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DETECTING CHANGE IN FOREST SPATIAL PATTERNS FROM REFERENCE CONDITIONS

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Abstract. Timber harvest, fire suppression, road construction, and domestic livestock grazing have transformed spatial patterns of Interior Northwest forests. As a consequence, parameters of current disturbance regimes differ radically from historical regimes; present-day wildlife habitat distributions differ from historical distributions; and long-term survival of some native terrestrial species is uncertain. Public land managers are under increasing scientific and social pressure to mold existing forest spatial patterns to reflect those resulting from natural disturbance regimes and patterns of biophysical environments. However, knowledge of the characteristics of natural spatial patterns is unavailable.

Using a dichotomized ordination procedure, we grouped the 343 forested subwatersheds (mean area, 8000 ha) on the eastern slope of the Cascade Mountains in Washington State into ecological subregions by similarity of area in potential vegetation and climate attributes. We built spatially continuous ''historical'' (1938–1956) and ''current'' (1985–1993) vegetation maps for 48 randomly selected subwatersheds from aerial photo interpretations. From remotely sensed attributes, we classified cover types, structural classes, and potential vegetation types and attributed them to individual patches. We then estimated a reference variation (RV) in spatial patterns of patch types (cover type and structural class), by subwatersheds and five forested ecological subregions, using the 48 historical vegetation maps stratified by subregion and a spatial pattern analysis program. Finally, we compared the current pattern of an example subwatershed (MET_11) with the RV estimates of its corresponding subregion to illustrate how reference conditions can be used to evaluate the importance of spatial pattern change. By evaluating pattern changes in light of RV estimates (nominally, the sample median 80% range of a metric) and the full range of class and landscape metrics, we could identify both current and historical conditions of MET_11 that fell outside the RV. This approach gives land managers a tool to compare characteristics of present-day managed landscapes with reference conditions to reveal significant pattern departures, as well as to identify specific pattern characteristics that might be modified through management. It also provides a means to identify ''outlier'' conditions, relative to subregion RV estimates, that may occasionally be the object of pattern restoration activities.

Key words: biological diversity; change detection; disturbance; ecosystem management; forest spatial patterns; historical range of variability; natural range of variability; reference conditions; reference variation; restoration; spatial patterns.

INTRODUCTION

Landscape ecology is founded on the notion that landscape patterns at many scales influence ecosystem processes and functioning (Forman and Godron 1986, Urban et al. 1987; Turner 1989, 1990). For example, genetic and life history diversity among populations of native salmonids vary with the spatial and temporal patterns of their aquatic habitats (Lee et al. 1997). Thus, multiscale assessment of spatial pattern change is essential to understanding change in terrestrial or aquatic ecosystem functioning.

Borrowing from recent developments in conservation biology and landscape ecology, a key tenet of ecosystem management (Overbay 1992, Society of American Foresters 1993) is that native species have evolved within a context of natural disturbance regimes and the spatial patterns of habitats that were consequences of those regimes (Franklin 1980, Frankel and Soule 1981). Hence, the potential for survival of any given species may be diminished if temporal and spatial patterns of their habitats shift outside a natural range of variation, especially if shifts occur too quickly to allow adaptation or migration.

Managing ecosystems within a ''natural range of variation'' has been forwarded with appropriate caution as a scientifically defensible approach to conserving native species diversity and ecosystem processes (Mor-

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gan et al. 1994, Swanson et al. 1994, Landres et al. 1999). The approach provides an empirical basis for meeting societal objectives of producing sustainable flows of commodities from terrestrial habitats, while maintaining spatial patterns of vegetation that will support viable populations of native species, as articulated in the National Forest Management Act and Endangered Species Act. Lacking are explicit examples of characteristic spatial patterns and natural pattern variability of forest ecosystems. Knowledge of the variability of early 20th century forest patterns would provide a window through which managers could view characteristic features of sustainable ecosystems and would enhance understanding of the pattern–process interactions of contemporary ecosystems. We use the terms ''historical'' or ''recent historical'' to describe a time frame (1938–1956) that is relevant to current climatic conditions and contemporary forest ecosystem behavior. We use the terms ''natural'' or ''native'' when we refer to vegetation, disturbance regime, and environmental conditions that are minimally altered by 20th century management activities, but may reflect patterns or conditions resulting from interactions of aboriginal peoples with their environments.

Relationship to the interior Columbia basin assessment

In a recent ecological assessment, we sampled biophysical environments and vegetation conditions representative of each of the major forest and rangeland provinces of the interior Columbia River basin. We characterized recent historical and current vegetation composition and structure, and quantified change in vegetation spatial patterns and landscape vulnerability to fire, insect, and pathogen disturbances over the most recent 50–60 yr period, based on a stratified random sample of 337 subwatersheds (Hessburg et al. 1999, Ottmar et al., *in press*). Results of change analyses were pooled to province-scale strata, but high variability of environments pooled at that scale masked much of the change that had occurred. Grouping subwatersheds (sixth level in the hydrologic unit hierarchy) into smaller subregional strata based on similarity of ecological attributes, would partition environmental variation, thereby enabling estimation of spatial pattern reference conditions, and aid in evaluating the significance of change.

Here, we critically examine a subset of the Columbia basin study area, the eastern Washington Cascade Mountains. Objectives of the study were as follows: (1) to classify subwatersheds of the study area into ecological subregions, based on their similar composition of climate and potential vegetation attributes; (2) to estimate, for each subregion, reference variability of forest spatial patterns; and (3) to illustrate the use of reference conditions to evaluate the significance and meaning of landscape pattern changes. We base our work on four assumptions. First, that vegetation spatial patterns and disturbance patterns are closely linked with climate and environment. Second, that environmental composition of subwatersheds can be approximated using potential vegetation and climate attributes. Third, historical aerial photographic coverages portray vegetation conditions relevant to contemporary forest ecosystems. Fourth, the earliest historical aerial photographs reflect spatial pattern conditions that show the least alteration by resource management activities.

Alternative methods for estimating natural variation in spatial patterns

Two general approaches have been used to estimate natural variability of spatial patterns (Swanson et al. 1994). Both approaches assume that landscapes are comprised of unique ''patches'' (Brooks and Grant 1992*a*, *b*), and patches change state as a result of disturbance, succession, and stand dynamics processes. The first approach emphasizes delphic or empirical estimation of the area of patches belonging to a particular class (e.g., Caraher et al. 1992, U.S. Forest Service 1993, Hann et al. 1994, Lehmkuhl et al. 1994, O'Hara et al. 1994). Expert panels have been convened to characterize natural or reference variability of forest cover types, seral stages, or structural classes using limited data and expert opinion (Caraher et al. 1992, U.S. Forest Service 1993). Advantages of a delphic approach are economy and efficiency, but the validity of estimates is unknown. For example, Lehmkuhl et al. (1994) compared their empirically derived estimates of reference variation in area of seral stages with delphic estimates for the Grande Ronde basin in the Blue Mountains of Oregon (Caraher et al. 1992). They agreed on estimated early seral stage area (20–30% vs. 20–40%, respectively), but disagreed on area in late-seral park-like conditions (10–25% vs. 20–40%).

Via fire scar interpretation and cross dating, disturbance chronologies document historical disturbance frequency and severity, but inferences about associated vegetation spatial patterns are relatively crude (Arno and Sneck 1977, Arno 1980, McBride 1983, Fritts and Swetnam 1989, Arno et al. 1995). Spatial accuracy depends upon either regular or irregular distributions of often widely spaced observations. Similarly, via stem mapping, tree ring, and cohort analysis, stand reconstructions provide spatially precise information about composition and structure that emerged locally through time (Oliver and Larson 1996). However, because reconstructions are intensive and highly detailed, reconstructed areas are relatively small, often consisting of one to several patches, and inferences about broader landscape spatial patterns are tenuous.

A second area-specific approach is used when information about historical spatial patterns is not explicitly available or emphasized. Historical disturbance regime areas are mapped, and unique patch dynamics

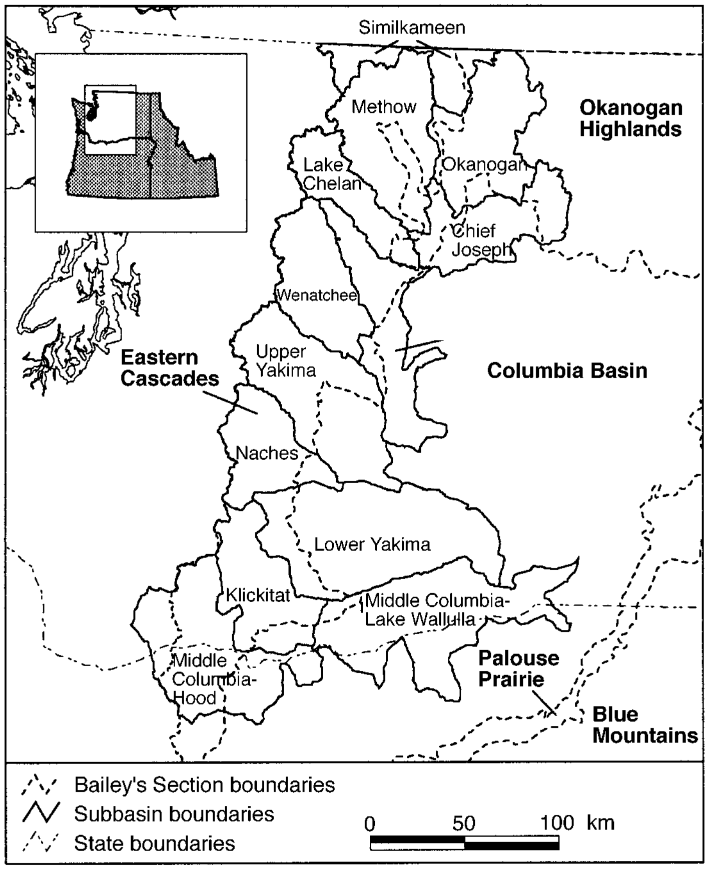

FIG. 1. Map of the subbasins and study area in Washington State.

are associated with regime areas (e.g., see Cissel et al. [1998]). In this issue, Cissel et al. (1999) further illustrate the disturbance regime approach. In our study, we employ an empirical estimation approach, and we expand on those methods here.

METHODS

Mapping ecological subregions

We constrained the study area to include all subwatersheds in the subbasins (mean area, 425 000 ha), shown in Fig. 1. Subwatersheds (Fig. 2) were used as basic landscape sampling units for two reasons: (1) studied landscapes must be large enough to avoid the problem of landscape pattern attribute correlation with size of analysis area (O'Neill et al. 1988, Turner 1989); and (2) delimiting landscapes by hydrologic boundaries enabled future use of data and results in integrated terrestrial and aquatic ecosystem analysis. In studies of forest patterns in western Washington, Lehmkuhl and Raphael (1993) found that sample estimates of landscape attributes changed asymptotically, rather than linearly, with area. Most pattern attributes differed significantly when landscape area increased from 2000 to 3250 ha, but few attributes differed in value when landscapes were within 3250–7325 ha. We used subwatersheds ≥4000 ha to avoid bias associated with smaller sampling units. Smaller subwatersheds were joined with an adjacent subwatershed.

Classes of four variables were attributed to a spatially continuous digital coverage of all study area subwatersheds in a geographical information system (GIS): potential vegetation group, mean annual daytime temperature, total annual precipitation, and average annual daytime shortwave radiative flux (hereafter, ''solar radiation'') for the 1989 weather year (Fig. 3). These data were available in continuous 1 or 2 km raster coverages for the study area.

