous. Conversely, the HRVStat approach was computationally complex, but provided a statistically sound measurement of the departure of current conditions from simulated historical conditions. While each approach has promise, more research related to the application of fire history information and the spatial units for measuring departure is needed to develop a consistent map of ecological departure across the United States.

For further project information, please visit the LANDFIRE website at www.landfire.gov.

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Appendix 11-A—Names of PVT codes for zones 16 and 19

Zone 16 PVT code	Zone 16 PVT name	Zone 19 PVT code	Zone 19 PVT name
1601	Spruce Fir – Blue Spruce	1902	Western Redcedar
1602	Spruce Fir – Blue Spruce – Lodgepole Pine	1914	Grand Fir – Rocky Mtn. White Fir
1603	Spruce Fir – Spruce Fir	1920	Spruce – Fir / Western Larch
1604	Spruce Fir – Spruce Fir – Lodgepole Pine	1921	Spruce – Fir / Douglas-fir
1611	Grand Fir – White Fir	1922	Spruce – Fir / Timberline Pine
1612	Grand Fir – White Fir - Maple	1924	Spruce – Fir / Lodgepole Pine
1621	Douglas-fir – Timberline Pine	1930	Douglas-fir / Western Larch
1622	Douglas-fir – Douglas-fir	1931	Douglas-fir / Ponderosa pine
1623	Douglas-fir – Lodgepole Pine	1932	Douglas-fir / Lodgepole Pine
1631	Timberline Pine	1934	Douglas-fir / Timberline Pine
1632	Ponderosa Pine	1936	Douglas-fir / Douglas-fir
1633	Lodgepole Pine	1940	Lodgepole Pine
1634	Aspen	1942	Ponderosa Pine
1641	Pinyon Juniper–Mtn. Big Sagebrush - North	1944	Timberline Pine / Limber Pine
1642	Pinyon Juniper–Mtn. Big Sagebrush - South	1946	Timberline Pine / Whitebark Pine
1643	Pinon Juniper-Wyoming-Basin Big Sagebrush-North	1950	Rocky Mountain Juniper
1644	Pinyon Juniper-Wyoming-Basin Big Sagebrush-South	1952	Riparian Hardwood
1645	Pinyon Juniper – Mountain Mahogany	1960	Riparian Shrub
1646	Pinyon Juniper – Gambel Oak	1962	Mountain Mahogany
1651	Blackbrush	1964	Dry Shrub
1652	Salt Desert Shrub	1965	Dry Shrub/Conifer
1653	Warm Herbaceous	1970	Dwarf Sagebrush Complex
1654	Cool Herbaceous	1971	Dwarf Sage/Conifer
1661	Dwarf Sagebrush	1972	Mtn. Big Sagebrush Complex
1662	Wyoming-Basin Big Sagebrush	1973	Mtn. Big Sage/Conifer
1663	Mountain Big Sagebrush	1974	Threetip Sagebrush
1671	Riparian Hardwood	1975	Threetip Sage/Conifer
1672	Riparian Shrub	1976	Wyoming/Basin Big Sagebrush Complex
1673	Wetland Herbaceous	1977	Wyoming/Basin Big Sage/Conifer
1680	Alpine	1980	Wetland Herbaceous
1690	Open Water	1982	Alpine
1691	Urban - Developed	1984	Fescue Grasslands
1692	Barren	1985	Fescue Grasslands/Conifer
1693	Agricultural	1986	Bluebunch Wheatgrass
1694	Snow - Ice	1987	Bluebunch Wheatgrass/Conifer
		1990	Open Water
		1991	Urban - Developed
		1992	Barren
		1993	Agricultural
		1994	Snow - Ice

Appendix 11-B

Mean and standard deviation (SD) of departure estimates and a ranking of the five PVTs with the greatest departure across each of the three spatial domains of mapping zone (Zone), simulation landscape (SL), and landscape reporting unit (LRU) across Zone 16 using the FRCC Guidebook method. Overall, the PVTs with the highest departure were similar across the three spatial domains, but departure values generally decreased as the size of the spatial domain decreased (from Zone to SL to LRU). For the smallest spatial domain of LRU, departure values for each PVT were generally higher using the FRCC methods.

