Expanding Our Understanding of Forest Structural Restoration Needs in the Pacific Northwest

Authors: DeMeo, Tom, Haugo, Ryan, Ringo, Chris, Kertis, Jane, Acker, Steve, et al.

Source: Northwest Science, 92(1) : 18-35

Published By: Northwest Scientific Association

URL: https://doi.org/10.3955/046.092.0104

Tom DeMeo[1], USDA Forest Service, Pacific Northwest Region, 1220 SW Third Avenue, Portland, OR 97204

Ryan Haugo, The Nature Conservancy, The Nature Conservancy, 821 SE 14th Avenue, Portland, OR 97214

Chris Ringo, Department of Crop and Soil Science, Oregon State University, Corvallis, OR 97331

Jane Kertis, USDA Forest Service, 3200 SW Jefferson Way, Corvallis, OR 97331

Steve Acker, USDA Forest Service, 16400 Champion Way, Sandy, OR 97055

Mike Simpson, USDA Forest Service, 63095 Deschutes Market Rd., Bend, OR 97701

and

Mark Stern, The Nature Conservancy, 821 SE 14th Avenue, Portland, OR 97214

Expanding Our Understanding of Forest Structural Restoration Needs in the Pacific Northwest

Abstract

Ecological departure, or how much landscapes have changed from a natural range of variation (NRV), has become a key metric in forest planning and restoration efforts. In this study we define forest restoration need as the specific change in structural stage abundance necessary to move landscapes into the NRV. While most restoration projects in the forested ecosystems of the Pacific Northwest, USA (Oregon and Washington) have embraced this paradigm, our understanding of what treatments to apply where, when, and at what magnitude is evolving and continues to be refined. We build on a body of existing LANDFIRE/Fire Regime Condition Class (FRCC) work on ecological departure to assess the ecological departure of all forested landscapes in the region. Moreover, we assess departure in moister forests west of the Cascade crest, and compare them with fire-dependent forests east of the crest and in southwest Oregon. These "moister Westside" forests have received relatively less attention in a fire ecology context, and we hypothesize restoration needs there are quite different. We show a substantial need for disturbance-related treatments in the drier fire-dependent portion of this region (east of the Cascade crest plus southwest Oregon), with over half of this treatment type falling on Federally-administered land. On the Westside the need for succession is more pronounced. The lack of pronounced disturbance need west of the Cascade crest suggests restoration there may require strategies more nuanced than in the fire-dependent zone.

Introduction

In recent years, forest management in western North America has been shaped by a growing awareness that substantial areas are departed from a natural, sustainable range of variation (Landres et al.1999, Morgan et al. 1994, Swetnam et al. 1999, Keane et al. 2009, Wiens et al. 2012). The natural range of variation (NRV) is the central tendency in variation of the structure, processes, and composition of landscapes over time, in the absence of modern human interference (Landres et al. 1999, Barrett et al. 2010). Because this can be difficult to quantify in the current era, particularly with a changing climate, the historical range of variation is used as an approximation of the natural range. In the Pacific Northwest, this is commonly defined as the 400 years prior to European settlement, or 1450-1850 (Hann et al. 2003). Departure from the central tendency in structure (seral stages) or processes (such as disturbance, notably fire) is assumed to indicate landscapes less resilient and sustainable than those within the natural range.

Landscape management initiatives such as the Eastside Restoration Project in Oregon (Aney 2016), the Ecological Restoration Implementation Plan in California (USFS 2013), or projects

[1]Author to whom correspondence should be addressed. Email: tdemeo@fs.fed.us

generated by the Collaborative Forest Landscape Restoration Act (USFS 2015) use the concepts of the NRV and ecological departure (Barrett et al. 2010) as key justifications for active treatments to promote ecological restoration, "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society for Ecological Restoration 2002)."

Fire regimes are characteristic patterns of fire frequency and severity associated with broad potential vegetation types across landscapes (Agee 1993). Five broad regimes are recognized in the Pacific Northwest. Each regime has a characteristic pattern of fire frequency and severity, ranging from frequent low intensity fire in Fire Regime I to the very infrequent high intensity fire of Fire Regime V (Table 1). Fire regimes can be mapped, since they correlate with corresponding potential vegetation types. The association of each fire regime with a potential vegetation type also means a characteristic median abundance of each seral stage in each potential vegetation type in the pre-European settlement era (prior to 1850 in the Pacific Northwest). This era is assumed to represent a sustainable NRV across landscapes.

Comparing these characteristic historical (assumed natural) abundances of seral stages across the landscape with their current abundances (by potential vegetation type) allows us to gauge departure of these landscapes from an NRV. To report on landscape departures across the US for policy makers, and to implement this broadly among managers, fire regime condition class (FRCC) was developed as an interagency standard approach to assessing ecological departure from an NRV (Schmidt et al. 2002). The vegetation component of departure is assessed with a simple similarity matrix comparing the current abundance (proportion) of seral stages to their estimated historical abundance. Five seral stages are commonly used in this assessment: early seral, mid-seral closed canopy, mid-seral open canopy, late seral open canopy, and late seral closed canopy. FRCC methodology also includes a departure metric for fire frequency and severity, but because both historical and current estimates of these attributes are usually incomplete or lacking, it is often omitted, and we follow that practice here.

Our work builds on a process of expansion and refinement of FRCC methods since their inception in 2002 (Hann and Bunnell 2001, Schmidt et al. 2002, Ryan et al. 2006, Schussmann and Smith 2006, Rollins et al. 2007, Hann et al. 2008, Barrett et al. 2010, Haugo et al. 2015). The ecological departure analyses of both the LANDFIRE/Fire Regime Condition Class (FRCC) programs (Barrett et al. 2010, LANDFIRE 2017) and the restoration needs analysis of Haugo et al. (2015) have emphasized the importance of understanding that NRV reference conditions represent a state of increased ecological resilience and adaptive capacity (Landres et al. 1999, Swetnam et al. 1999, Keane et al. 2009, Wiens et al. 2012, McGarigal and Romme 2012, Moritz et al. 2013). Haugo et al. (2015) extended previous studies of ecological departure by both quantifying levels of ecological departure and also by explicitly distinguishing where, how much, and what types of ecological change (i.e., disturbance vs. succession) were needed to restore NRV forest structures at landscape scales. These treatments could take the form of thinning, prescribed burning, or planning for wildfire as a tool, or in allowing areas to grow into later seral stages through succession.

In this paper, our objectives are to further advance our understanding of forest structural restoration needs, where they occur on the landscape, and what treatments are needed. We hypothesize that the relative abundance of disturbance and succession restoration needs will be very different in moister forest landscapes west of the Cascade crest, when compared with the fire-dependent Eastside and Southwest Oregon. Specifically, we sought these enhancements: 1) to expand the area of assessment to include the entire area west of the Cascade crest (the Westside); 2) to use updated core datasets now available, notably the 2012 iteration of the gradient nearest neighbor (GNN) vegetation layer; 3) to incorporate a refined understanding of ponderosa pine (*Pinus ponderosa*) fire regimes in the Blue Mountains; 4) to use the refined methodology of Davis et al. (2015) in determining structural classes west of

TABLE 1. Historical fire regime groups from Barrett et al. (2010), with examples of corresponding forested potential vegetation types.

Fire Regime Group	Frequency	Description
I	0–35 years	Generally low severity fires replacing less than 25% of dominant overstory; can include mixed severity fires that replace up to 75% of the overstory. Example: Ponderosa Pine (*Pinus ponderosa*)
II	0–35 years	Example: Not applicable, since it is a non-forest fire regime
III	35–200 years	Generally mixed-severity, can also include low severity fires. Example: Mixed conifer.
IV	35–200 years	High-severity fires. Example: Lodgepole pine (*Pinus contorta*).
V	200+ years	Generally replacement-severity, can include any severity type in this frequency range. Example: Moister western hemlock (*Tsuga heterophylla*)

the Cascade crest; and 5) to organize land management areas on Federally-administered land into categories of active management, preservation, or multiple objectives. These refinements are a response to specific feedback from land managers and ecologists on Haugo et al. (2015), and hence expand the body of knowledge needed to make more complete and effective land management decisions.

Methods

Spatial Extent

Figures 1 and 2 provide an overview of the Pacific Northwest (Oregon and Washington). Figure 1 illustrates forest ownership. Figure 2 shows map zones (ecological subregions) and management designations.