In the broad-scale interior Columbia basin landscape assessment (Hann et al. 1997, 1998), 88 potential vegetation types (PVTs) were mapped to indicate site potential differences across the basin. At a point in time, a PVT is the theoretical endpoint of a successional pathway, and it identifies a unique biophysical setting that supports a distinctive plant community (Arno et al. 1985, Steele and Geier-Hayes 1989). From these 88 PVTs, Hann et al. (1997) developed 10 broad-scale potential vegetation groups by clustering similar PVTs, based on climate, topography, disturbance regimes, and geomorphology (Keane and Long 1998; Fig. 3A). The potential vegetation group map was available in a continuous 1-km raster coverage. We obtained mean annual daytime temperature (°C), total annual precipita-

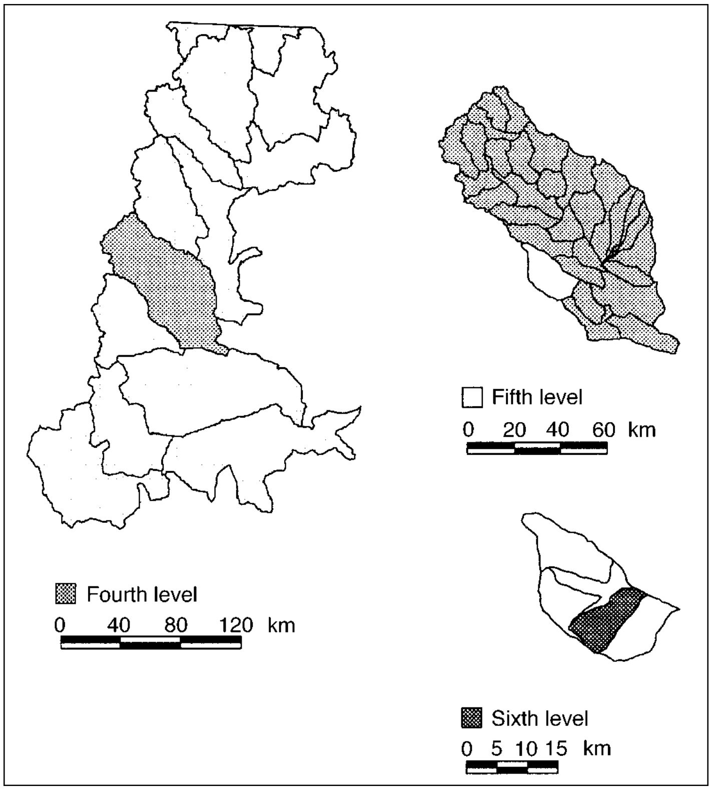

FIG. 2. Hierarchical organization of subwatersheds (sixth level), watersheds (fifth level), and subbasins (fourth level) in the eastern Washington Cascades (see also Seaber et al. [1987]).

tion (mm), and mean annual daytime solar radiation (W/m^2) raster maps for the 1989 weather year, from the Numerical Terradynamics Simulation Group at the University of Montana (Thornton et al. 1997). Continuous maps were modeled and interpolated using daily meteorological observations from ~500 weather stations in the Interior Northwest and the MTCLIM model (Running et al. 1987, Hungerford et al. 1989, Glassy and Running 1994). Temperatures, ranging from -10° to 14°C across the study area, were reclassified into 10 classes of equal interval (Fig. 3B). Precipitation, also integer data ranging from 0–10 000 mm, were reclassified into six natural logarithm classes (Fig. 3C). Solar radiation values ranging from 0–450 W/m^2 were reclassified into nine classes of equal interval (Fig. 3D). Continuous climate variables were classified to categorical variables to pare the sparse matrix submitted to TWINSPAN ordination to a manageable size. We conducted sensitivity analysis in TWINSPAN to optimize the number of classes of each variable. Subwatershed area in each potential vegetation group, temperature, precipitation, and solar radiation class was attributed to each subwatershed in a GIS.

Using hierarchical cluster analysis (VARCLUS procedure, SAS 1989), we clustered subwatersheds into six groups according to their similar composition of potential vegetation and climate attributes. We mapped subwatershed clusters and subjectively evaluated each grouping. Cluster composition was then compared with that of clusters generated by two-way indicator species analysis (TWINSPAN, Hill 1979), a dichotomized ordination procedure used in community ecology analysis. We submitted the data to iterative TWINSPAN analysis using subwatersheds as objects and the classes of each variable as attributes. Four subwatershed groups were identified after two divisions, and data from each group was independently submitted to TWINSPAN for additional division. TWINSPAN analysis resulted in eight groups. Subregion membership was assigned to each subwatershed in a GIS, and a map was generated. We compared maps generated by the two techniques, and collapsed the TWINSPAN divisions to six groups with 86% agreement in group assignment (Fig. 4).

Classifying forest composition, structure, and potential vegetation

We randomly selected 48 subwatersheds from the interior Columbia basin midscale assessment (Hessburg et al., 1999), stratified them by five forested subregions, and quantified spatial pattern reference conditions. For each selected subwatershed, we constructed historical (1938–1956) and current (1985–1993) vegetation maps from interpretations of aerial photographs. Using remotely sensed raw vegetation attributes, we derived and attributed cover types (CT), structural classes (SC), and potential vegetation types (PVT) to individual patches. We estimated reference variation (RV) in spatial patterns of patch types (CT × SC) by subwatersheds and five forested ecological subregions using the 48 sampled historical vegetation maps stratified by subregion, and the FRAGSTATS (McGarigal and Marks 1995) spatial pattern analysis program.

Vegetation patches were delineated to a minimum size of 4 ha from stereo color (current) or black and white (historical) aerial photography. Photo scale ranged from 1:12 000 for recent color resource photography, to 1:20 000 black and white historical photography. Higher stereoscopic magnification was used with decreasing photo scale to provide comparable resolution of attributes. Vegetation patches were mapped for historical and existing conditions, using the same attributes, standards, equipment, working conditions, and photo interpreters. Existing conditions were mapped first. We obtained experienced photo interpreters with field knowledge of vegetation conditions, landforms, and management history to interpret photography and map vegetation. Photo interpreters used field inventory plot data, available for most subwatersheds, to supervise visual interpretations. The following remotely sensed patch attributes were estimated: (1) total tree crown cover; (2) overstory tree crown cover; (3) understory tree crown cover, computed by subtracting overstory from total crown cover; (4) clumpiness of tree cover (tree cover evenness); (5) clump density of tree cover; (6) average clump size of tree cover; (7) degree of crown differentiation among overstory tree crowns; (8) canopy layers; (9) riparian or wetland status; (10) nonforest type; (11) type of visible logging entry; (12) overstory size class; (13) understory size class; (14) overstory species or species mix; (15) understory species or species mix; (16) dead tree and snag abundance; (17) elevation belt (broad elevation setting, e.g., upper montane or subalpine); and (18) overstory canopy cover of nonforest types. Items 1–9 and 11–16 were interpreted for forest patches; items 9–11, 17, and 18 applied to nonforest patches. Items 1–3 were estimated to the nearest 10%. Patch attributes were interpreted for all forest and rangeland vegetation in the sampled subwatersheds. Refer to Hessburg et al. (1999) for additional detailed descriptions of photo interpretation methods and attribute classes.

Patches were delineated on the basis of within-patch uniformity of attributes. A single class change of any attribute prompted delineation of a new patch, provided the 4 ha minimum patch size limitation was satisfied. Patches were delineated on stereo aerial photo pairs with the aid of variable magnification, mirrored scanning stereoscopes, and transferred to Mylar overlays on geo-referenced 1:24 000 orthophotographs. Riparian vegetation areas were delineated first, within the effective area of each photo pair. Overlay maps were digitally scanned, edited, and edge-matched using LTplus raster-to-vector conversion software, and imported into the ARC/INFO GIS, where they were merged with patch attribute files. The final product was a vector ARC/INFO map dynamically linked to a relational database of raw patch attributes.

Cover types.—Vegetation cover attributes were classified into cover types (CTs). A CT was assigned from overstory and understory species composition and crown cover attributes. Both pure and mixed cover conditions were interpreted for forest patches. Cover types were based on the overstory species attribute when overstory crown cover was ≥25%; and on the understory species attribute, when overstory crown cover was ≤20% and understory crown cover exceeded overstory crown cover.

Forest CTs were classified according to published Society of American Foresters forest cover type definitions (Eyre 1980). To be identified as forest cover, total crown cover was ≥25%. To be identified as a component of a mixed CT, a species comprised >20% of the total basal area, estimated using size class and crown cover attributes, where trees were pole-sized or larger; or >20% of the total trees per hectare, where trees were seedlings or saplings. Forest CTs were: ponderosa pine (PIPO, *Pinus ponderosa*); western larch (LAOC, *Larix occidentalis*); lodgepole pine (PICO, *Pinus contorta*); Douglas-fir (PSME, *Pseudotsuga menziesii*); grand fir (ABGR, *Abies grandis*); subalpine fir/Engelmann spruce (ABLA2/PIEN, *Abies lasiocarpa/Picea engelmannii*); Pacific silver fir (ABAM, *Abies amabilis*); western hemlock/western redcedar (TSHE/THPL, *Tsuga heterophylla*/*Thuja plicata*); mountain hemlock (TSME, *Tsuga mertensiana*); western white pine (PIMO, *Pinus monticola*); whitebark pine/subalpine larch (PIAL/LALY, *Pinus albicaulis*/*Larix lyallii*); and hardwood species (HDWD). We collapsed all rangeland CTs into their respective physiognomic condition (woodland, shrubland, or herbland). Nonforest, nonrange, and anthropogenic types were classified into the CT ''Other''.

Structural classes.—Oliver and Larson (1996) identified four process-based structural stages to describe single-cohort stand development following stand replacement disturbance. These stages were defined primarily by availability of and competition for site resources. Oliver's stages were as follows: stand initiation (si), closed canopy-stem exclusion (secc), understory re-initiation (ur), and old growth. We expanded their classification to seven classes, in order to include conditions characteristic of stand development in Interior Northwest forests with their frequent disturbance (see O'Hara et al. 1996). Additional structural classes (SCs) were: open canopy–stem exclusion (seoc), young forest multistory (yfms), and old forest–single story (ofss). Our ''old forest multistory'' (ofms) class was equivalent to Oliver's ''old growth'' stage. Rules for classifying SCs from overstory and understory crown