PVT	Zone level mean	Zone level rank	Zone level SD	SL- level mean	SL- level rank	SL- level SD	LRU- level mean	LRU- level rank	LRU- level SD
Agricultural	28		15	20		11	13		8
Alpine	37		17	22		14	11		7
Aspen	54		9	31		11	11		9
Barren	41		17	32		14	17		9
Blackbrush	54		16	31		15	10		9
Cool Herbaceous	61		13	45		12	28		9
Douglas-fir / Douglas-fir	64		9	44		13	19		14
Douglas-fir / Lodgepole Pine	69	3	7	53	3	12	33	4	15
Douglas-fir / Timberline Pine	77	1	15	65	1	18	42	1	18
Dwarf Sagebrush	55		12	35		13	17		12
Grand Fir – White Fir	65		9	47		12	25		13
Grand Fir – White Fir / Maple	54		11	31		12	12		8
Lodgepole Pine	65		10	50		14	24		14
Mountain Big Sagebrush	63		9	41		13	14		13
Open Water	33		20	25		15	14		12
Pinyon – Juniper / Gambel Oak	62		12	39		15	21		13
Pinyon – Juniper / Mountain Big Sagebrush / North	62		8	42		10	23		11
Pinyon – Juniper / Mountain Big Sagebrush / South	75	2	8	57	2	11	36	2	15
Pinyon – Juniper / Mountain Mahogany	62		11	39		15	19		13
Pinyon – Juniper / Wy. – Basin Big Sagebrush / N	66		13	44		17	19		15
Pinyon – Juniper / Wy. – Basin Big Sagebrush / S	71	5	12	52	5	15	28		15
Ponderosa Pine	62		12	49		13	30		14
Riparian Hardwood	54		10	29		11	8		6
Riparian Shrub	56		17	40		15	19		10
Salt Desert Shrub	63		14	48		15	35	3	18
Spruce – Fir / Blue Spruce	66		9	48		12	26		13
Agricultural	28		15	20		11	13		8
Alpine	37		17	22		14	11		7
Aspen	54		9	31		11	11		9
Barren	41		17	32		14	17		9
Blackbrush	54		16	31		15	10		9
Spruce – Fir / Blue Spruce / Lodgepole Pine	68	4	12	53	4	17	31	5	17
Spruce – Fir / Spruce – Fir	67		9	51		13	24		14
Spruce – Fir / Spruce – Fir / Lodgepole Pine	67		11	49		14	23		17
Urban–Developed	24		13	17		8	13		6
Warm Herbaceous	56		10	40		11	26		11
Wetland Herbaceous	56		13	36		16	22		12
Wyoming – Basin Big Sagebrush	63		13	38		14	17		13

Appendix 11-C

Mean and standard deviation (SD) of departure estimates and ranking (up to 5) for each PVT for the landscape reporting unit (LRU) spatial domain across Zone 19 using the FRCC Guidebook method. Departure values for each PVT were generally higher than those estimated using HRVStat methods.

PVT	LRU-level mean	LRU-level rank	LRU-level SD
Alpine	43.94		15.07
Bluebunch Wheatgrass	62.42	1	19.56
Bluebunch Wheatgrass / Conifer	47.71		16.03
Douglas-fir / Douglas-fir	33.96		13.80
Douglas-fir / Lodgepole Pine	36.57		14.09
Douglas-fir / Ponderosa Pine	40.51		13.88
Douglas-fir / Timberline Pine	35.38		13.86
Douglas-fir / Western Larch	42.35		12.29
Dry Shrub	57.61	2	20.07
Dry Shrub / Conifer	41.69		14.26
Dwarf Sage / Conifer	40.28		12.44
Dwarf Sagebrush Complex	48.32	5	23.50
Fescue Grasslands	47.97		16.88
Fescue Grasslands / Conifer	41.42		14.54
Grand Fir - White Fir	43.62		13.68
Lodgepole Pine	43.34		14.10
Mountain Mahogany	41.14		14.56
Mountain Big Sage Complex / Conifer	39.18		15.07
Mountain Big Sagebrush Complex	31.65		16.21
Ponderosa Pine	45.44		15.68
Riparian Hardwood	48.97	4	16.16
Riparian Shrub	44.01		15.75
Rocky Mountain Juniper	43.52		16.29
Spruce – Fir / Douglas-fir	36.87		14.03
Spruce – Fir / Lodgepole Pine	47.81		15.80
Spruce – Fir / Timberline Pine	42.42		15.72
Spruce – Fir / Western Larch	39.60		17.27
Threetip Sagebrush / Conifer	35.63		11.28
Threetip Sagebrush	30.74		13.62
Timberline Pine / Limber Pine	36.30		13.88
Timberline Pine / Whitebark Pine	34.95		11.92
Western Redcedar	52.22	3	14.98
Wetland Herbaceous	45.84		15.81
Wy. – Basin Big Sage Complex / Conifer	40.57		14.91
Wy. – Basin Big Sagebrush Complex	38.66		17.12

Appendix 11-D

Average and standard deviation for departure and observed significance by PVT for Zone 16, estimated using the HRVStat method, percent of classified HRVStat departure groups by PVT across the zone, and percent of zone composed of that PVT. Departure values for each PVT were generally lower than those estimated using FRCC methods.