The crest of the Cascade Mountains is an important ecological divide in the region. Broadly speaking, areas west of this crest (the Westside) feature higher rainfall and more productive forests, whereas east of the crest (the Eastside) is generally drier, with more fire-dependent forests. An important exception to this is the Southwest Oregon map zone, which is part of the Greater Klamath ecological region extending into California. This map zone is drier than the rest of the Westside, so for our work we are including it in the Eastside. Westside map zones in Figure 2 therefore include the Washington (WA) Coast Range, WA West Cascades, WA North Cascades, Oregon (OR) Coast Range, and OR West Cascades. Eastside map zones include WA East Cascades, WA Columbia Basin, WA Northeast, OR East Cascades, OR Blue Mountains, OR Southeast, and OR Southwest.

We hypothesize Westside landscapes are different and have correspondingly different restoration needs. To make our comparison of Eastside and Westside, we divide the region into two major zones: the Eastside fire-dependent assessment area of Haugo et al. (2015), including all areas east of the Cascade crest plus southwest Oregon; and the Westside (all areas west of the Cascade crest except southwest Oregon). We use "fire-dependent" as a short descriptive phrase for landscapes that historically featured more frequent fires than on the moister west side of the Cascade crest. It is admittedly a simple phrase for complex landscapes—Eastside forests include higher elevation, longer-interval fire regimes as well; and recent work, under development, suggests there may be more area on the Westside in mixed severity than previously thought (Littell et al. 2009, Perry et al. 2011, Tepley et al. 2013, Hessburg et al. 2016)—but it serves to accurately capture the broad ecological differences in these map zones at broad scale. The Westside assessment area includes the OR Coast Range, OR West Cascades, WA Coast Range, WA West Cascades, and WA North Cascades map zones used in the Integrated Landscape Assessment Project (ILAP; Halofsky et al. 2014). ILAP map zone boundaries were adjusted slightly in some areas to coincide with watershed boundaries. This adds 9.2 million ha of forest land to the Haugo et al. (2015) assessment of 11.6 million ha, for a total of 20.8

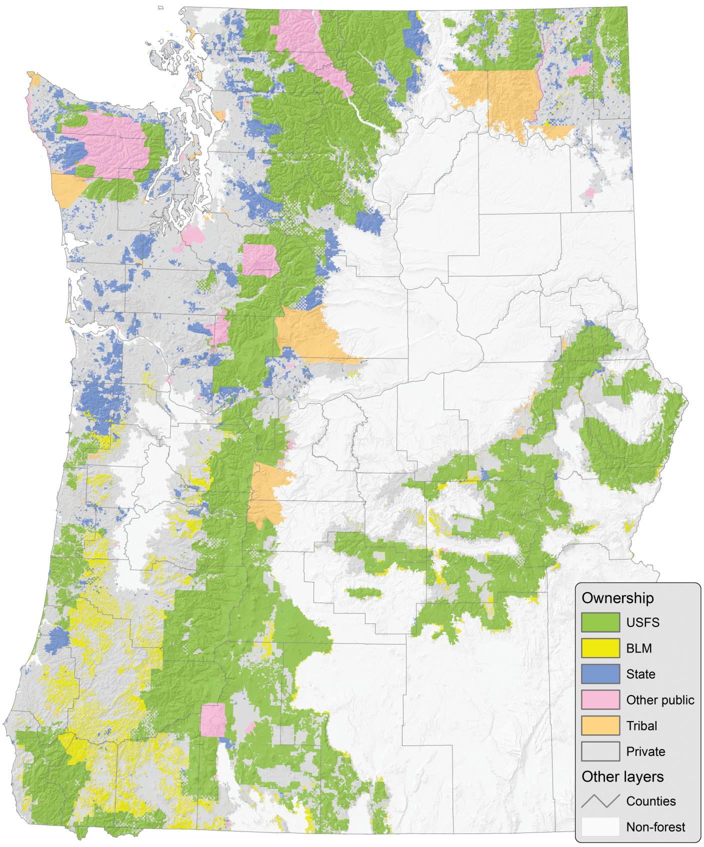

Figure 1. Forest ownership in Oregon and Washington.

million ha. Thus the entire forested area of OR and WA is included (Figures 1 and 2).

Data Inputs

Landscape Analysis Units— We used nested landscape analysis units as in Haugo et al. (2015): "map zones" from the ILAP project (Halofsky et al. 2014) for vegetation types in fire regime groups (FRGs) IV and V; subbasins (8-digit hydrologic units) for FRG III vegetation types; and watersheds (10-digit hydrologic units) for FRG I and II vegetation types (see Haugo et al. (2015) for further details).

Classification and Mapping of Forest Potential Vegetation—Potential vegetation maps at broad scale were used to frame the fire regimes for analysis, because potential vegetation can be associated with specific fire regimes (Table 1). We used the ILAP Potential Vegetation Type (PVT) dataset (Halofsky et al. 2014) to map these biophysical settings across our study region. For this study, we modified the ILAP distributions of xeric and mesic ponderosa pine biophysical settings in the Blue Mountains zone in order to bring the proportion of Fire Regimes I (frequent low severity fire) and III (mixed severity and moderate frequency fire) more in line with actual conditions on the ground.

NRV Reference Conditions for Each Biophysical Setting—Reference conditions are based on the LANDFIRE biophysical setting state-and-transition simulation models (Daniel and Frid 2012, Daniel et al. 2016) developed by the US Forest Service Regional Ecology Program, as part of a team with other Federal, state, and non-governmental partners. These were associated with each ILAP potential vegetation type through crosswalks.

Use of a More Current Map of Existing Forest Structure—Current forest conditions are represented by the distribution of structural stages on the present day landscape, derived from the 2012 Gradient Nearest Neighbor (GNN) forest structure layer (Ohmann and Gregory 2002; Ohmann et al. 2012, 2014; Bell et al. 2015). We assumed these structural stages were an approximation of seral stages. We did not model species composition changes over time, only structural changes.

Structural Classes in Forests West of the Cascade Crest—Tree structural attributes as predicted by the GNN method were observed to be less accurate

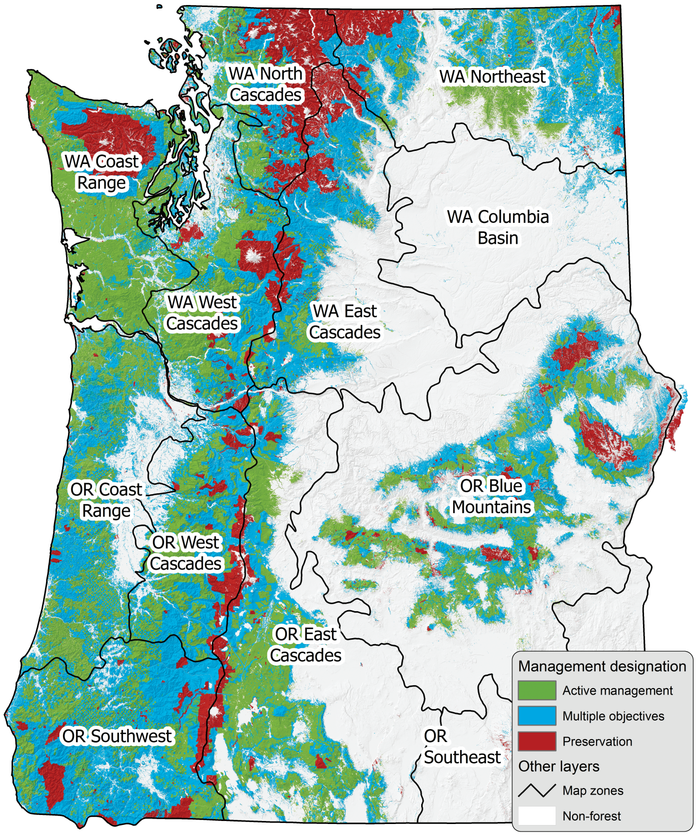

Figure 2. Management designations and ecological map zones in Oregon and Washington.

for forests west of the Cascade crest, probably due to both larger tree sizes and more variation in diameter class distributions. For these reasons, Westside forests were omitted from Haugo et al. (2015).

Because assessing the Westside was one of our key objectives, we sought to improve our understanding of assignment of current forest size class for this subregion. To address this, we used the Old Growth Structure Index (OGSI) developed by Davis et al. (2015) and applied it to GNN coverages. We developed this process to map late-successional states for Westside forests (northwest Oregon and western Washington) based on the definitions and process outlined in the Northwest Forest Plan (NWFP) 20-year status and trends report (Davis et al. 2015). An old growth index was created for each tree series across the NWFP area using density of large live trees, density of large snags, cover of downed wood, and tree diameter diversity. Eighty to 200-year thresholds were determined (OGSI-80 and OGSI-200, respectively), which were intended to bracket a continuum of old growth structural characteristics. We used the OGSI-80 index values to develop tree density thresholds, seeking to find the lower limit where some late-successional characteristics are present in order to help identify late development successional classes, following LANDFIRE biophysical setting definitions. We wanted the mid-seral stage development successional classes to include vegetation that had minimal representation of late- successional forest characteristics, making the need for restoration unambiguous. We realize this required making assumptions about the discreteness of each seral stage that are an approximation of actual forests. Specific details of the process are available in Supplementary Document S1 and Supplementary Table S1.