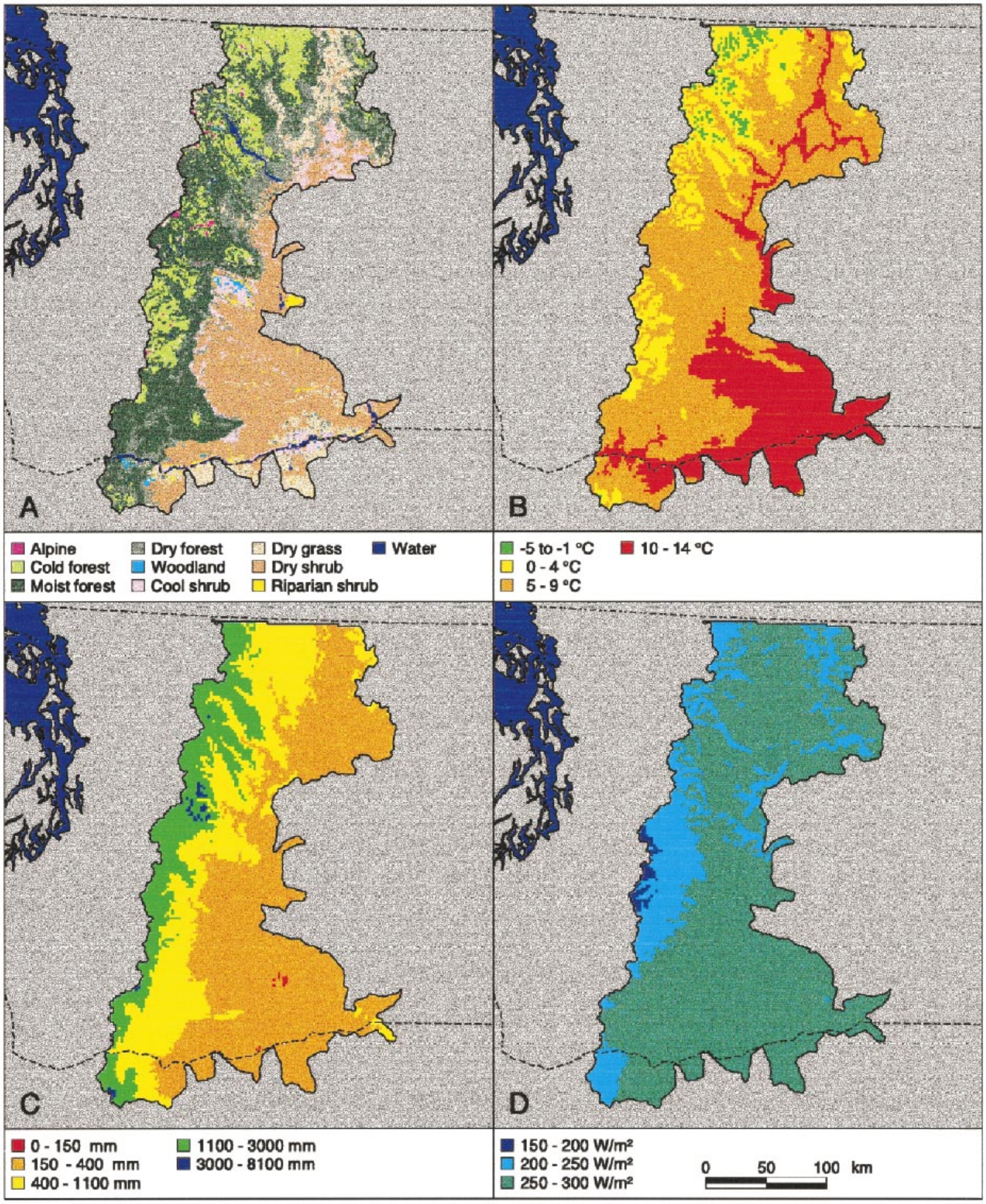

FIG. 3. (A) Broadscale maps of potential vegetation groups, (B) mean annual daytime temperature, (C) total annual precipitation, and (D) mean annual daytime shortwave solar radiative flux for the 1989 weather year in the eastern Washington Cascades and vicinity.

cover and size class data are provided in Hessburg et al. (1999).

Agee (1990, 1993) defined high severity, stand-replacing fires in the Pacific Northwest as those that caused mortality to ≥70% of the overstory basal area. Therefore, a substantial overstory residuum is possible, even after stand-replacing disturbance. For the purpose of classifying forest SCs, we defined old forests as

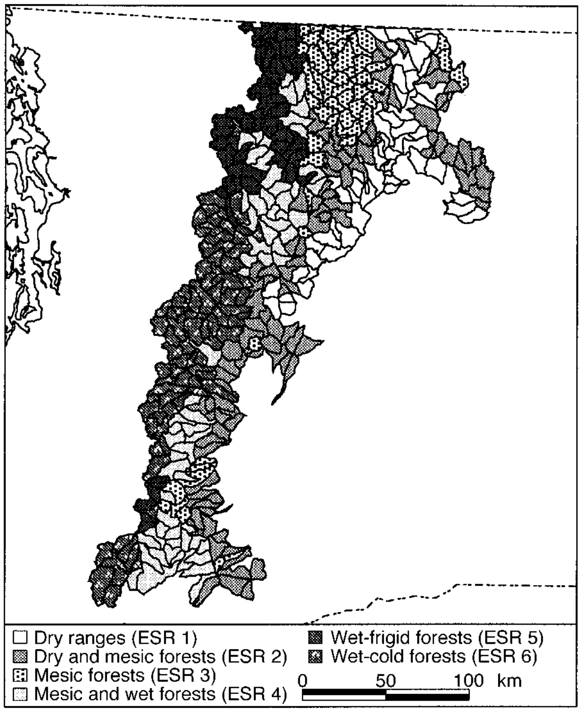

FIG. 4. Map of ecological subregions of the eastern Washington Cascades. Subwatersheds are grouped by TWINSPAN ordination according to their similar composition of potential vegetation and climate attributes.

those structures displaying ≥25% large tree (dbh > 63.5 cm) crown cover (30% crown cover class, range 25–34%). Other structure conditions could display up to 24% large tree crown cover (20% crown cover class, range 15–24%). We did so to allow remnant trees surviving stand replacing disturbance to be a factor in structural definitions.

The CT and SC attributes were assigned to each patch, and the assigned patch type was that couplet (e.g., Douglas-fir/stand initiation (PSME_si). In subsequent analysis, patch types are the unique elements of the landscape mosaic and are the focus of RV estimates and spatial pattern analysis.

Potential vegetation types.—Environments that are similar in their climate, landforms, and geomorphic processes display a similar distribution of vegetation in the absence of disturbance (Arno et al. 1985, Steele and Geier-Hayes 1989). We term this unique vegetation class the PVT. We mapped forest PVTs to frame our estimates of RV by environmental setting, to allow comparison of changes occurring in similar environmental settings in differing geographic locations, and ultimately to contrast differences in magnitude and direction of change as a function of site potential. Forest PVTs were classified at approximately the series level (e.g., see Lillybridge et al. 1995) using methods of Hessburg et al. (1999). As used here, a series is a conceptual grouping of related plant associations sharing the same predicted dominant ''climatic climax'' conifer

TABLE 1. Transitions from historical to current-condition patch types of MET_11, a subwatershed of the eastern Washington Cascades Mesic Forests subregion, where patch types were couplets of cover type and structural class.

	Current patch type														
Historical patch type	ABGR	ABLA2				HDWD	Herb-land	Other	PIAL			PICO			
	ur	secc	si	ur	yfms	ur			seoc	si	ur	seoc	si	ur	yfms
ABLA2_seoc	···	···	···	···	···	···	···	···	···	···	···	···	0.1	···	···
ABLA2_si	···	···	0.8	0.1	···	···	···	···	···	0.1	0.1	···	0.5	0.1	···
ABLA2_ur	···	0.1	0.1	2.8	···	···	···	···	···	···	···	···	0.5	0.5	···
HDWD_secc	···	···	···	···	···	···	···	0.1	···	···	···	···	···	···	···
Herbland	···	···	···	···	···	···	···	···	···	···	···	···	···	···	···
Other	···	···	···	···	···	0.1	···	···	0.3	···	···	1.1	0.1	···	···
PIAL_seoc	···	···	···	···	···	···	···	···	2.5	···	···	0.1	0.4	···	···
PIAL_si	···	···	0.1	···	···	···	···	···	0.2	···	0.3	···	···	···	···
PICO_yfms	···	···	···	···	0.1	···	···	···	0.1	···	···	···	1.9	···	···
PIPO_ofms	···	0.4	···	···	0.1	0.3	···	···	···	···	···	···	···	···	1.3
PIPO_seoc	···	···	···	···	···	···	···	···	···	···	···	···	···	···	···
PIPO_si	···	···	···	···	···	···	···	0.1	···	···	···	···	···	···	···
PIPO_yfms	···	···	···	···	···	···	···	···	···	···	···	···	···	···	···
PSME_ofms	···	0.5	0.2	···	0.6	0.6	···	···	···	···	···	···	0.4	0.8	0.1
PSME_seoc	···	···	···	···	···	···	···	···	···	···	···	···	···	···	···
PSME_si	···	···	···	···	···	···	···	0.1	···	···	···	···	···	···	···
PSME_ur	0.1	···	···	···	···	0.1	···	···	···	···	···	···	···	···	···
PSME_yfms	0.7	0.3	···	0.1	0.3	···	0.3	0.2	···	···	···	···	···	···	···
Total	0.8	1.4	1.2	3.1	1.2	1.1	0.3	2.7	3.1	0.1	0.4	1.2	4.0	1.5	1.4

Notes: Values are the percentages of the subwatershed area transforming from one type in the historical condition to another in the current condition, rounded to one decimal place. Structural classes are as follows: si, stand initiation; seoc, stem exclusion, open canopy; secc, stem exclusion, closed canopy; ur, understory reinitiation; yfms, young forest multistory; ofms, old forest multistory; ofss, old forest single story. Cover types are as follows: PIPO, ponderosa pine; PSME, Douglas-fir; ABGR, grand fir; HDWD, Hardwood; PICO, lodgepole pine; ABLA2 (=ABLA2/PIEN), subalpine fir–Engelmann spruce; PIAL (=PIAL/LALY), whitebark pine–subalpine larch; herbland, all herbland cover types and structural classes combined; other, all nonforest/nonrangeland and anthropogenic types combined.

species. The PVT of each forest patch was identified using both remotely sensed historical and current overstory and understory species composition, and elevation, slope, and aspect coverages generated from 90-m digital elevation models. Forest PVTs were: ponderosa pine; warm–dry and cool–moist Douglas-fir/grand fir; warm–dry and cool–moist western hemlock/western redcedar; Pacific silver fir; mountain hemlock; warm–dry, cool–moist, and harsh–cold subalpine fir/Engelmann spruce; whitebark pine/subalpine larch; quaking aspen; Oregon white oak; and edaphic lodgepole pine.

The PVTs of small inclusions of herbland, shrubland, and woodland were classified as broad habitat type groups. Rangeland PVTs were: antelope bitterbrush steppe, Wyoming big sagebrush, mountain big sagebrush steppe, Fescue grassland, Fescue grassland with conifers, three-tip sagebrush steppe, mountain shrub, riparian sedge, bluebunch wheatgrass steppe with conifers, and alpine herbland with low shrubs (Hessburg et al. 1999). All nonforest and nonrange types were classified as ''Other.''

Estimating reference variation in forest spatial patterns

We used the subregion map (Fig. 4) to stratify sampled historical subwatershed vegetation maps for RV analysis and to extrapolate results to subwatersheds of a subregion. We applied the FRAGSTATS program to summarize spatial relations of CT × SC patch types of historical subwatersheds of a subregion.

TABLE 1. Extended.