PVT	Departure		Observed significance		Classified HRVStat departure			% of zone
	Mean	Std. dev.	Mean	Std. dev.	1	2	3	
Pinyon – Juniper / Mountain Big Sagebrush / South	0.28	0.24	0.01	0.01	1.00%	4.98%	25.77%	5.22%
Pinyon – Juniper / Wy. – Basin Big Sagebrush / S.	0.12	0.16	0.01	0.03	9.47%	19.34%	23.66%	16.47%
Salt Desert Shrub	0.29	0.36	0.03	0.10	1.47%	1.57%	9.69%	2.13%
Grand Fir – White Fir	0.09	0.13	0.02	0.05	4.17%	8.68%	5.87%	7.02%
Ponderosa Pine	0.15	0.17	0.01	0.02	0.78%	3.12%	4.73%	2.48%
Douglas-fir / Douglas-fir	0.12	0.16	0.02	0.06	1.78%	3.76%	4.42%	3.17%
Pinyon – Juniper / Wyo. – Basin Big Sagebrush / N.	0.13	0.17	0.02	0.07	1.39%	2.82%	3.82%	2.43%
Pinyon – Juniper / Gambel Oak	0.17	0.20	0.01	0.04	0.81%	1.51%	3.63%	1.44%
Mountain Big Sagebrush	0.05	0.09	0.03	0.07	8.66%	9.39%	2.76%	8.67%
Wyoming – Basin Big Sagebrush	0.06	0.13	0.04	0.09	4.88%	4.45%	2.63%	4.45%
Dwarf Sagebrush	0.06	0.12	0.06	0.14	5.95%	3.95%	2.29%	4.48%
Pinyon – Juniper / Mountain Mahogany	0.17	0.17	0.01	0.02	0.32%	1.30%	2.26%	1.06%
Pinyon – Juniper / Mountain Big Sagebrush / North	0.15	0.17	0.01	0.01	0.31%	1.50%	2.08%	1.16%
Riparian Hardwood	0.06	0.11	0.02	0.06	1.74%	2.44%	0.98%	2.11%
Grand Fir – White Fir / Maple	0.06	0.09	0.01	0.03	1.39%	3.49%	0.75%	2.61%
Urban–Developed	0.08	0.16	0.02	0.06	0.51%	0.87%	0.64%	0.74%
Agricultural	0.04	0.10	0.02	0.07	1.36%	2.29%	0.60%	1.87%
Douglas-fir / Timberline Pine	0.13	0.14	0.01	0.02	0.18%	0.61%	0.60%	0.47%
Aspen	0.04	0.08	0.04	0.09	2.37%	2.09%	0.55%	2.07%
Barren	0.04	0.07	0.04	0.10	3.19%	2.80%	0.51%	2.76%
Spruce – Fir / Blue Spruce	0.05	0.09	0.05	0.10	1.51%	1.05%	0.41%	1.15%
Spruce – Fir / Spruce – Fir / Lodgepole Pine	0.01	0.03	0.09	0.15	24.51%	8.81%	0.33%	13.25%
Spruce – Fir / Spruce – Fir	0.02	0.03	0.09	0.14	15.04%	5.14%	0.22%	7.97%
Riparian Shrub	0.03	0.08	0.07	0.13	1.62%	0.77%	0.22%	1.00%
Warm Herbaceous	0.04	0.08	0.04	0.09	0.95%	0.69%	0.17%	0.73%
Spruce – Fir / Blue Spruce / Lodgepole Pine	0.03	0.07	0.05	0.11	0.63%	0.54%	0.11%	0.54%
Open Water	0.03	0.09	0.19	0.35	0.67%	0.35%	0.10%	0.43%
Wetland Herbaceous	0.04	0.10	0.05	0.10	0.34%	0.25%	0.10%	0.27%
Blackbrush	0.03	0.07	0.10	0.15	0.68%	0.22%	0.06%	0.36%
Douglas-fir / Lodgepole Pine	0.02	0.05	0.07	0.12	0.31%	0.14%	0.02%	0.19%
Timberline Pine	0.06	0.07	0.02	0.04	0.03%	0.04%	0.01%	0.03%
Lodgepole Pine	0.02	0.02	0.05	0.10	1.08%	0.75%	0.00%	0.81%
Cool Herbaceous	0.01	0.02	0.06	0.11	0.23%	0.11%	0.00%	0.14%
Snow – Ice	0.01	0.05	0.12	0.20	0.00%	0.00%	0.00%	0.00%
Alpine	0.01	0.02	0.11	0.15	0.66%	0.19%	0.00%	0.33%

Appendix 11-E

Average and standard deviation for departure and observed significance by PVT for Zone 19, estimated using the HRVStat method, percent of classified HRVStat departure group by PVT across the zone, and percent of zone composed of that PVT. Departure values for each PVT were generally lower than those estimated using FRCC methods.