Management Classes on US Forest Service-Administered Lands—In order to improve our understanding of land management options, the current analysis incorporates a new spatial database of land management allocations on National Forests across Oregon and Washington. Land resource management plan (LRMP) spatial databases were obtained for each national forest in the region, together with a database of Northwest Forest Plan (USDA and USDI 1994) allocations (Ringo et al. 2016). Each LRMP and NWFP land management designation was then classified according to “restrictions for conducting mechanical treatments that are key to reducing wildfire risk, providing socioeconomic benefits as part of restoration programs, and preparing forests for prescribed fire where appropriate" (USDA and USDI 1994). In cases in which forest LRMP and NWFP coding differed, the more restrictive code was adopted. Outside national forest lands, the same ILAP (Halofsky et al. 2014) management layer was used as in our previous study, although codes were grouped differently.

For the purposes of the current study, land use management was grouped into three categories: "Active management", intended to capture those areas where the use of forest restoration tools such as mechanical thinning or prescribed fire is generally allowed; "Preservation", which includes protected areas such as wilderness, in which active management intervention for forest restoration purposes is prohibited; and "Multiple objectives", which includes areas in which such treatments are allowed only under certain circumstances, such as riparian reserves, inventoried roadless areas, or late-successional reserves designated under the NWFP. (The Conservation and Stand Age Dependent categories from Ringo et al. (2016) are included in our category of Multiple Objectives.) See Supplementary Tables (S2, S3, S4, and S5) for further details on management coding.

Using the Data Inputs

Following Haugo et al. (2015), we evaluated forest restoration needs for each watershed (5^{th}-field hydrologic unit code, or HUC). Within a HUC, we compared current seral stage abundance for a biophysical setting with the corresponding NRV seral stage abundance. This comparison of relative abundance identifies whether each seral stage-potential vegetation type-landscape unit combination is currently in excess, deficit, or within range when compared with NRV reference conditions.

Next, for each landscape unit-biophysical setting combination, the transitions between successional classes needed to "rebalance" the successional classes relative to NRV reference conditions were determined. Each specific transition between successional classes was characterized as requiring either "disturbance only," "disturbance then succession," or "succession only." "Disturbance only" represents transitions from closed canopy to open canopy and/or from later development to earlier development successional classes. "Successional only" represents transitions from open to closed canopy and/or from earlier to later development successional classes. "Disturbance then succession" represents the combination of the previous two categories, typically a transition from the early or mid-development closed canopy (through thinning or other action) to the late-development open canopy successional class (through growth over time). A complete description of the restoration needs calculation methodology can be found in Haugo et al. (2015).

Comparison with Standard Fire Regime Condition Class Metrics

In order to further facilitate communication and understanding with departure metrics commonly in use, we also present our comparison of current conditions versus NRV reference conditions using standard Fire Regime Condition Class metrics (Barrett et al. 2010). We see our ongoing work as furthering the refinement and understanding of this metric of ecological departure from the NRV, as well as improved facilitation of applying this work to field projects.

Complete assessment of FRCC also includes a comparison of current fire frequency and severity with the corresponding historical estimates (as shown in Table 1). FRCC can be assessed in a number of ways. Departure can be reported by landscape units (typically watersheds), biophysical settings within landscape units (referred to as strata), and by identifying the area (hectares) within a watershed in excess or deficit when compared with the historical amount expected by potential vegetation and seral stage. The excess/deficit approach is referred to as S (seral) class relative amount (Barrett et al. 2010). The FRCC departure metric is sometimes referred to as the "Simple 7" since it incorporates assessment of (five) seral stages plus (two) fire occurrence metrics (frequency and severity), or a total of seven. It is considered "simple" since it uses the standard

FRCC method of comparing current abundance of seral stages against the modeled abundance of seral stages in the NRV (Barrett et al. 2010).

Region Wide Trends in Forest Restoration Need

We generated tallies of forest structural restoration needs by land ownership need for disturbance, need for succession, restoration need by owner and map zone, restoration need by fire-dependent zone/moister zone, and fire regime group. For comparison with a more standard FRCC approach, we also calculated FRCC results by biophysical setting (strata) using the Simple 7 method (Barrett et al. 2010).

Results

The overall restoration need in Oregon and Washington for change in forest structural class through disturbance such as thinning, prescribed burning, or wildfire (combined disturbance only and disturbance then succession restoration need categories) is about 4,424,000 ha or 21% of the entire forested landscape (Table 2, Figure 3). Fifty-seven percent of the total disturbance restoration needs are on Forest Service and Bureau of Land Management (BLM)-administered lands (Table 2). Restoration needs by land ownership are presented in Table 2. Restoration needs for the Eastside and Westside are presented in Tables 3 and 4, respectively.

The contrast between fire-dependent areas (east of the Cascade crest plus Southwest Oregon) and the moister Westside is striking. Of the 11.6 million ha of forests in Fire-dependent (Eastside) areas, 3.8 million ha (or 33%) are in need of disturbance, or disturbance followed by succession (Table 3, Figure 3); 0.8 million ha (or 7%) are in need of succession only. In Westside forests, only 0.6 million ha (or 7.0%) of the 9.2 million ha of forests found there are in need of disturbance, or disturbance plus succession (Table 4); 24% of Westside forests are in need of succession only. This contrast is supported in Figures 3 and 4.

Land ownership plays an important role in planning restoration. Because of restrictions on active management in wilderness areas, normally only lands outside of Preservation areas are considered for treatment. Of the fire-dependent Eastside area in need of disturbance restoration (disturbance or disturbance followed by succession), 2 million ha (or 57%) fall on Forest Service- or BLM-administered lands outside Preservation (primarily Wilderness) areas (Table 3, Figure 5). On the Westside, 0.2 million ha of the 0.5 million ha (or 36%) of disturbance restoration needs fall on Forest Service- or BLM-administered lands designated outside Preservation (Table 4, Figure 5). In terms of succession only restoration outside of Preservation areas, 47% (0.3 million ha) of the need can be met on Forest Service and BLM-administered lands in fire-dependent Eastside areas (Table 3, Figure 5), while only 12% (0.3 million ha) of the succession-only need of 2.0 million ha can be met on Forest Service and BLM-administered Westside forests (Table 4).

Within the fire-dependent Eastside zone, 1.4 million ha of the total 3.8 million ha of disturbance-related need (or 38%) falls on land designated for Active Management, 2.0 million ha (or 54%) is on land designated for Multiple Objectives, and the balance of 0.3 million ha (or 8%) falls on Preservation land (Table 3). In the Westside zone, the need for disturbance-related restoration is about the same for Active Management and Multiple Objectives (0.3 million ha and 0.24 million ha respectively), with 0.1 million ha in Preservation (Table 4).

In our study, Forest Service- and Bureau of Land Management (BLM)-administered lands comprise 0.8 million ha (or 56%) of the 1.4 million ha identified as needing disturbance-related restoration in the Active Management portion of the fire-dependent Eastside, and 58% (or 1.2 million ha) of the 2.0 million ha designated as Multiple Objectives (Table 3). In the Westside zone, the totals are different, with only 16% of the Active Management disturbance-related need (47000 ha of 0.3 million ha) identified on Forest Service or BLM land (Table 4). For Multiple Objectives land, more Forest Service/BLM land is identified, with 146,000 ha of 240,000 ha (or 61%) of total lands in this category. Owners of non-Federally administered lands may of course have other

TABLE 2. Forest restoration needs by land ownership in forested areas of the Pacific Northwest. USFS=United States Forest Service, BLM=Bureau of Land Management. Southwest Oregon is included in the Eastside totals.