Current patch type										
PIPO					PSME					
secc	seoc	si	ur	yfms	secc	seoc	si	ur	yfms	Total
···	···	···	···	···	···	···	···	···	···	0.2
···	···	···	···	···	···	···	···	···	···	1.7
···	···	···	···	···	···	0.1	0.1	0.2	0.4	5.1
···	···	···	···	···	···	···	···	···	···	0.1
···	1.7	···	0.1	0.1	···	···	···	···	···	1.9
···	0.5	···	0.1	0.1	···	···	···	···	···	4.5
···	···	···	···	···	···	···	.	···	···	3.1
···	···	···	···	···	···	···	···	···	···	0.6
···	···	···	···	···	···	···	···	···	···	2.2
5.7	0.6	2.4	1.4	5.2	5.5	0.6	0.6	1.2	1.0	26.3
0.8	6.9	3.4	0.2	3.4	···	···	0.1	0.1	···	14.9
0.5	11.4	···	···	1.5	0.1	···	0.1	···	···	13.8
···	2.2	···	···	1.0	0.3	···	···	···	0.4	4.0
0.2	0.1	···	···	0.6	0.1	···	0.1	1.4	0.1	5.7
···	···	···	···	···	0.1	···	···	···	···	0.1
···	0.1	0.5	0.3	0.2	0.5	···	1.1	0.5	···	3.3
1.0	0.1	0.3	···	0.3	3.1	0.1	0.1	2.1	2.8	10.1
···	0.1	···	···	···	···	···	···	0.2	0.3	2.5
8.2	23.8	6.8	2.0	12.4	9.7	0.8	2.1	5.7	5.0	100.0

We chose three class metrics to succinctly display area and connectivity relations: percentage of landscape area, %LAND; patch density per 10 000 ha, PD; and mean patch size, MPS. Mean, median, range, and median 80% range statistics were computed for sampled subwatersheds of a subregion in S-PLUS (Statistical Sciences 1993). Significant change was any change in the current median value of a metric that fell outside the historical median 80% range. We chose the median 80% range instead of the full range as our estimate of the RV of class and landscape metrics for several reasons. First, historical data distributions were skewed, and the sample median most accurately reflected central tendency. Second, most observations clustered within the median 75–80% range, and few observations accounted for differences between the full range and that of the clustered observations. Finally, we reasoned that more extreme variation usually results from either unique environmental contexts or rare events. By imposing the contrast between current values and a typical range of conditions in departure analysis, managers using RV estimates would retain the ability to detect conditions resulting from management activities, random chance, rare events, or perhaps extreme climatic conditions. We deemed this critical, because rare or extreme events may be especially important to creating spatial patterns of structure and composition (Swetnam and Betancourt 1998).

We characterized spatial patterns of patch types within subregions using a suite of landscape pattern indices. Metrics we chose for spatial pattern characterizations enabled us to identify pattern characteristics within subregions, as well as diagnose factors responsible for those characteristics. Pattern characteristics of primary interest were patch type richness, diversity, dominance, evenness, dispersion, interspersion, contagion, juxtaposition, and edge contrast. Ten metrics concisely displayed spatial pattern conditions: relative patch richness (RPR) and absolute patch richness (PR); Shannon's diversity index (SHDI) and Hill's transformation of SHDI (N1; Hill 1973); Hill's transformation of Simpson's λ (N2; Simpson 1949, Hill 1973), which is both a diversity and dominance measure; a modified Simpson's evenness index (MSIEI) and Alatalo's evenness index (R21; Alatalo 1981) which measures evenness of dominant patch types; a contagion index (CONTAG); an interspersion and juxtaposition index (IJI); and an area-weighted mean edge contrast index (AWMECI). We supplemented the FRAGSTATS source code with computational algorithms for metrics N1, N2, and R21. Mean, median, range, and median 80% range statistics (RV) were computed for landscape metrics of historical subwatersheds of a subregion in S-PLUS. RV estimates were tabulated for CT × SC

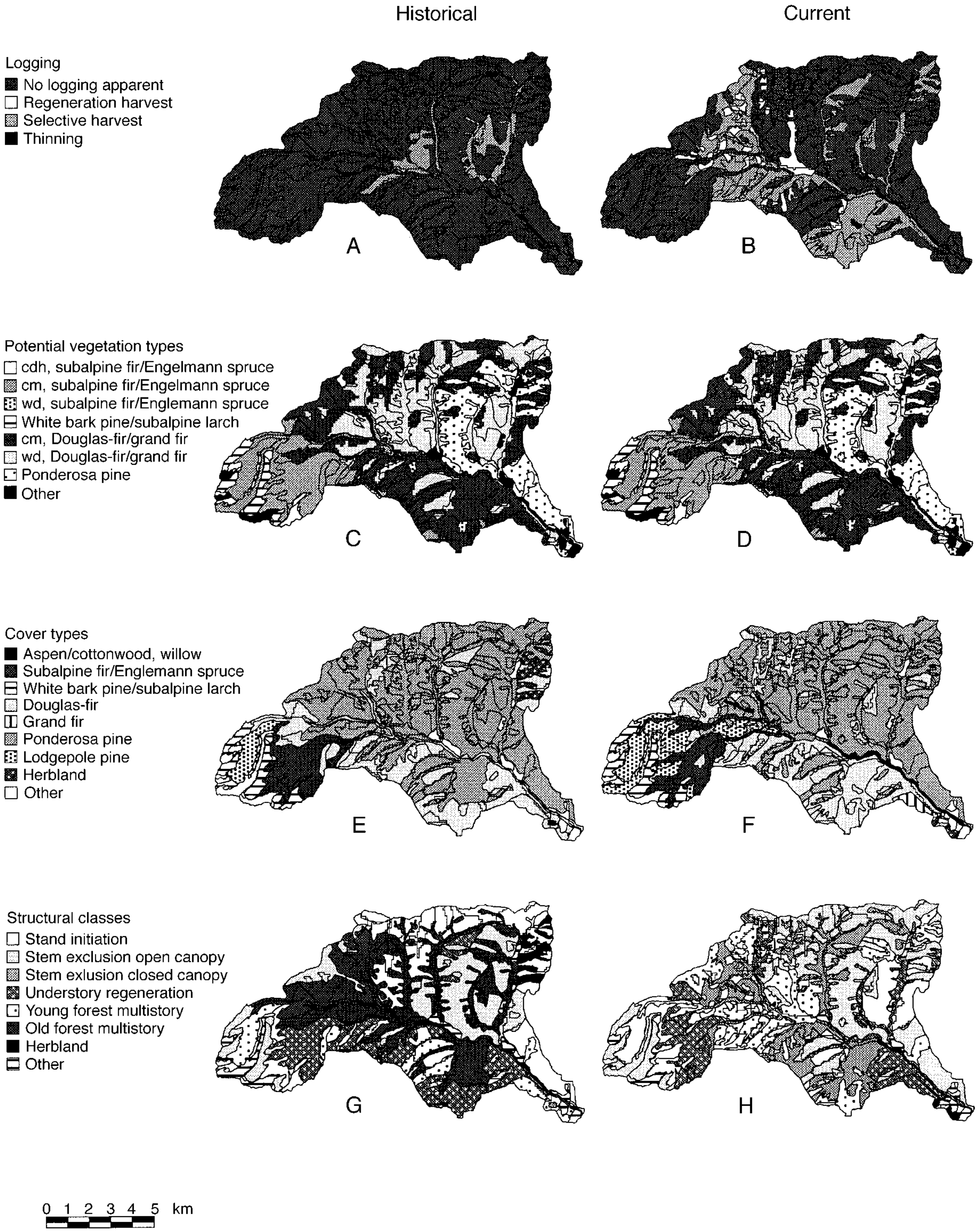

FIG. 5. Maps of the Libby Creek subwatershed MET_11 of the eastern Washington Cascades Mesic Forests subregion displaying historical (1956) and current (1992) visible logging extent (A, B), potential vegetation types (C, D), cover types (E, F), and structural classes, respectively (G, H).

patch types, as well as CT × SC patch types of PVTs of each subregion.

In the *Results* section that follows, we use RV estimates for class and landscape metrics of the Mesic Forests subregion (Fig. 4) to quantify significant spatial pattern departures of an example subwatershed (MET_11) in its current condition. The example subwatershed resides in the Methow subbasin (Fig. 1). We compare MET_11 current conditions with RV estimates to show that significant class and landscape pattern departures are readily diagnosed. We then compare MET_11 historical conditions with RV estimates to suggest that, relative to RV estimates, outlier conditions of class and landscape metrics can and should be diagnosed if effects of unique, rare, or extreme events or conditions are to be identified and considered in pattern restoration. Finally, we conduct transition analysis to compare historical and current CT × SC conditions of MET_11 and discover the principal transformations (Table 1). In a GIS, transition analysis is quite simply accomplished. First, vector versions of historical and current CT × SC maps are rasterized to a pixel size of 30 m. Second, the 30-m raster versions of the historical and current maps are intersected into a single map coverage, such that each 30 m pixel has a historical and current CT × SC identity. We then compute pixel frequency for each unique historical to current transition type, divide the number of pixels in each transition type by the total number of pixels, and multiply that result by 100 to derive a percentage of the subwatershed area. Finally, we array the results in matrix format.

RESULTS

Vegetation spatial patterns result from patterns of environments and disturbances. To evaluate complex spatial patterns and changes therein, we examine characteristics of the patterns themselves, and the spatial relations of component patch types. The suite of class and landscape metrics chosen enables the evaluation. Fig. 5 reflects historical and current logging (Fig. 5A, B), potential vegetation (Fig. 5C, D), cover type (Fig. 5E, F), and structure conditions (Fig. 5G, H), respectively, in the 10 386 ha Libby Creek subwatershed, MET_11. Table 1 displays all cover type × structural class (CT × SC) patch type transitions occurring from the historical to the current condition. In the historical vegetation coverage, MET_11 displayed evidence of prior timber harvest entry over 6.7% of the subwatershed area. All harvest was selection cutting, and most cutting was low impact, i.e., CT and SC were unchanged by harvest. Approximately 34.4% of the subwatershed area has been influenced by cutting in the current condition (historical plus current harvested area). Early selection cutting targeted large, ponderosa pine growing in warm–dry and cool–moist Douglas-fir/grand fir potential vegetation types (PVTs), and rarely dry ponderosa pine PVTs. Most harvesting in the current condition has been in these same environments.

Diagnosing patch type area and connectivity departures.—In Table 2, we compare current values of three class metrics, %LAND, PD, and MPS, for each CT × SC patch type in MET_11, with corresponding reference variation (RV) estimates for the Mesic Forests subregion. For example, the RV estimate for %LAND of the PIPO_secc patch type was 0–2.4% of the subwatershed area. In the current condition, the PIPO_secc patch type occupies 8.2% of the subwatershed area, and patch type area is above RV estimates. Under native fire regimes, frequent surface fires killed most PIPO seedlings and saplings that regenerated after fires, thereby discouraging full site occupancy by trees. Absent frequent fires, seedlings and saplings of early seral and shade-tolerant species survived, and secc structures emerged as a landscape feature of increased dominance. Also in Table 2, we display historical class metric values of MET_11, and the full range of historical values for each patch type and metric. Significant departures from RV are indicated with a ‘‘parallel lines’’ (‖) symbol.

Class metrics of many current and historical MET_11 patch types were outside the estimated RV (Table 2). Among subwatersheds of the subregion, MET_11 was unique in the number of historical class metric values that were outside the estimated RV. Owing to the widespread distribution of dry and mesic environments and dominance of surface fire regimes that favored fire-tolerant, early seral species, the PIPO CT was most widely distributed (59% of the area), and structure classes of the PIPO CT exhibited the greatest departure. For example, the current value of %LAND for the PIPO_si patch type was well above RV estimates, and the historical value was nearly double the current value, indicating that at least one large stand replacement disturbance event predated the MET_11 historical condition. Likewise, current area of the PIPO_seoc and PIPO_secc patch types was well above the RV. Current area of other structural classes of the PIPO CT were within estimated RV ranges. In the historical condition, there was no area of secc or ur patches in the PIPO CT, and area in yfms patches was small. The likely explanation is that frequent historical surface fires maintained open rather than closed canopy stem exclusion structures and minimized the presence of coniferous understories that might have otherwise been associated with ur and yfms structures. The net effect was overall simplification of the landscape mosaic; land cover was dominated by PIPO cover on six of every 10 ha, and there were three dominant structural classes.