PVT	Departure		Observed significance		Classified HRVStat departure			% of zone
	Mean	Std. dev.	Mean	Std. dev.	1	2	3	
Bluebunch Wheatgrass	0.67	0.31	0.00	0.00	0.03%	4.16%	18.65%	6.09%
Wyoming – Basin Big Sagebrush Complex	0.22	0.29	0.02	0.10	9.28%	15.89%	13.80%	14.64%
Douglas-fir / Douglas-fir	0.17	0.22	0.01	0.04	5.65%	12.09%	8.17%	10.56%
Fescue Grasslands	0.53	0.31	0.01	0.00	0.02%	1.65%	5.10%	2.02%
Douglas-fir / Ponderosa Pine	0.23	0.26	0.01	0.02	0.49%	3.29%	4.04%	3.05%
Spruce – Fir / Western Larch	0.11	0.17	0.03	0.08	13.78%	8.45%	3.29%	8.25%
Ponderosa Pine	0.44	0.30	0.01	0.01	0.03%	0.85%	3.21%	1.14%
Mountain Big Sagebrush Complex	0.15	0.22	0.01	0.05	2.40%	6.16%	2.83%	5.09%
Riparian Hardwood	0.43	0.31	0.01	0.01	0.07%	1.33%	2.81%	1.42%
Dry Shrub	0.59	0.33	0.01	0.00	0.03%	1.13%	2.79%	1.27%
Douglas-fir / Lodgepole Pine	0.12	0.20	0.03	0.09	6.37%	4.27%	2.37%	4.21%
Spruce – Fir / Lodgepole Pine	0.09	0.17	0.06	0.11	17.97%	5.78%	2.03%	6.72%
Spruce – Fir / Douglas-fir	0.11	0.18	0.03	0.09	6.47%	4.10%	1.86%	4.02%
Riparian Shrub	0.34	0.30	0.01	0.01	0.07%	0.84%	1.49%	0.85%
Lodgepole Pine	0.10	0.17	0.05	0.12	7.16%	3.56%	1.45%	3.66%
Douglas-fir / Western Larch	0.15	0.19	0.01	0.02	0.42%	3.07%	1.44%	2.44%
Wetland Herbaceous	0.41	0.31	0.01	0.02	0.06%	0.68%	1.34%	0.71%
Douglas-fir / Timberline Pine	0.23	0.24	0.01	0.02	0.27%	1.25%	1.22%	1.12%
Mountain Big Sage Complex / Conifer	0.28	0.26	0.01	0.02	0.12%	0.81%	1.03%	0.76%
Spruce – Fir / Timberline Pine	0.05	0.10	0.07	0.14	26.14%	7.66%	0.96%	8.91%
Western Redcedar	0.37	0.28	0.01	0.00	0.01%	0.56%	0.94%	0.56%
Wy. – Basin Big Sage Complex / Conifer	0.32	0.28	0.01	0.01	0.05%	0.49%	0.92%	0.50%
Fescue Grasslands / Conifer	0.38	0.29	0.01	0.00	0.02%	0.44%	0.87%	0.46%
Bluebunch Wheatgrass / Conifer	0.49	0.29	0.01	0.00	0.00%	0.19%	0.77%	0.26%
Grand Fir- White Fir	0.19	0.19	0.01	0.00	0.01%	1.02%	0.65%	0.82%
Mountain Mahogany	0.31	0.23	0.01	0.00	0.01%	0.29%	0.46%	0.28%
Dwarf Sagebrush Complex	0.39	0.35	0.01	0.02	0.02%	0.29%	0.30%	0.25%
Dry Shrub / Conifer	0.25	0.23	0.01	0.01	0.03%	0.23%	0.26%	0.21%
Rocky Mountain Juniper	0.42	0.28	0.01	0.00	0.01%	0.11%	0.24%	0.12%
Threetip Sagebrush	0.13	0.21	0.01	0.05	0.27%	0.66%	0.21%	0.53%
Timberline Pine / Limber Pine	0.26	0.23	0.01	0.01	0.02%	0.14%	0.18%	0.13%
Timberline Pine / Whitebark Pine	0.11	0.13	0.01	0.02	0.11%	0.59%	0.11%	0.45%
Alpine	0.40	0.30	0.01	0.01	0.00%	0.03%	0.07%	0.03%
Threetip Sagebrush / Conifer	0.17	0.19	0.01	0.01	0.00%	0.03%	0.01%	0.02%
Dwarf Sagebrush Complex / Conifer	0.34	0.26	0.01	0.00	0.00%	0.00%	0.00%	0.00%