Forest Owner	Total ha.	Disturbance Only ha.	%	Disturbance then Succession ha.	%	Succession Only ha.	%
Eastside	11,589,000	1,565,000	14	2,212,000	19	845,000	7
USFS	6,352,000	948,000	15	1,008,000	16	371,000	6
BLM	705,000	93,000	13	196,000	28	74,000	10
State	390,000	50,000	13	89,000	23	26,000	7
Other public	141,000	22,000	16	12,000	9	11,000	8
Tribal	697,000	83,000	12	152,000	22	38,000	5
Private	3,304,000	369,000	11	755,000	23	325,000	10
Westside	9,229,000	208,000	2	439,000	5	2,188,000	24
USFS	2,604,000	137,000	5	78,000	3	254,000	10
BLM	389,000	11,000	3	32,000	8	60,000	15
State	1,045,000	5,000	0	37,000	4	277,000	27
Other public	678,000	29,000	4	9,000	1	83,000	12
Tribal	123,000	1,000	1	6,000	5	52,000	42
Private	4,390,000	25,000	1	277,000	6	1,462,000	33
Regional Totals	20,826,000	1,773,000	9	2,651,000	13	3,033,000	15

objectives, but our work still provides a useful broader landscape context for these ownerships.

Restoration needs for disturbance (area in ha) in shorter interval fire regimes (Fire Regimes I and III) are greatest in the Oregon Southwest, Washington Northeast, Oregon Blue Mountains, Oregon East Cascades, and Washington East Cascades, in that order. Succession needs (area in ha) are in the longer-interval fire regimes (Fire Regimes IV and V) in the Oregon Coast Range, Washington Coast Range, Washington West Cascades, and Washington North Cascades, in that order (Figure 6).

Discussion

Our results indicate different approaches will be needed to meet restoration needs across the region. Although both disturbance and succession strategies are needed in both fire prone and mesic areas, more than three times the need for all disturbance-related restoration (i.e., disturbance plus disturbance then succession) occurs on the fire-dependent Eastside, compared with the Westside (3.78 million ha vs. 0.65 million ha, respectively; Tables 3 and 4). In contrast, the need for succession restoration on the Westside is more than twice that in the fire-dependent zone (2.2 million ha versus 0.84 million ha, respectively). These results may reflect the current deficit of the late development -closed canopy successional class in many Westside forest types because of extensive logging in the 1970s and 1980s. Although succession as a restoration strategy is called for on the Westside (Figure 4), some silvicultural interventions, such as variable density thinning, may be useful tools to help meet this need for succession by accelerating the successional development of complex, closed canopy forests (Bailey and Tappeiner 1998, Garman 1999, Busing and Garman 2002, Franklin et al. 2002, Franklin and Johnson 2012).

A growing awareness of the need to manage fire both inside and outside wilderness (Preservation) areas to meet restoration objectives has emerged within the fire management and fire ecology communities. The magnitude of the restoration need suggests consideration of options such as letting some fires burn, or letting fires burn within certain constraints.

In recent years, a lack of early seral stage structure in many western forests has been documented (Spies and Johnson 2007, Swanson et al. 2011, Swanson 2012). (For a thorough review

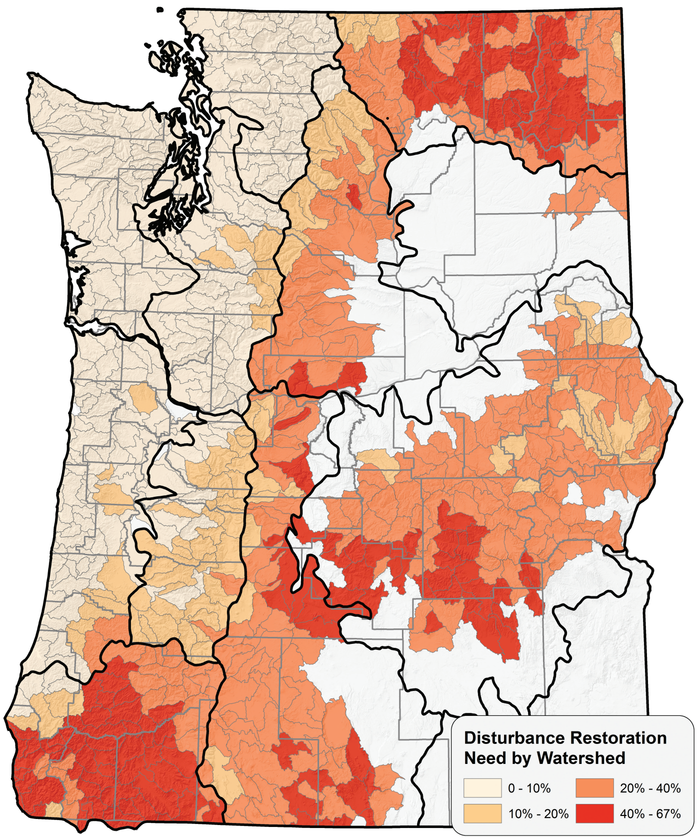

Figure 3. Disturbance restoration needs (disturbance only plus disturbance then succession) in forested areas of the Pacific Northwest.

see Swanson 2012.) There is a growing body of work documenting the importance of naturally-structured, complex early seral areas incorporating legacies of downed wood, snags, and other elements from the preceding forest (Franklin et al. 2000, 2002; Hutto 2008; Donato et al. 2012). Somewhat surprisingly, we found few deficits of the early development successional class. We found no disturbance need (i.e., creating early seral forest) in any of these map zones, with the exception of the Sitka spruce biophysical setting along the coast, where 27000 ha of disturbance followed by succession are indicated for the Oregon Coast Range, 40000 ha in the Washington Coast Range, and a negligible amount (6 ha) in the Western Washington Cascades. (See Table B3 accompanying this paper online). Deal et al. (2015) found a deficit of early seral forest on Federally-administered land, and an excess on private land. Our results are in general agreement with Deal et al. (2015) for private lands, but we failed to find a major need for early seral on Federally-administered land.

These differences may be explained by our analysis methodology. Within biophysical settings historically characterized by infrequent, high severity fire (Fire Regime Groups IV and V) our landscape unit for our analysis was the map zone (e.g., Washington West Cascades, Oregon Coast Range, etc.). Consequently, the abundance of early development successional classes resulting from logging on the extensive private industrial forest lands in Westside map zones offset the lack of recent disturbance on federal forests.

We also add a strong caveat, however, that our work did not distinguish between naturally-structured early seral areas and the relatively simple structure resulting from plantations with relatively few legacy elements from the previous forest. Plantations will likely have a different plant composition and be on a different seral trajectory than early seral caused by natural disturbances (Poage and Tappeiner 2002). Our work did not include evaluation of how well these early seral areas match the composition of areas naturally disturbed. Moreover, the apparent relative abundance of early seral land on private lands likely reflects a plantation approach with a lack of complexity.

Some work indicates Westside forests historically had larger areas in early seral than they do today (Wimberly et al. 2000, Takaoka and Swanson 2008), and historically were often in an open early seral state for long periods of time (Teensma et al. 1991, Tappeiner et al. 1997, Franklin et al.

TABLE 3. Restoration needs by management category and land administration in forested areas of the Pacific Northwest for the fire-dependent areas east of the Cascade crest, and also including southwest Oregon (Eastside). Management categories are from Ringo et al. (2016). Multiple objectives also includes the Conservation and Stand Age Dependent categories from that document. Administration/restoration combinations with areas less than 500 ha are indicated by a dash.

	Total	Disturbance Only		Disturbance then Succession		Succession Only	
	ha.	ha.	%	ha.	%	ha.	%
Active management							
USFS	2,016,000	293,000	15	433,000	21	98,000	5
BLM	247,000	26,000	11	62,000	25	26,000	11
State	81,000	9,000	11	18,000	22	6,000	7
Other public	4,000	-	-	1,000	25	-	-
Tribal	580,000	75,000	13	130,000	22	31,000	5
Private	1,217,000	138,000	11	259,000	21	131,000	11
Multiple objectives							
USFS	3,198,000	496,000	16	510,000	16	182,000	6
BLM	382,000	59,000	15	115,000	30	42,000	11
State	284,000	38,000	13	67,000	24	18,000	6
Other public	35,000	6,000	17	7,000	20	3,000	9
Tribal	117,000	8,000	7	22,000	19	7,000	6
Private	2,051,000	226,000	11	486,000	24	191,000	9
Preservation							
USFS	1,138,000	160,000	14	65,000	6	91,000	8
BLM	76,000	8,000	11	19,000	25	6,000	8
State	25,000	3,000	12	4,000	16	2,000	8
Other public	102,000	16,000	16	4,000	4	7,000	7
Tribal	-	-	-	-	-	-	-
Private	36,000	5,000	14	10,000	28	3,000	8

2002, Poage et al. 2009). In the Pacific Northwest, state-and-transition modeling has a long history, typically using Vegetation Dynamics Development Tool (VDDT) software, now updated with State-and Transition Simulation Modeling (ST-Sim) (Daniel and Frid 2012, Daniel et al. 2016). We hypothesize that more recent VDDT/ST Sim modeling more accurately captures the historical pattern, and that the early seral structural stage did not persist as long as previous thought. Clearly, the complexity, longevity, and extent of early seral forest on the Westside needs further investigation and refinement. Refining models of the NRV to better account for temporal variability in fire sizes and low probability/high impact fire events should be part of this. Assessing landscapes can be seen as an ongoing process of successive refinement, and in future iterations of our work we intend to explore and incorporate a distinction for early seral complexity/lack of complexity in the analysis.