The RV estimate for PIPO_ofms patch type area was 0.0–16.7%, but the historical area of PIPO_ofms was 26.3%, a value well above the estimated RV range. Among subwatersheds of the Mesic Forests subregion,

TABLE 2. Comparison of current area and connectivity conditions in subwatershed MET_11 with reference variation (RV) estimates of sampled subwatersheds of the eastern Washington Cascades Mesic Forests subregion, where patch types were couplets of cover type and structural class.

	%LAND, percentage area (%)						PD, patch density (n/10 000 ha)					
			RV†		Full range				RV†		Full range	
Structural class‡	C§	H§	Min.	Max.	Min.	Max.	C§	H§	Min.	Max.	Min.	Max.
Ponderosa pine (PIPO)												
si	6.8‖	13.8‖	0.0	5.6	0.0	13.8	22.0‖	5.0	0.0	5.0	0.0	5.0
seoc	23.8‖	14.9	0.0	19.0	0.0	28.3	23.0‖	10.0	0.0	11.0	0.0	14.0
secc	8.2‖	0.0	0.0	2.4	0.0	8.0	2.0‖	0.0	0.0	1.0	0.0	4.0
ur	2.0	0.0	0.0	4.7	0.0	6.4	2.0	0.0	0.0	10.0	0.0	12.0
yfms	12.4	4.0	0.0	23.5	0.0	31.0	9.0	7.0	0.0	18.0	0.0	24.0
ofms	0.0	26.3‖	0.0	16.7	0.0	26.3	0.0	5.0	0.0	5.0	0.0	6.0
Douglas-fir (PSME)												
si	2.2	3.3‖	0.0	2.3	0.0	3.3	8.0‖	6.0‖	0.0	4.0	0.0	6.0
seoc	0.8	0.1	0.0	4.1	0.0	4.1	4.0	1.0	0.0	9.0	0.0	10.0
secc	9.7‖	0.0	0.0	5.2	0.0	13.4	5.0‖	0.0	0.0	5.0	0.0	9.0
ur	5.8	10.1	0.0	16.8	0.0	32.2	8.0	4.0	0.0	12.0	0.0	18.0
yfms	5.0	2.5	0.0	24.3	0.0	29.9	6.0	4.0	0.0	16.0	0.0	17.0
ofms	0.0	5.8‖	0.0	4.7	0.0	5.8	0.0	2.0	0.0	3.0	0.0	4.0
Lodgepole pine (PICO)												
si	4.0	0.0	0.0	28.2	0.0	51.1	2.0	0.0	0.0	12.0	0.0	23.0
seoc	1.2	0.0	0.0	5.8	0.0	8.1	1.0	0.0	0.0	7.0	0.0	14.0
ur	1.5	0.0	0.0	10.7	0.0	13.1	2.0	0.0	0.0	15.0	0.0	21.0
yfms	1.4	2.2	0.0	7.5	0.0	13.2	2.0	1.0	0.0	11.0	0.0	17.0
Grand fir (ABGR)												
ur	0.8‖	0.0	0.0	0.1	0.0	0.4	1.0‖	0.0	0.0	1.0	0.0	2.0
Subalpine fir-Engelmann spruce (ABLA2-PIEN)												
si	1.2	1.7	0.0	3.3	0.0	7.0	2.0	2.0	0.0	8.0	0.0	16.0
seoc	0.0	0.2	0.0	4.3	0.0	6.3	0.0	1.0	0.0	12.0	0.0	19.0
secc	1.4	0.0	0.0	12.6	0.0	27.6	1.0	0.0	0.0	13.0	0.0	24.0
ur	3.1	5.1	0.0	7.9	0.0	11.8	1.0	1.0	0.0	14.0	0.0	20.0
yfms	1.2	0.0	0.0	9.6	0.0	20.2	2.0	0.0	0.0	14.0	0.0	21.0
Whitebark pine & subalpine larch (PIAL-LALY)												
si	0.1	0.6	0.0	2.8	0.0	7.5	1.0	2.0	0.0	7.0	0.0	12.0
seoc	3.1	3.1	0.0	6.4	0.0	11.6	6.0	4.0	0.0	8.0	0.0	9.0
ur	0.4	0.0	0.0	0.6	0.0	0.9	1.0	0.0	0.0	4.0	0.0	5.0
Hardwood (HDWD)												
secc	0.0	0.1‖	0.0	0.0	0.0	0.1	0.0	1.0	0.0	0.0	0.0	1.0
ur	1.2‖	0.0	0.0	0.0	0.0	0.0	2.0‖	0.0	0.0	0.0	0.0	0.0
Herbland												
Herbland	0.3‖	1.9	0.6	13.8	0.5	18.1	3.0‖	8.0	3.4	10.0	2.0	11.0
Other												
nonforest–nonrange	2.7	4.5	0.1	9.5	0.1	16.8	11.0	10.0	1.0	23.0	1.0	24.0

† RV reference variation (i.e., 80% range).

‡ Structural classes are: si, stand initiation; seoc, stem exclusion, open canopy; secc, stem exclusion, closed canopy; ur, understory reinitiation; yfms, young forest multistory; ofms, old forest multistory; ofss, old forest single story.

§ C, current; H, historical.

‖ The current or historical value for the metric is outside the estimated reference variation (RV) which is nominally the sample median 80% range of the metric.

MET_11 historically displayed high area in si and ofms structures, and that area was aggregated in a few large patches, reflecting the spatially aggregated nature of past fire disturbances (Fig. 5G). This can also be seen when we examine historical values of the PD and MPS metrics for those patch types. It may be more appropriate to consider the full range of values for the %LAND, PD, and MPS metrics when evaluating opportunities to restore area and connectivity of MET_11 PIPO_si and PIPO_ofms patch types. Similarly, in the PSME CT, historical area of PSME_si and PSME_ofms patch types was outside the RV range (Table 2). While current %LAND values for either patch type are within the RV, historical values were well above the estimated RV. Likewise, historical MPS values were above the RV. It is apparent that selection cutting converted PIPO_ofms and PSME_ofms patches to si, seoc, secc, ur, and yfms structures (Table 1). For example, histor-

TABLE 2. Extended.

MPS, mean patch size (ha)					
		RV†		Full range	
C§	H§	Min.	Max.	Min.	Max.
30.7	286.1‖	0.0	111.8	0.0	286.1
102.9	155.1	0.0	219.9	0.0	264.1
425.0‖	0.0	0.0	60.1	0.0	200.3
102.9‖	0.0	0.0	85.6	0.0	189.9
142.8	59.7	0.0	169.0	0.0	259.8
0.0	546.8‖	0.0	316.7	0.0	546.8
27.9	56.6‖	0.0	55.0	0.0	56.6
21.4	8.3	0.0	54.0	0.0	72.0
202.1‖	0.0	0.0	79.5	0.0	143.6
74.6	263.2‖	0.0	202.1	0.0	263.2
87.1	64.2	0.0	146.6	0.0	178.1
0.0	298.4‖	0.0	245.0	0.0	298.4
208.1	0.0	0.0	333.9	0.0	922.1
122.0‖	0.0	0.0	94.1	0.0	119.6
76.7‖	0.0	0.0	65.3	0.0	74.6
71.6	227.2‖	0.0	121.8	0.0	227.2
83.3‖	0.0	0.0	6.7	0.0	22.3
60.2	88.6‖	0.0	87.4	0.0	88.6
0.0	17.8	0.0	36.4	0.0	43.4
141.1‖	0.0	0.0	88.6	0.0	115.2
317.0‖	527.3‖	0.0	199.7	0.0	527.3
60.3	0.0	0.0	89.8	0.0	94.9
12.2	32.4	0.0	50.7	0.0	61.4
54.2	79.4	0.0	107.9	0.0	174.4
40.7‖	0.0	0.0	14.2	0.0	16.9
0.0	7.6‖	0.0	2.3	0.0	7.6
59.7‖	0.0	0.0	0.0	0.0	0.0
11.9	24.6	9.5	355.5	6.8	896.5
25.4	46.3	5.6	95.8	5.2	158.9

ical PIPO_si patches developed into PIPO_seoc, PIPO_secc, and PIPO_yfms patches. But PIPO_si patches were regenerated in the current condition, not by fire over large areas, but by regeneration harvest of PIPO_ofms and PIPO_seoc types in small dispersed patches (Tables 1 and 2, Fig. 5B).

Diagnosing landscape spatial pattern departures.—In addition to characterizing area and connectivity departures of patch types relative to RV, we characterized departure in spatial patterns. We compared the overall pattern of MET_11 in its current condition with overall patterns of sampled historical subwatersheds of the Mesic Forests subregion, using the landscape metrics we have described. Results of that comparison are given in Table 3. Current values of four of the 10 metrics were outside the RV; only the historical value of relative patch richness (RPR) was outside the RV estimate. The historical value of RPR was 32.73%, a value only slightly below the RV, indicating that just less than one-third of the possible patch types observable within the subregion were observed in the MET_11 historical condition. The current value of absolute patch richness (PR) exceeded the RV estimate, indicating that seven new CT × SC patch type combinations developed on the landscape as a consequence of differences between the effects of natural or aboriginal fire disturbances and timber management activities. Natural and aboriginally caused surface fires tended to simplify composition by favoring large patches of fire-tolerant, early seral species, and by minimizing patch area dominated by shade-tolerant conifers. Surface fires also simplified spatial patterns of forest structure by destroying conifer understory regeneration, and again by favoring large patches. This can be clearly seen in Table 2 in the PIPO CT, where three structural classes in that CT dominate the historical landscape.

Accordingly, the current value of the Shannon diversity index (SHDI), which measures the proportional abundance of patch types and equitability of patch type area distribution, was well above the RV. Of the diversity metrics we used, SHDI is most sensitive to increases in PR. The current value of Hill's index, N1, was also above the RV. N1 is less sensitive than SHDI to changes in PR, because rare patch types receive less weight in the calculation. The current value of N1 indicates increased equitability of patch type area. This change is confirmed by the change in values of N2: with increased value of N2 in the current condition, there is greater patch type diversity, the dominance of any one type is less, and two dominant patch types were added. In a sense, harvest activities had a homogenizing effect on the historical landscape, as measured by these metrics. The current value of CONTAG was also outside the RV. Contagion (spatial aggregation of patches of any type) was reduced by the fragmenting of historical areas of si and ofms structures in the PIPO and PSME CTs, presumably through exclusion of fire and selection cutting.

DISCUSSION

Gauging pattern restoration opportunities

By examining current spatial pattern relations of MET_11 patch types, and by comparing existing conditions to reference variation (RV) estimates, we define an approximate range of conditions for which there is a certain measure of ecological justification, and we identify specific pattern features (patch types) that may be modified through restorative treatments. But patches of any given type (e.g., PSME_si) can occur across a wide variety of environmental settings (see e.g., Table 4). Spatial patterns of patches of the same type will

TABLE 3. Comparison of current landscape spatial pattern conditions in subwatershed MET_11 with reference variation (RV) and full range estimates from sampled historical subwatersheds of the eastern Washington Cascades Mesic Forests subregion, where patch types were couplets of cover type and structural class.