A related concern in FRCC methodology is forest species composition. The FRCC method uses forest structure to define seral stages; species composition is not taken fully into account. Hugh Safford (USDA Forest Service, personal communication) and others have reported this weakness when FRCC methods are applied to fire-dependent California forests. In the Pacific Northwest, grand fir (*Abies grandis*) in potential vegetation types (notably ponderosa pine), where it was historically less abundant, is a composition concern in management that may be missed if only forest structure is considered (Hessburg et al. 2015). Previous logging that emphasized the removal of large ponderosa pine may also have an effect on current late seral species composition.

TABLE 4. Restoration needs by management category and land administration in forested areas of the Pacific Northwest for the area west of the Cascade crest (Westside), excluding southwest Oregon. Management categories are from Ringo et al. (2016). Multiple objectives also includes the Conservation and Stand Age Dependent categories from that document. Land administration/restoration combinations with areas less than 500 ha are indicated by a dash.

	Total	Disturbance Only		Disturbance then Succession		Succession Only	
	ha.	ha.	%	ha.	%	ha.	%
Active management							
USFS	301,000	17,000	6	16,000	5	22,000	7
BLM	104,000	3,000	3	11,000	11	16,000	15
State	477,000	1,000	0	20,000	4	145,000	30
Other public	2,000	-	-	-	-	-	-
Tribal	123,000	1,000	1	6,000	5	52,000	42
Private	3,099,000	15,000	0	210,000	7	1,089,000	35
Multiple objectives							
USFS	1,635,000	64,000	4	53,000	3	169,000	10
BLM	274,000	8,000	3	21,000	8	43,000	16
State	508,000	3,000	1	16,000	3	122,000	24
Other public	4,000	-	-	-	-	1,000	25
Tribal	-	-	-	-	-	-	-
Private	1,263,000	9,000	1	66,000	5	365,000	29
Preservation							
USFS	668,000	56,000	8	9,000	1	63,000	9
BLM	11,000	-	-	-	-	1,000	9
State	60,000	1,000	2	1,000	2	10,000	17
Other public	672,000	29,000	4	9,000	1	81,000	12
Tribal	-	-	-	-	-	-	-
Private	28,000	-	-	1,000	4	6,000	21

Land allocations are also an important consideration in assessing restoration needs, as they can indicate practical options (or lack of options) on landscapes. In Tables 3 and 4, we use three broad land use management categories of Active Management, Multiple Objectives, and Preservation, following Ringo et al. (2016). We caution that this work is far from prescriptive, and that any work on the ground must involve careful planning to reflect local complexities. Nevertheless, our work should be a powerful planning tool to indicate forest structural restoration needs at the scale of Regional assessments, National Forest plans, and BLM District resource management plans.

A comparison of this analysis with results from the "Simple 7" analysis (Figure 7) shows Westside ecological departure in different ways. The Simple 7 approach reports overall landscape departure, regardless of whether that departure reflects a need for disturbance or succession. The clearly departed areas west of the Cascade crest reflect a need for succession. The Simple 7 analysis is a reminder that departure can result from a variety of sources, including past logging history, and not only from fire suppression. The moister Westside map zones show a stronger need for succession than for disturbance (Table 4), and this is reversed on the fire-dependent Eastside (including Southwest Oregon) where the need for disturbance and disturbance followed by succession is more prominent (Table 3). Use of a our more targeted approach, where specific needs for disturbance and succession are identified, offers a clearer picture of restoration needs than the broader FRCC strata map (Figure 7).

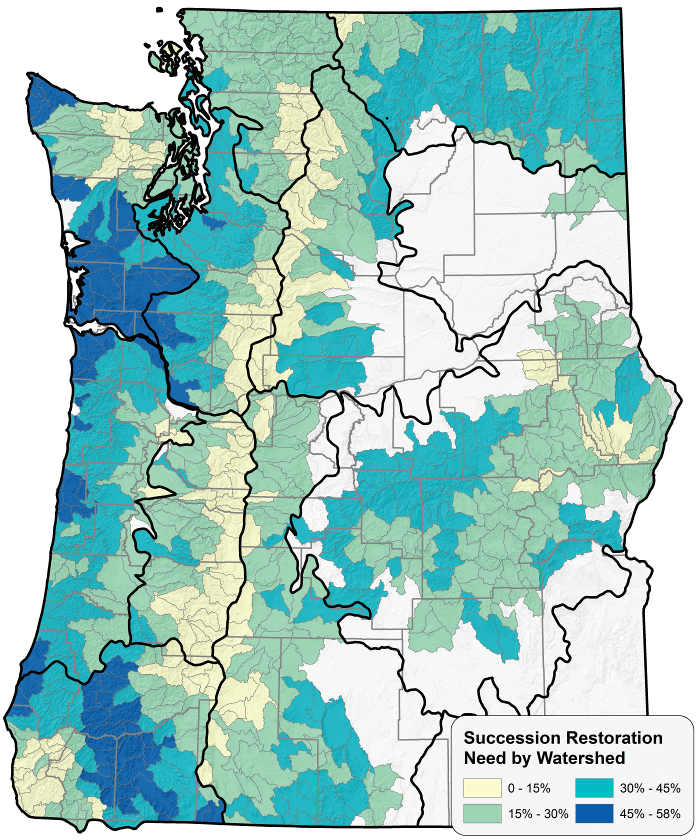

Figure 4. Map of succession restoration needs (succession only plus disturbance then succession) in forested areas of the Pacific Northwest

With a changing climate, increased numbers of large fires are expected in the Pacific Northwest (Trouet et al. 2006, Littell et al. 2009, 2010; Rogers et al. 2011, Raymond and McKenzie 2012). Recent work by Reilly et al. (2017), documenting fires in the region from 1985-2010, indicates fire severity and sizes are within historical norms, with the notable exception of the ponderosa pine zone (Fire Regime I) east of the Cascade crest. Fire suppression has resulted in shifts in species composition and fuel accumulations that led to higher severity fire effects. Future large fires of concern are associated with drought events, since they can generate fires with unique, uncertain ecological outcomes (Littell et al. 2010). In the moist Westside zone, fires during 1985-2010 were consistent with historical norms. Although fire extent is predicted to increase three times by the 2040s, they are still predicted to cover a relatively small area (Littell et al. 2010). Reilly et al. (2017) builds on a growing body of work (Dillon et al. 2011, North et al. 2015, Calkin et al. 2015) pointing to the need for a revised suppression strategy, letting some fires burn under less extreme fire weather conditions so that fires in extreme weather conditions are minimized and more within the NRV.

In recent years the adequacy of potential vegetation and the range of natural variation have come into question. Some authors have suggested a future range of variation be developed (Thompson et al. 2006, 2009; Moritz et al. 2013). Patterns of vegetation and ecological processes within an historical range of variation may not be stable, not only because of land development and alteration since 1850, but because of a changing climate. As we continue to learn, we build an understanding of what a future range of variation might look like, but it is also important to keep perspective. Our understanding of the historical range of variation is currently better developed than our understanding of a future range (Keane et al. 2009). Moritz et al. (2013) have suggested a bounded range of variation building on the NRV but incorporating socio-ecological thresholds. At present, an historical range of variation offers our best understanding of what the NRV is, and hence our best understanding of sustainable and resilient landscapes. We should continue to refine these understandings until we reach a point where we can use a future range of variation with confidence. As Reilly et al. (2017) have shown, fires in the ponderosa pine type are now outside the historical range in fire size, but in other potential vegetation types they are still within historical norms. This

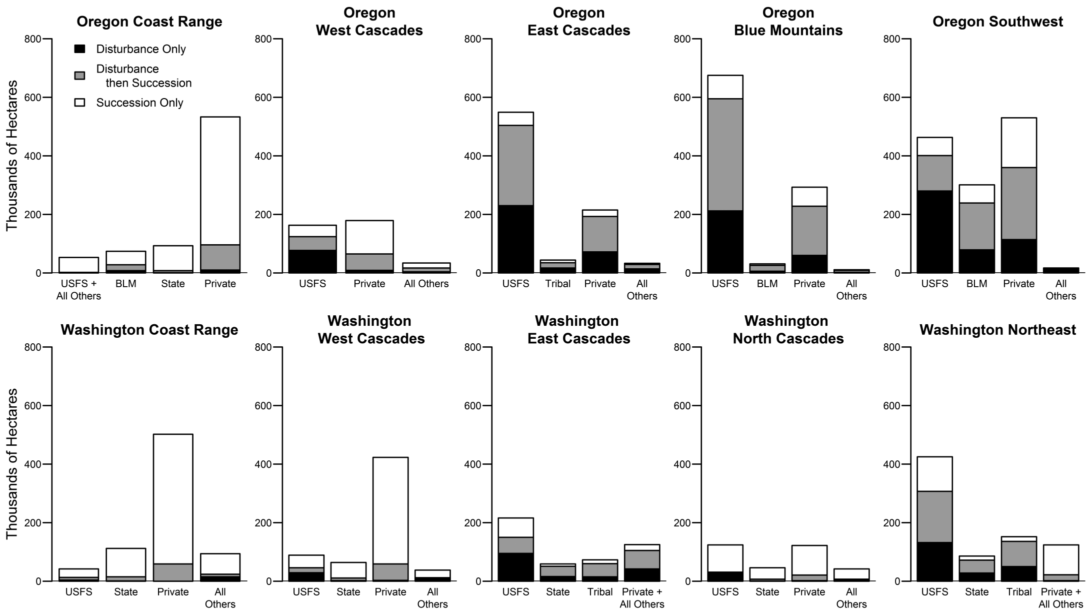

Figure 5. Restoration needs (hectares) in forested areas of the Pacific Northwest by land administration and map zone. Not listed: Oregon Southeast and Washington Columbia Basin, because of minor amounts of forested area.

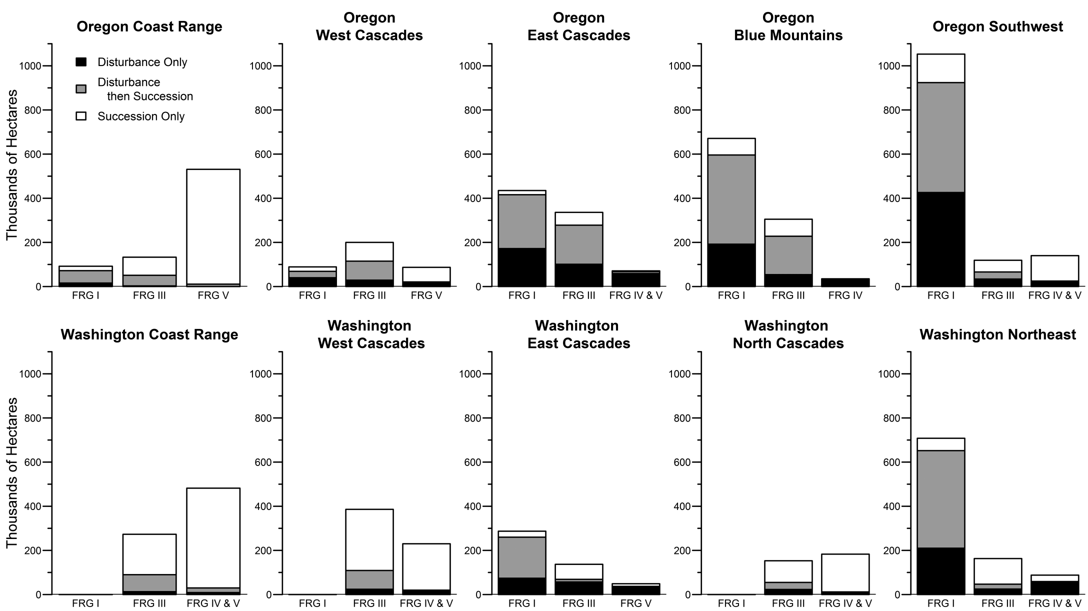

Figure 6. Restoration needs (hectares) in forested areas of the Pacific Northwest by fire regime group and map zone. Not listed: Oregon Southeast and Washington Columbia Basin because of minor forest areas.

adapt as more is learned, there is little evidence that current recommendations for restoration through thinning, prescribed fire, and wildland fire use based on our current understanding of potential vegetation and the NRV will have adverse effects. Indeed, the experience so far is that they will be inadequate, and that we should seek ways to effectively increase the magnitude of our impact.

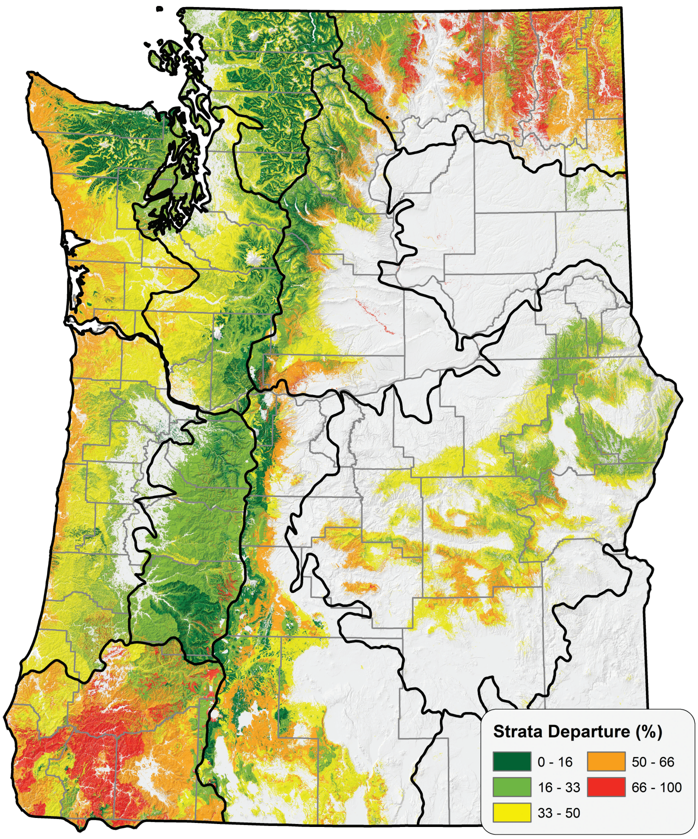

Figure 7. Fire regime condition class (FRCC) assessment of the study area by potential vegetation type and landscape unit (strata) using a modified Simple 7 method to display percent departure from natural range of variation (NRV). See text for further discussion.

Summary

Our work clearly indicates a strong difference in forest structural restoration need between the fire-dependent zone east of the Cascade crest and Southwest Oregon (the Eastside), and moister forests west of the Cascade crest (the Westside). Eastside forests are dominated by a need for disturbance, and Westside forests by a need for succession.

In our work, we did not distinguish between complex early seral and the relatively simple structure of forest plantations. This is an important issue, and the provision for complex early seral forest, in contrast to that generated by conifer plantations and/or removal of early seral hardwoods on industrial forests, remains a pressing management concern. We intend to add this refinement in future work.

Forest restoration should consider species composition in addition to structure. This is a weakness inherent in FRCC-related metrics. Planned restoration treatments should take this into consideration. Another consideration for Westside structural restoration is the opportunity for silvicultural treatments, such as variable density thinning, to accelerate development of late-seral forest characteristics.

will undoubtedly change with a warming climate (Littell et al. 2009, 2010). Vegetation is affected not only by systematic climate changes, but also by local, non-climatic factors (Parmesan and Yohe 2003). Fires are often affected by local topographic factors, so they may not directly follow climate shifts (Moritz et al. 2013). Insects and pathogens will also have an influence in this process. Finally, in adaptive management the challenge of applying science is to avoid severe mistakes that preclude options. In the face of uncertain or incomplete information, management decisions that "do no harm" can be acceptable, and can be adjusted as time goes on. Although we should continually

A warming climate is another factor affecting the implications of our work. However, all evidence encountered so far indicates both Eastside and Westside restoration treatments will be effective tools to help landscapes remain or become more resilient in the face of climate impacts.

Refinements in our understanding of ecological departure and restoration reported in this paper include: 1) a more recent mapping of current forest structure; 2) better determination of structural classes, particularly in more productive forests west of the Cascade crest; 3) a more accurate depiction ponderosa pine biophysical setting mapping for the Blue Mountains of northeast Oregon; and 4) complete coverage of the forested areas of Oregon and Washington.

Considerations of early seral needs, species composition, and silvicultural options to encourage development of late seral characteristics are important considerations for planning restoration on the Westside, making it more nuanced than the Eastside. And local planning always involves a complex set of environmental, economic, and social considerations and constraints. Nevertheless, our work is a powerful tool for planning forest structural restoration needs at the scale of regional or Forest plan assessments.