Landscape metrics†	Reference condition		MET_11	
	Minimum	Maximum	Current conditions	Historical conditions
Richness and diversity				
RPR, full range	23.91	56.52		
RPR, 80% range (RV)	33.05	50.44	45.45	32.73‡
PR, full range	11.00	26.00		
PR, 80% range (RV)	15.20	23.20	25.00‡	18.00
SHDI, full range	1.61	2.77		
SHDI, 80% range (RV)	1.63	2.55	2.64‡	2.32
N1, full range	4.98	15.98		
N1, 80% range (RV)	5.11	12.89	14.07‡	10.13
N2, full range	3.25	12.98		
N2, 80% range (RV)	3.75	9.68	9.53	7.46
Evenness				
MSIEI, full range	0.49	0.79		
MSIEI, 80% range (RV)	0.49	0.73	0.70	0.70
R21, full range	0.57	0.80		
R21, 80% range (RV)	0.59	0.75	0.65	0.71
Contagion and interspersion				
CONTAG, full range	52.28	65.07		
CONTAG, 80% range (RV)	53.96	62.63	53.29‡	54.68
IJI, full range	49.04	77.54		
IJI, 80% range (RV)	58.88	74.28	67.15	63.10
Edge contrast				
AWMECI, full range	28.85	47.70		
AWMECI, 80% range (RV)	29.98	41.07	30.22	38.23

† RPR, relative patch richness; PR, patch richness; SHDI, Shannon diversity index; N1, Hill's index, N1 = e^{SHDI}; N2, Hill's index, N2 = 1/(1/SIDI), where SIDI is Simpson's diversity index (Simpson 1949; see also SIDI as defined in McGarigal and Marks [1995]); MSIEI, modified Simpson's evenness index; R21, Alatalo's evenness index, R21 = (N2 − 1)/(N1 − 1); CONTAG, contagion index; IJI, interspersion and juxtaposition index; AWMECI, area-weighted mean edge contrast index (see also McGarigal and Marks [1995]).

‡ The value for the metric is outside the RV (nominally the median 80% range of that metric).

naturally vary with the environmental composition of the neighborhood in which they reside. This is so because fire, insect, and pathogen disturbance regimes, which account for much of the variation in vegetation spatial patterns, strongly correlate with environmental setting (Pickett and White 1985, Keane and Long 1998). To identify specific environmental settings for revising pattern relationships, one additional landscape analysis step is needed: it is necessary to characterize RV for patch types of each potential vegetation type (PVT). We accomplish this by intersecting in a GIS, each of the sampled historical cover type × structural class (CT × SC) maps of the subregion with its unique PVT map. Intersection of the PVT map with the CT × SC map enables one to visualize a multiway comparison of each of the possible PVT × CT × SC patch type permutations. We then compute RV estimates for class and landscape metrics of each PVT × CT × SC patch type. Likewise, we intersect the current CT × SC map of MET_11 with its own unique PVT map, and then compare current conditions of MET_11 with RV estimates for each PVT × CT × SC patch type. Results of that comparison are provided in Table 4.

In Table 4, we observe that historical PIPO_si patches occurred in the PIPO, warm–dry PSME/ABGR, and cool–moist PSME/ABGR PVTs, and PIPO_si area was unevenly distributed among PVTs. More than twice as much area could be found in PIPO_si structures in warm–dry PSME/ABGR vs. PIPO or cool–moist PSME/ABGR PVT settings, suggesting that stand-replacing disturbance was more than twice as common on warm–dry PSME/ABGR sites than on PIPO or cool–moist PSME/ABGR PVT sites. Mean patch size (MPS) values for PIPO_si structures in all three PVTs indicated the historical nature of fire regimes: mean patch sizes of PIPO_si structures were relatively small in warm–dry PSME/ABGR (42.5 ha) and cool–moist PSME/ABGR settings (9.1 ha), and more than four-fold larger in PIPO settings, indicating patch regeneration by mixed severity and lethal fires, respectively. Current PIPO_si area in the cool–moist PSME/ABGR PVT is equivalent to that which occurred historically, current patch density (PD) is lower and current MPS is greater than existed historically, but values for all three metrics are above the estimated RV. Area of PIPO_si was historically more spatially aggregated in MET_11 than would be otherwise indicated by RV estimates, especially on PIPO and warm–dry PSME/ABGR PVTs. To that end, restoration activities on cool–moist PSME/ABGR PVTs might focus on increasing PIPO_si PD and decreasing MPS while maintaining %LAND at a value above the maximum value of the RV, but within the full range. Restoration activities in PIPO and warm–dry PSME/ABGR settings might focus on maintaining PIPO_si PD and increasing MPS values.

In the historical condition, 26.3% of the area of MET_11 was occupied by PIPO_ofms patches (Table 2). Nearly all area of this type was evenly distributed in warm–dry and cool–moist PSME/ABGR settings (Table 4). Consistent with observations made by Camp et al. (1997) in the Wenatchee Mountains, most historical MET_11 ofms patches (Fig. 5G) resided in valley bottom settings, stream confluence zones, in northerly aspects, and in mid- and upper headwall settings. Camp et al. argued that these topographic and physiographic settings historically functioned with moderate to high probability as refuges from stand-replacing fires. It is apparent that these same settings functioned as fire refugia in MET_11, and that historical patterns of stand replacement fires in MET_11 were simple and coarsely grained. It would seem ecologically justifiable to focus activity to restore area and connectivity of PIPO_ofms patches in these same refugial environments, with the highest target PD in warm–dry PSME/ABGR settings, and largest target MPS in cool–moist PSME/ABGR settings. Fig. 6 contrasts the distribution of CT × SC patch types between historical and current conditions of MET_11 in the warm–dry PSME/ABGR PVT. The pattern shown for the historical condition is one of many spatial arrangements that could be interpreted from RV and full range estimates.

In the historical condition, no area was comprised of PIPO_secc and PSME_secc patches (Table 2). In the current condition, 4.2% and 1.0% of the subwatershed area are comprised of these types in the warm–dry PSME/ABGR PVT, and 3.9% and 8.1% of the subwatershed area in the cool–moist PSME/ABGR PVT, respectively (Table 4, Fig. 6). Nonlethal surface fires were historically the most common fire disturbance of warm–dry and cool–moist PSME/ABGR PVT settings. It is likely that these frequent surface fires of low to moderate intensity prevented full site occupancy as in the secc structural condition. In Table 1, we show that PIPO_ofms patches were transformed to PIPO_secc and PSME_secc patches. Further analysis revealed that these transitions were mediated by selection and overstory removal cutting. The focus of activities to restore area and connectivity of PIPO_ofms patches might be in current areas of secc structure.

Most native herbland inclusions in forest historically resided in dry PIPO settings (Fig. 5C, E). Fires set by lightning and by American Indians maintained open grassland area interspersed among forest and woodland (Gruell 1983*a*). It is likely that some natural grassland areas were expanded with intentional fire setting. Fires were recurrently set by Indians for purposes of communicating between scattered bands, to improve forage for horses and big game species, to revitalize berry fields and seasonally wet Camas meadows, to drive game, and for other purposes (Gruell 1983*a*, *b*). In the absence of lightning and Indian fires, herblands were invaded by ponderosa pine (Table 1) and are currently comprised of PIPO_seoc patches (Fig. 5F, H). Efforts to reestablish herbland should be mostly constrained to these drier settings.

Management implications

We introduce a method that managers can use to estimate reference variation of forest spatial patterns using a sampling of historical vegetation maps created from remotely sensed data, and an ecological regionalization to stratify the sample. We conservatively estimate RV as the historical median 80% range of class and landscape metrics. By comparing current and historical values of metrics with RV estimates, and the full range of historical values, we can detect significant change and unique landscape attributes that do not neatly fit within a range of reference conditions.

We acknowledge that our use of a range statistic is somewhat arbitrary and that other variance statistics alternative to range can and perhaps should be considered in related applications. As a matter of practicality, we chose to use the median observation as a useful measure of central tendency, and the median 80% range to portray typical RV. Perhaps other ranges would be better in certain applications, and under some circumstances it may not be appropriate to use a range statistic as a primary focus of variation estimates. Others measures, such as variance, skewness, or kurtosis, may in fact be more informative. We opted to use a range measure after observing data distributions, their skewness, higher moments, and central tendency, but a great deal more thinking and research is needed by landscape ecologists, historical ecologists, and managers alike to elucidate the statistical measures of variance and higher moments that may be most appropriate and useful in each research and management application.

Reference variation estimates as presented here, can and should be augmented to include more variation resulting from stochastic features of ecological systems. This can be done, for example, by broadening samples across both space and time, where data are available, and by merging this empirical approach with a process-modeling approach, such as that used by

TABLE 4. Comparison of current area and connectivity conditions in subwatershed MET_11 with reference variation (RV) estimates of sampled historical subwatersheds of the eastern Washington Cascades Mesic Forests subregion, where patch types were triplets of potential vegetation type (PVT), cover type, and structural class.

Mesic forests (ESR3)† ($n = 8$)	%LAND (percentage area)						PD (patch density; no. trees/10 000 ha)					
			RV		Full range				RV		Full range	
	C‡	H‡	Min.	Max.	Min.	Max.	C‡	H‡	Min.	Max.	Min.	Max.
Ponderosa pine PVT												
PIPO_si	0.0	3.4§	0.0	1.1	0.0	3.4	2.0	2.0	0.0	2.6	0.0	4.0
PIPO_seoc	12.0§	7.0	0.0	9.9	0.0	16.8	13.0§	7.0	0.0	9.1	0.0	14.0
PIPO_secc	0.1§	0.0	0.0	0.0	0.0	0.0	5.0§	0.0	0.0	0.0	0.0	0.0
PIPO_ur	0.4§	0.0	0.0	0.3	0.0	0.9	10.0§	0.0	0.0	2.4	0.0	8.0
PIPO_yfms	0.8	0.3	0.0	2.4	0.0	3.1	3.0	1.0	0.0	15.2	0.0	18.0
PIPO_ofms	0.0	0.5	0.0	0.6	0.0	0.7	0.0	9.0§	0.0	6.9	0.0	9.0
PSME_si	0.0	0.0§	0.0	0.0	0.0	0.0	2.0§	3.0§	0.0	0.9	0.0	3.0
PSME_ur	0.2§	0.0§	0.0	0.0	0.0	0.0	3.0§	1.0	0.0	2.2	0.0	5.0
Herbland	0.0	1.7§	0.0	0.9	0.0	1.7	0.0	6.0	0.0	7.2	0.0	10.0
Other	0.1	0.7§	0.0	0.2	0.0	0.7	3.0	13.0§	0.0	6.7	0.0	13.0
Warm–dry, Douglas-fir–grand fir PVT												
PIPO_si	3.7§	7.4§	0.0	3.2	0.0	7.4	18.0§	17.0§	0.0	10.0	0.0	17.0
PIPO_seoc	8.1§	4.7	0.0	4.7	0.0	4.8	66.0§	44.0§	0.0	28.6	0.0	44.0
PIPO_secc	4.2§	0.0	0.0	0.6	0.0	2.0	23.0§	0.0	0.0	4.5	0.0	15.0
PIPO_ur	1.2	0.0	0.0	2.7	0.0	4.4	5.0	0.0	0.0	5.9	0.0	8.0
PIPO_yfms	6.4	1.9	0.0	10.8	0.0	14.6	17.0	7.0	0.0	28.7	0.0	49.0
PIPO_ofms	0.0	12.2§	0.0	4.3	0.0	12.2	0.0	45.0§	0.0	26.1	0.0	45.0
PICO_yfms	0.6§	0.0	0.0	0.3	0.0	0.9	3.0§	0.0	0.0	2.1	0.0	7.0
PSME_si	0.4§	0.3§	0.0	0.2	0.0	0.3	9.0§	10.0§	0.0	5.1	0.0	10.0
PSME_seoc	0.4§	0.0	0.0	0.4	0.0	0.5	2.0	0.0	0.0	5.8	0.0	10.0
PSME_secc	1.0§	0.0	0.0	0.0	0.0	0.2	25.0§	0.0	0.0	0.3	0.0	1.0
PSME_ur	1.2	0.6	0.0	2.7	0.0	6.4	13.0	13.0	0.0	37.6	0.0	95.0
PSME_yfms	0.4	0.4	0.0	6.9	0.0	12.5	7.0	2.0	0.0	31.7	0.0	66.0
PSME_ofms	0.0	0.5	0.0	1.0	0.0	1.6	0.0	7.0	0.0	7.3	0.0	8.0
ABGR_ur	0.1§	0.0	0.0	0.0	0.0	0.0	1.0§	0.0	0.0	0.0	0.0	0.0
HDWD_secc	0.0	0.1§	0.0	0.0	0.0	0.1	0.0	1.0§	0.0	0.3	0.0	1.0
HDWD_ur	0.2§	0.0	0.0	0.0	0.0	0.0	1.0§	0.0	0.0	0.0	0.0	0.0
Other	0.3	0.1	0.0	0.4	0.0	0.4	13.0	13.0	0.0	20.2	0.0	37.0
Cool–moist, Douglas-fir–grand fir PVT												
PIPO_si	3.1§	3.0§	0.0	1.3	0.0	3.0	23.0§	33.0§	0.0	12.7	0.0	33.0
PIPO_seoc	3.6	3.3	0.0	7.1	0.0	8.1	96.0§	43.0§	0.0	40.9	0.0	43.0
PIPO_secc	3.9§	0.0	0.0	1.7	0.0	5.6	15.0§	0.0	0.0	2.4	0.0	8.0
PIPO_ur	0.4	0.0	0.0	1.9	0.0	2.0	10.0	0.0	0.0	13.1	0.0	18.0
PIPO_yfms	5.1	1.8	0.0	12.1	0.0	14.3	26.0	19.0	0.0	58.0	0.0	121.0
PIPO_ofms	0.0	13.0§	0.0	11.4	0.0	13.0	0.0	42.0§	0.0	16.8	0.0	42.0
PICO_ur	0.4	0.0	0.0	1.8	0.0	3.4	1.0	0.0	0.0	3.3	0.0	4.0
PICO_yfms	0.7	0.0	0.0	1.4	0.0	4.8	4.0	0.0	0.0	7.2	0.0	24.0
PSME_si	1.7	3.0§	0.0	2.0	0.0	3.0	10.0§	8.0§	0.0	5.2	0.0	8.0
PSME_seoc	0.4	0.1	0.0	3.3	0.0	3.7	3.0	1.0	0.0	10.6	0.0	12.0
PSME_secc	8.1§	0.0	0.0	1.8	0.0	3.4	9.0§	0.0	0.0	8.5	0.0	12.0
PSME_ur	3.8	8.4	0.0	12.8	0.0	23.1	9.0	13.0	0.0	24.4	0.0	51.0
PSME_yfms	3.4	1.0	0.0	13.6	0.0	14.3	9.0	4.0	0.0	43.2	0.0	46.0
PSME_ofms	0.0	2.7	0.0	2.7	0.0	2.7	0.0	26.0§	0.0	14.1	0.0	26.0
ABGR_ur	0.7§	0.0	0.0	0.1	0.0	0.4	2.0§	0.0	0.0	0.6	0.0	2.0
HDWD_ur	0.9§	0.0	0.0	0.0	0.0	0.0	3.0§	0.0	0.0	0.0	0.0	0.0
Herbland	0.1	0.2	0.0	1.7	0.0	4.2	1.0	30.0§	1.4	23.0	0.0	30.0
Other	0.1	0.1	0.0	0.6	0.0	1.2	8.0	13.0	0.7	20.4	0.0	26.0
Warm–dry, subalpine fir–Engelmann spruce PVT												
PSME_secc	0.3§	0.0	0.0	0.3	0.0	1.0	2.0	0.0	0.0	7.5	0.0	11.0
PSME_ur	0.0	0.3	0.0	0.5	0.0	0.8	0.0	2.0	0.0	4.9	0.0	7.0
PSME_yfms	0.2	0.3	0.0	0.3	0.0	0.4	1.0	2.0	0.0	4.0	0.0	4.0
ABLA2_ur	0.0	0.1	0.0	1.1	0.0	3.4	0.0	1.0	0.0	4.8	0.0	9.0
Herbland	0.2§	0.0	0.0	0.0	0.0	0.0	1.0§	0.0	0.0	0.0	0.0	0.0
Cool–moist, subalpine fir–Engelmann spruce PVT												
PIPO_yfms	0.0§	0.0	0.0	0.0	0.0	0.0	1.0	3.0§	0.0	2.3	0.0	3.0
PIPO_ofms	0.0	0.7	0.0	1.0	0.0	1.7	0.0	19.0§	0.0	7.8	0.0	19.0
PICO_si	3.6	0.0	0.0	14.4	0.0	25.3	2.0	0.0	0.0	28.0	0.0	49.0

† See Table 1 notes for definition of structural classes and cover types.

‡ C, Current; H, Historical.

§ The current or historical value for the metric is outside the estimated reference variation (RV), which is nominally the sample median 80% range of the metric.

TABLE 4. Extended.

MPS (mean patch size; ha)					
		RV†		Full range	
C§	H§	Min.	Max.	Min.	Max.
0.3	178.2§	0.0	55.0	0.0	178.2
96.1	103.5	0.0	108.2	0.0	119.2
1.3§	0.0	0.0	0.0	0.0	0.0
4.4§	0.0	0.0	3.4	0.0	11.4
29.0§	34.5§	0.0	25.9	0.0	34.5
0.0	5.9	0.0	7.5	0.0	11.0
0.2	0.8§	0.0	0.2	0.0	0.8
5.2§	2.6§	0.0	0.9	0.0	2.6
0.0	29.2	0.0	35.6	0.0	50.5
4.5§	5.4§	0.0	1.8	0.0	5.4
20.1	42.5§	0.0	26.0	0.0	42.5
12.2	10.5	0.0	40.7	0.0	73.4
18.2§	0.0	0.0	4.0	0.0	13.4
24.4	0.0	0.0	66.9	0.0	131.6
37.0§	28.1	0.0	35.2	0.0	48.3
0.0	27.0	0.0	29.8	0.0	36.5
20.8§	0.0	0.0	4.0	0.0	13.2
4.7§	2.9	0.0	4.0	0.0	6.5
21.1§	0.0	0.0	6.1	0.0	9.2
4.1§	0.0	0.0	3.2	0.0	10.8
9.3§	5.0	0.0	8.7	0.0	13.2
6.1	20.3	0.0	36.5	0.0	74.4
0.0	7.6	0.0	23.8	0.0	57.2
6.3§	0.0	0.0	0.0	0.0	0.0
0.0	7.5§	0.0	2.2	0.0	7.5
17.8§	0.0	0.0	0.0	0.0	0.0
2.1	0.7	0.0	9.7	0.0	29.9
13.4§	9.1	0.0	11.0	0.0	15.5
3.8	7.5	0.0	80.8	0.0	186.8
25.4§	0.0	0.0	20.9	0.0	69.8
4.0	0.0	0.0	15.0	0.0	18.5
19.6	9.3	0.0	22.0	0.0	35.6
0.0	30.6	0.0	105.9	0.0	187.0
42.2	0.0	0.0	51.6	0.0	85.4
17.1§	0.0	0.0	6.1	0.0	20.2
17.1	38.6§	0.0	37.3	0.0	38.6
12.0	8.3	0.0	39.2	0.0	44.6
93.8§	0.0	0.0	26.8	0.0	28.7
44.2	66.7	0.0	98.8	0.0	173.5
39.2§	25.0	0.0	31.2	0.0	31.3
0.0	10.4	0.0	67.6	0.0	111.7
38.5§	0.0	0.0	6.8	0.0	22.5
30.1§	0.0	0.0	0.0	0.0	0.0
9.5	0.5	0.4	30.3	0.0	72.4
1.0	0.7	0.1	18.8	0.0	43.5
16.3§	0.0	0.0	2.9	0.0	9.4
0.0	16.3§	0.0	12.6	0.0	16.3
18.2§	13.2§	0.0	10.9	0.0	13.2
0.0	10.4	0.0	18.2	0.0	36.4
18.4§	0.0	0.0	0.0	0.0	0.0
3.2§	0.7	0.0	0.8	0.0	0.9
0.0	3.5	0.0	20.3	0.0	59.4
188.7§	0.0	0.0	56.3	0.0	134.4

Keane et al. (1996), where simulated and remotely sensed maps comprise the sample frame for computing some variance measure of reference conditions.

Capturing reference data on historical vegetation conditions can be an expensive and time-consuming process. The derivation of RV estimates may require considerable expertise and analytical resources that are not broadly available. But we have found, over the last several years as we have learned and refined our methods, that data capture, programming, and analysis associated with landscape assessment is several orders of magnitude simpler and more cost efficient than when we started. In our own experience, cooperative prototypal projects between research and management entities have contributed most to streamlined cost and efficiency, and will produce operational examples of the utility of applications.

We use comparisons of current landscape conditions with RV and full historical range estimates, where patch types are CT × SC couplets, to diagnose the most significant compositional and structural departures. Managers can use these tools to carry out similar landscape or watershed diagnoses in other areas. To identify specific environments for revising patterns, we associate RV estimates with specific PVT settings, because we know that natural distributions of CT × SC patch types vary significantly by environmental setting. We develop a transition matrix to display the primary transitions occurring as a consequence of management. When we itemize the primary transitions, we obtain additional ecological insight into which types in the current condition can be primarily targeted for modification where pattern restoration is desired.

In the interior Columbia basin, midscale assessment (Hessburg et al. 1999, Ottmar et al., *in press*), we learned that significant changes in vital ecosystem processes, such as fire, insect, and pathogen disturbances, are linked to recent changes in vegetation spatial patterns. Risk of stand replacement fire has increased dramatically throughout the forest-dominated portion of the basin, and the likelihood of nonlethal surface fires has declined in equally dramatic fashion. Elevated risk is indicated by increased ground fuel loading, crown fire potential, flame length, fire rates of spread, and fire line intensity, each of which are direct or indirect consequences of changes in spatial patterns of both living and dead forest cover and structure. To address concerns over elevated landscape vulnerability to stand replacement fires, it will be necessary to greatly modify current patterns of living and dead structure and composition.

The fields of landscape ecology and conservation biology provide a strong rationale and framework for managing ecosystems within their RV, both to sustain native species and processes and to maintain productivity of ecosystems (Morgan et al. 1994, Swanson et al. 1994, Jensen et al. 1996, Landres et al. 1999). The

TABLE 4. Continued.