Acknowledgments

This work builds on a body of LANDFIRE/FRCC work accomplished over many years. This includes the national LANDFIRE/FRCC team, notably Wendell Hann, Steve Barrett, and Jim Menakis. Regionally, our colleagues at The Nature Conservancy, Cathy Macdonald and Steve Buttrick, had a role in FRCC refinement and reporting. FRCC training sessions over the years helped refine our thinking on developing more specific FRCC methods. Bill Aney, Chris Johnson, and Gregg Riegel of the Forest Service; Louisa Evers and Doug Havlina of the Bureau of Land Management; and Reese Lolley of The Nature Conservancy all shared ideas that eventually led to this work. Authors for Haugo et al. (2015) who did not directly contribute to this paper are likewise acknowledged and appreciated. We thank the reviewers of the manuscript. We thank Ray Davis for his work in developing the OGSI to improve the structural stages used in the analysis. Finally, we are grateful for significant formatting and editing help from Amy Nathanson.

Literature Cited

Agee, J. K. 1993. Fire Ecology of Pacific Northwest Forests. Washington, DC: Island Press.

Aney, W. C. 2016. NFS-R6-Accelerated eastside restoration. Pendleton, OR: USDA Forest Service Briefing paper.

Bailey, J. D., and J. C. Tappeiner. 1998. Effects of thinning on structural development in 40-to100-year-old Douglas-fir stands in western Oregon. Forest Ecology and Management 108:99-113.

Barrett, S., D. Havlina, J. Jones, W. Hann, C. Frame, D. Hamilton, K. Schon, T. DeMeo, L. Hutter, and J. Menakis. 2010. Interagency Fire Regime Condition Class Guidebook. Version 3.0 Available online at https://www.frames.gov/partner-sites/frcc/frcc-guidebook-and-forms/ (accessed 19 June 2017).

Bell, D. M., M. J. Gregory, and, L. Ohmann. 2015. Imputed forest structure uncertainty varies across elevational and longitudinal gradients in the western Cascade Mountains, Oregon, USA. Forest Ecology and Management 358:154-164.

Busing, R. T., and S. L. Garman. 2002. Promoting old-growth characteristics and long-term wood production in Douglas-fir forests. Forest Ecology and Management 160:161-175.

Calkin, D. E., M. P. Thompson, and M. A. Finney. 2015. Negative consequences of positive feedbacks in US wildfire management. Forest Ecosystems 2:9. doi: 10.1186/s40663-015-0033-8.

Daniel, C. J., and L. Frid. 2012. Predicting landscape vegetation dynamics using state-and-transition simulation models. *In*: B. K. Kerns, A. J. Shlisky, and C. J. Daniel (technical editors), Proceedings of The First Landscape State-and-Transition Simulation Modeling Conference, June 14–16, 2011, Portland, Oregon. USDA Forest Service General Technical Report PNW-GTR-869, Pacific Northwest Research Station, Portland, OR. Pp. 5-22.

Daniel, C. J., L. Frid, B. M. Sleeter, and M. Forin. 2016. State-and-transition simulation models: A framework for forecasting landscape change. Methods in Ecology and Evolution 7:1413-1423.

Davis, R. J., J. L. Ohmann, R. E. Kennedy, W. B. Cohen, M. J. Gregory, Z. Yang, H. M. Roberts, A. N. Gray, and T. A. Spies. 2015. Northwest Forest Plan—the first 20 years (1994-2013): Status and trends of late-successional and old-growth forests. USDA Forest Service General Technical Report PNW-GTR-911, Pacific Northwest Research Station, Portland, OR.

Deal, R. L., S. Stanton, M. Betts and Z. Yang. 2015. Early-seral stand age and forest structural changes in public and private forestlands in Western Oregon and Washington. *In*: S. M. Stanton, and G. A. Christensen (compilers 2015), Pushing Boundaries: New Directions in Inventory Techniques and Applications: Forest Inventory and Analysis (FIA) Symposium 2015. 2015 December 8–10; Portland, Oregon. USDA Forest Service General Technical Report PNW-GTR-931 (revised edition). Pacific Northwest Research Station, Portland, OR. Pp 94.

Dillon, G. K., Z. A. Holden, P. Morgan, M. A. Crimmins, E. K. Heyerdahl, and C. H. Luce. 2011. Both topography and climate affected forest and woodland burn severity in two regions of the western US, 1984 to 2006. Ecosphere 2:130.

Donato, D. C., J. L. Campbell, and J. Franklin. 2012. Multiple successional pathways and precocity in forest development: can some forests be born complex? Journal of Vegetation Science 23:576-584.

Franklin, J. F., D. B. Lindenmayer, J. A. MacMahon, A. McKee, J. Magnuson, D. A. Perry, R. Waide, and D. Foster. 2000. Threads of continuity: ecosystem disturbance, recovery, and the theory of biological legacies. Conservation Biology in Practice 1(1):8-16.

Franklin, J .F., T. A. Spies, R. Van Pelt, A. B. Carey, D. A. Thornburgh, D. R. Berg, D. B. Lindenmayer, M. E. Harmon, W. S. Keeton, D.C. Shaw, K. Bible, and J. Chen. 2002. Disturbances and structural development of natural forest ecosystem with silvicultural implications: Using Douglas-fir forests as an example. Forest Ecology and Management 155:399-423.

Franklin, J. F., and K. N. Johnson. 2012. A restoration framework for federal forests in the Pacific Northwest. Journal of Forestry 110:429-439.

Garman, S. L. 1999. Accelerating development of late-successional conditions from young managed Douglas-fir stands: a simulation study. Technical Report. Forest Science Laboratory, Oregon State University, Corvallis, OR.

Halofsky, J. E., M. K. Creutzburg, M. A. Hemstrom, and A. Miles (editors). 2014. Integrating social, economic, and ecological values across large landscapes. USDA Forest Service General Technical Report PNW-GTR-896, Pacific Northwest Research Station, Portland, OR.

Hann, W. J., and D. L. Bunnell. 2001. Fire and land management planning and implementation across multiple scales. International Journal of Wildland Fire 10:389-403.

Hann, W. J., M. J. Wisdom, and M. M. Rowland. 2003. Disturbance departure and fragmentation of natural systems in the Interior Columbia Basin. Portland, OR: USDA and USDI Research Paper PNW-RP-545.

Hann, W. J., A. Shlisky, D. Havlina, K. Schon, S. Barrett, T. DeMeo, K. Pohl, J. Menakis, D. Hamilton, J. Jones, and M. Levesque. 2008. Interagency Fire Regime Condition Class Guidebook. Interagency and The Nature Conservancy fire regime condition class website. USDA Forest Service, US Department of the Interior, The Nature Conservancy, and Systems for Environmental Management. Available online at https://www.frames.gov/documents/frcc/documents/FRCC+Guidebook_2008.10.30.pdf (accessed 19 June 2017).

Haugo, R., C. Zanger, T. DeMeo, C. Ringo, A. Shlisky, K. Blankenship, M. Simpson, K. Mellen-McLean, J. Kertis, and M. Stern. 2015. A new approach to evaluate forest structure restoration needs across Oregon and Washington, USA. Forest Ecology and Management 335:37-50.

Hessburg, P.F., D.J. Churchill, A.J. Larson, R. D. Haugo, C. Miller, T. A. Spies, M. P. North, N. A. Povak, R. T. Belote, P. H. Singleton,W. L. Gaines, R. E. Keane, G. H. Aplet, S.L. Stephens, P. Morgan, P. A. Bisson, B. E. Rieman, R. B. Salter, and G. H. Reeves. 2015. Restoring fire-prone Inland Pacific landscapes: Seven core principles. Landscape Ecology 30: 1805-1835.

Hessburg, P. F., T. A Spies, D. A. Perry, C. N. Skinner, A. H. Taylor, P. M. Brown, S. L. Stephens, A. J. Larson, D. J. Churchill, N. A. Povak, P. H. Singleton, B. McComb, W. J. Zielinski, B. M. Collins, R. B. Salter, J. J. Keane, J. F. Franklin, and G. Riegel. 2016. Tamm review: Management of mixed-severity fire regime forests in Oregon, Washington, and Northern California. Forest Ecology and Management 366:221-250.

Hutto, R. L. 2008. The ecological importance of severe wildfires: some like it hot. Ecological Applications 18:1827-1834.

Keane, R. E., P. F. Hessburg, P. B. Landres, and F. J. Swanson. 2009. The use of historical range and variability (HRV) in landscape management. Forest Ecology and Management 258:1025-1037.

LANDFIRE. 2017. [Homepage of the LANDFIRE Project, U.S. Department of Agriculture, Forest Service; U.S. Department of Interior], [Online]. Available: http://www.landfire.gov/index.php (accessed 8 February 8 2013).

Landres, P. B., P. Morgan, and F. J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179-1188.

Littell, J. S., M. McGuire Elsner, L. C. Whitely Binder, and A. K. Snover (editors). 2009. The Washington Climate Change Impacts Assessment: Evaluating Washington's Future in a Changing Climate. Seattle, WA: Climate Impacts Group, University of Washington.

Littell, J.S., E. E. Oneil, D. McKenzie, J. A. Hicke, J. A. Lutz, R. A. Norheim, and M. M. Elsner. 2010. Forest ecosystems, disturbance and climate change in Washington State, USA. Climatic Change 102:129-158.

McGarigal, K., and W. H. Romme. 2012. Chapter 9: Modeling historical range of variability at a range of scales: An example application. *In* J. A. Wiens, G. D. Hayward, H. D. Safford, and C. M. Giffen, (editors). Historical Environmental Verification in Conservation and Natural Resource Management, First Edition. John Wiley and Sons, New York, NY. Pp. 128-145.

Morgan, P., G. H. Aplet, H. B. Haufler, H. C. Humphries, M. M. Moore and W. D. Wilson. 1994. Historical Range of Variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry 2:87-111.

Moritz, M. A., M. D. Hurteau, K. N. Suding, and C. M. D'Antonio. 2013. Bounded ranges of variation as a framework for future conservation and fire management. Annals of the New York Academy of Science, The Year in Ecology and Conservation Biology, Pp. 1-16.

North, M. P., S. L. Stephens, B. M. Collins, J. K. Agee, G. Aplet, and P. Z. Fule. 2015. Reform forest fire management. Science 18:1280-1281.

Ohmann, J. L., and M. J. Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest-neighbor imputation in coastal Oregon, USA. Canadian Journal of Forest Research 32:725-741.

Ohmann, J. L., M. J. Gregory, H. M. Roberts, W. B. Cohen, R. E. Kennedy, and Z. Yang. 2012. Mapping change of older forest with nearest-neighbor imputation and Landsat time-series. Forest Ecology and Management 272:13-25.

Ohmann, J. L., M. J. Gregory, and H. M. Roberts. 2014. Scale considerations for integrating forest inventory plot data and satellite image data for regional forest mapping. Remote Sensing of Environment 151:3-15.

Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421:37-42.

Perry, D.A., P. F. Hessburg, C. N. Skinner, T. A. Spies, S. L. Stephens, A. H. Taylor, J. F. Franklin, B. McComb, and G. Riegel. 2011. Ecology of mixed-severity fire regimes in Washington, Oregon, and California. Forest Ecology and Management 262:703-717.

Poage, N. J., and J. C. Tappeiner II. 2002. Long-term patterns of diameter and basal area growth of old-growth Douglas-fir trees in western Oregon. 2002. Canadian Journal of Forest Research 32:1232-1243.

Poage, N. J., P. J. Weisberg, P. C. Impara, J. C. Tappeiner, and T. S. Sensenig. 2009. Influences of climate, fire, and topography on contemporary age structure patterns of Douglas-fir at 205 old forest sites in western Oregon. Canadian Journal of Forest Research 39:1518-1530.

Raymond, C. L., and D. McKenzie. 2012. Carbon dynamics of forests in Washington, U.S: projections for the 21st century based on climate-driven changes in fire regime. Ecological Applications 22:1589-1611.

Reilly, M. J., C. J. Dunn, G. W. Meigs, T. A. Spies, R. E. Kennedy, J. D. Bailey, and K. Briggs. 2017. Contemporary patterns of fire extent and severity in forests of the Pacific Northwest, USA (1985–2010). Ecosphere 8(3):e01695. 10.1002/ecs2.1695

Ringo, C., A. A. Ager, M. A. Day, and S. Crim. 2016. A spatial database for restoration management capability on national forests in the Pacific Northwest USA. USDA Forest Service General Technical Report PNW-GTR-919, Pacific Northwest Research Station, Portland, OR.

Rogers, B. M., R. P. Neilson, R. Drapek, J. M. Lenihan, J. R. Wells, D. Bachelet, and B. E. Law. 2011. Impacts of climate change on fire regimes and carbon stocks of the U.S. Pacific Northwest. Journal of Geophysical Research 116:G03037.

Rollins, M. G., B. C. Ward, G. Dillon, S. Pratt, and A. Wolf. 2007. Developing the LANDFIRE Fire Regime Data Products. Unpublished manuscript on file at USDA Forest Service Rocky Mountain Research Station, Intermountain Fire Sciences Laboratory, Missoula MT.

Ryan, K., K. Lee, M. Rollins, Z. Zhu, J. Smith, and D. Smith. 2006. LANDFIRE: National vegetation and fuel mapping for fire management planning. Forest Ecology and Management 234: S200.

Schmidt, K. M., J. P. Menakis, C. C. Hardy, W. J. Hann, and D. L. Bunnell. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. USDA Forest Service General Technical Report RMRS-GTR-87, Rocky Mountain Research Station, Fort Collins, CO.

Schussmann, S., and E. Smith. 2006. Historical Range of Variation and State and Transition Modeling of Historical and Current Landscape Conditions for Potential Natural Vegetation Types of the Southwest. Phoenix, AZ: The Nature Conservancy, Unpublished report on file.

Society for Ecological Restoration (Science & Policy Working Group). 2002. The SER Primer on Ecological Restoration, 9 p. www.ser.org/.

Spies, T. A., and K. N. Johnson. 2007. Projecting forest policy and management effects across ownerships in coastal Oregon. Ecological Applications 17:3-4.

Swanson, M. E., J. F. Franklin, R. L. Beschta, C. M. Crisafulli, D. A. DellaSala, R. L. Hutto, D. B. Lindenmayer, and F. J. Swanson. 2011. The forgotten state of forest succession: Early-successional ecosystems on forest sites. Frontiers in Ecology and the Environment 9:117-125.

Swanson, M. E. 2012. Early Seral Forest in the Pacific Northwest: A Literature Review and Synthesis of Current Science. Pullman, WA: Washington State University, Unpublished report on file.

Swetnam, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 9(4):1189-1206.

Takaoka, S., and F. J. Swanson. 2008. Change in extent of meadows and shrub fields in the central western Cascade Range, Oregon. The Professional Geographer 60(4):1-14.

Tappeiner, J. C., D. Huffman, D. Marshall, T. A. Spies, and J. D. Bailey. 1997. Density, ages and growth rates in old-growth and young growth forests in coastal Oregon. Canadian Journal of Forest Research 27:638-648.

Teensma, P. D. A., J. T. Rienstra, and M. A. Yelter. 1991. Preliminary reconstruction and analysis of change in forest stand age classes of the Oregon Coast Range from 1850 to 1940. USDI Bureau of Land Management Technical Note T/N OR-9.

Tepley, A. J., F. J. Swanson, and T. A. Spies. 2013. Fire-mediated pathways of stand development in Douglas-fir/western hemlock forests of the Pacific Northwest, USA. Ecology 94:1729-1743.

Supplemental material available online at http://www.bioone.org/loi/nwsc

Received 04 March 2017
Accepted 01 December 2017

Thompson, J.R., K.N. Johnson, M. Lennette, T.A. Spies, and P. Bettinger. 2006. Historical disturbance regimes as a reference for forest policy in a multi-owner province: a simulation experiment. Canadian Journal of Forest Research 36:401-417.

Thompson, J.R., S.L. Duncan, and K.N. Johnson. 2009. Is there potential for the historical range of variability to guide conservation given the social range of variability? Ecology and Society 14:18-32.

Trouet, V., A. H. Taylor, A. M. Carleton, and C. N. Skinner. 2006. Fire-climate interactions in forests of the American Pacific coast, Geophysical Research Letters 33: L18704, doi: 10.1029/2006GL027502.

U.S. Department of Agriculture, Forest Service; and U.S. Department of the Interior, Bureau of Land Management [USDA and USDI]. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning departments within the range of the northern spotted owl. [plus attachment A: standards and guidelines].

USFS. 2013. Ecological Restoration Implementation Plan. Vallejo, CA: USDA Forest Service.

USFS. 2015. Collaborative forest landscape restoration program: 5-year report, FY2010-2014. Washington, DC: USDA Forest Service Report FS-1047..

Wiens, J. A., G. D. Hayward, H. D. Safford, and C. Giffen, eds. 2012. Historical Environmental Variation in Conservation and Natural Resource Management. New York: Wiley-Blackwell.

Wimberly, M.C., T. A. Spies, C. J. Long, and C. Whitlock. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. Conservation Biology 14:167-180.