Mesic forests (ESR3)† (*n* = 8)	%LAND (percentage area)						PD (patch density; no. trees/10 000 ha)					
			RV		Full range				RV		Full range	
	C‡	H‡	Min.	Max.	Min.	Max.	C‡	H‡	Min.	Max.	Min.	Max.
PICO_seoc	1.1	0.0	0.0	3.1	0.0	6.4	1.0	0.0	0.0	12.5	0.0	16.0
PICO_ur	1.1	0.0	0.0	8.9	0.0	11.2	3.0	0.0	0.0	24.5	0.0	35.0
PICO_yfms	0.1	2.2	0.0	5.2	0.0	6.4	3.0	1.0	0.0	17.1	0.0	36.0
PSME_si	0.1§	0.0	0.0	0.0	0.0	0.1	1.0§	0.0	0.0	0.3	0.0	1.0
PSME_seoc	0.1	0.0	0.0	0.4	0.0	0.6	1.0	0.0	0.0	3.3	0.0	4.0
PSME_secc	0.3	0.0	0.0	3.1	0.0	8.8	5.0	0.0	0.0	11.4	0.0	17.0
PSME_ur	0.6	0.8	0.0	1.2	0.0	1.7	3.0	5.0	0.0	12.3	0.0	13.0
PSME_yfms	1.1	0.9	0.0	3.0	0.0	4.0	4.0	2.0	0.0	8.8	0.0	13.0
PSME_ofms	0.0	2.6§	0.0	1.3	0.0	2.6	0.0	7.0§	0.0	4.9	0.0	7.0
ABLA2_si	1.1	1.5	0.0	1.6	0.0	1.6	2.0	4.0	0.0	11.7	0.0	18.0
ABLA2_seoc	0.0	0.2	0.0	2.1	0.0	2.8	0.0	1.0	0.0	19.6	0.0	21.0
ABLA2_secc	1.4	0.0	0.0	11.2	0.0	25.8	1.0	0.0	0.0	21.0	0.0	35.0
ABLA2_ur	3.0	5.0	0.0	5.8	0.0	7.6	1.0	2.0	0.0	22.4	0.0	28.0
ABLA2_yfms	1.2	0.0	0.0	5.5	0.0	7.8	2.0	0.0	0.0	25.3	0.0	54.0
PIAL_seoc	0.2	0.1	0.0	0.4	0.0	1.0	16.0§	5.0	0.0	5.6	0.0	7.0
HDWD_ur	0.1§	0.0	0.0	0.0	0.0	0.0	1.0§	0.0	0.0	0.0	0.0	0.0
Other	0.1	1.2	0.0	1.4	0.0	1.9	5.0	4.0	0.0	14.5	0.0	18.0
Harsh–cold, subalpine fir–Engelmann spruce PVT												
PICO_si	0.3	0.0	0.0	3.2	0.0	9.7	2.0	0.0	0.0	16.8	0.0	49.0
ABLA2_si	0.1	0.2	0.0	1.3	0.0	3.9	1.0	2.0	0.0	5.0	0.0	12.0
PIAL_si	0.1	0.4	0.0	1.3	0.0	2.3	1.0	1.0	0.0	9.2	0.0	19.0
PIAL_seoc	0.0	0.3	0.0	1.4	0.0	3.8	0.0	5.0	0.0	6.2	0.0	9.0
PIAL_ur	0.4	0.0	0.0	0.6	0.0	0.9	1.0	0.0	0.0	4.3	0.0	5.0
Whitebark pine–subalpine larch PVT												
PICO_si	0.1§	0.0	0.0	0.0	0.0	0.0	12.0§	0.0	0.0	0.3	0.0	1.0
PICO_seoc	0.0§	0.0	0.0	0.0	0.0	0.0	5.0§	0.0	0.0	0.6	0.0	2.0
PICO_yfms	0.0	0.0§	0.0	0.0	0.0	0.0	0.0	2.0§	0.0	0.6	0.0	2.0
ABLA2_si	0.0§	0.0	0.0	0.0	0.0	0.1	4.0§	1.0	0.0	1.0	0.0	1.0
PIAL_si	0.0	0.2	0.0	1.2	0.0	3.6	0.0	1.0	0.0	4.0	0.0	11.0
PIAL_seoc	3.0	2.7	0.0	3.0	0.0	3.9	6.0	5.0	0.0	6.8	0.0	11.0
Other	0.0	0.3	0.0	0.6	0.0	1.5	5.0	21.0§	0.0	14.7	0.0	21.0
Other PVT												
Nonforest–nonrange	2.1	2.2	0.0	7.1	0.0	12.0	11.0	11.0	0.0	11.6	0.0	13.0

better we comprehend native patterns and the processes that have shaped and continue to shape ecosystem patterns, the better we are able to design management systems and activities that cooperate with, rather than run contrary to, these patterns and processes. Such knowledge is also highly useful to decision-makers who must gauge risks and uncertainties associated with intentionally deviating beyond the bounds of reference conditions.

We submit that using estimates of RV in the management of ecosystems will not return landscapes to any preexisting wild or pristine condition. Rather, RV estimates serve resource managers by providing at least four useful functions. Managers can use reference variation estimates to do the following: (1) evaluate current conditions and estimate consequences to native species and processes; (2) assess opportunities and risks to native species, processes, and ecosystem productivity associated with landscape patterns alternative to reference conditions; (3) develop specific landscape pattern restoration goals; and (4) set conservation and restoration priorities.

The magnitude of risk associated with ecosystem change will likely be related to the magnitude and direction of departures from natural ranges of variation (Landres et al. 1999). Risks and opportunities have ecological and social consequences, and the degree of risk management is a resource management decision with ecological and social dimensions. Use of reference variation estimates to gauge pattern departures under alternative landscape management scenarios will inform decision-makers and citizens of the ecological and social costs and benefits of decisions, and will be an aid in prioritizing investments of money, energy, and human effort in the management of ecosystems.

In the Interior West, where threats to native species and their habitats are well-documented, it is useful for land managers to be able to examine the distribution and arrangement of patch types in landscapes they manage. For example, at a variety of scales, terrestrial species interact with landscape spatial and temporal patterns that are more or less suitable to their specific habitat needs. Change in vegetation pattern across both space and time has a bearing on species persistence in

TABLE 4. Continued, Extended.

MPS (mean patch size; ha)					
		RV†		Full range	
C§	H§	Min.	Max.	Min.	Max.
114.9§	0.0	0.0	26.5	0.0	40.7
36.2§	0.0	0.0	34.5	0.0	39.4
4.1	226.3§	0.0	106.4	0.0	226.3
10.0§	0.0	0.0	1.2	0.0	4.1
7.4	0.0	0.0	10.0	0.0	14.1
5.6	0.0	0.0	20.1	0.0	50.6
20.9§	17.0§	0.0	16.2	0.0	17.0
27.3	44.8§	0.0	38.1	0.0	44.8
0.0	37.8§	0.0	27.6	0.0	37.8
55.5§	40.1	0.0	40.1	0.0	40.1
0.0	17.5§	0.0	15.4	0.0	17.5
141.2§	0.0	0.0	46.0	0.0	74.5
315.1§	257.5§	0.0	96.3	0.0	257.5
60.3§	0.0	0.0	51.4	0.0	52.4
0.9	1.4	0.0	5.7	0.0	15.7
11.4§	0.0	0.0	0.0	0.0	0.0
0.9	30.1§	0.0	23.8	0.0	30.1
15.8	0.0	0.0	15.8	0.0	19.9
7.7	8.4	0.0	15.5	0.0	32.0
12.2	45.5§	0.0	24.3	0.0	45.5
0.0	6.8	0.0	24.5	0.0	41.0
40.7§	0.0	0.0	14.3	0.0	16.9
0.6§	0.0	0.0	0.3	0.0	0.9
0.5§	0.0	0.0	0.2	0.0	0.7
0.0	0.5§	0.0	0.2	0.0	0.5
0.4	0.1	0.0	1.5	0.0	4.9
0.0	19.4	0.0	23.2	0.0	32.3
51.7§	55.4§	0.0	41.5	0.0	55.4
0.6	1.3	0.0	4.6	0.0	12.4
20.2	20.3	0.0	67.2	0.0	108.1

the landscape. As patterns change, different suites of species may be favored. However, as we can see in Tables 2 and 3, variability of landscape spatial patterns is the rule, not the exception. Such variability almost certainly affords periods of relative plenty and need, both of which are advantageous to adaptation and survival of native terrestrial and aquatic species (e.g., see Kushlan 1979, Franklin 1980, Frankel and Soule 1981, Karr 1982*a*, *b*, Karr and Freemark 1985, Swanson et al. 1994). It is clear that at any point in time, a certain measure of variability in vegetation spatial patterns is associated with native disturbance regimes and biophysical environments. Such variability across space and time may be vitally important to maintaining patterns of disturbance regimes, as well as for the long-term survival of native terrestrial and associated aquatic species.

One of the most daunting challenges facing forest managers today is that of conserving native biological diversity, and native ecosystem patterns, processes, and interactions. Their conservation with an ever-expanding human population would be challenge enough, had present-day managers inherited ecosystems unaffected by humans. But forest ecosystem patterns and processes are highly modified as a consequence of past management. The task of conserving natural patterns and associated process interactions is virtually impossible without some knowledge of natural pattern variability, and the disturbance regimes that influence such variability. To succeed in forest ecosystem management, present-day managers, much like engineers, must engage in simultaneous problem solving. They must have an understanding of native ecosystem patterns and functioning in order to conserve spatial patterns of living and dead vegetation that are consistent with native wildlife habitat patterns and parameters of native disturbance regimes. And they must provide some measure of commodity resources while conserving habitat

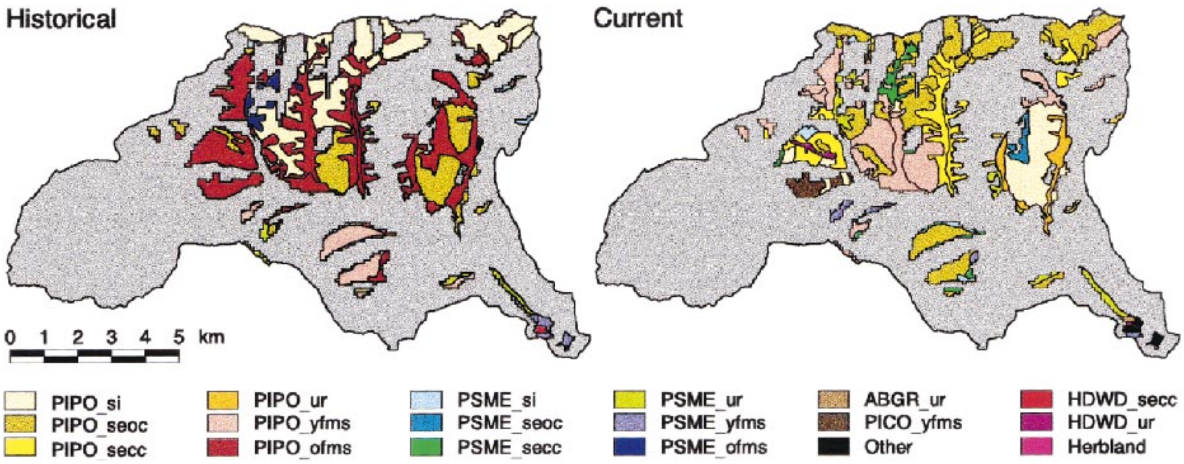

FIG. 6. Maps of the Libby Creek subwatershed MET_11 of the Mesic Forests subregion displaying historical and current distributions of cover type and structural class patch types of the warm–dry Douglas-fir–grand fir potential vegetation type.

patterns that ensure persistence of native species. The difficulty of this task is compounded by effects of past management activities that often constrain current options, as well as placing demands for timber and forage resources in conflict with terrestrial habitat conservation or disturbance regime management.

As human management activities continue to modify spatial patterns of forests, those concerned with managing commodity forest resources must develop a better predictive understanding of terrestrial species and habitat pattern outcomes associated with management. Reference variation estimates can provide valuable insight into vegetation patterns resulting from patterns of biophysical environments and disturbance regimes, and can assist managers to predict conditions better suited to some native species than the existing condition. Reference to natural ranges of conditions does not prescribe specific direction for ecosystem management, but it does define a range (albeit an imperfect range) of ecologically justifiable management decisions. Use of reference variation estimates in watershed analysis and ecosystem management planning defines a range within which compromises between ecological and social values will have to be forged.

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