WHITE PAPER

USDA Forest Service | Pacific Northwest Region | Umatilla National Forest

White Paper F14-SO-WP-Silv-3 | **March 2012**

Range of Variation Recommendations for Dry, Moist, and Cold Forests

David C. Powell; Forest Silviculturist
Supervisor's Office; Pendleton, OR

Initial Version: **DECEMBER 1998**

Introduction

The range of variation (RV) is defined as the range of conditions likely to have occurred in the Blue Mountains prior to Euro-American settlement in the mid 1800s (USDA Forest Service 1996). The RV concept has been a recurring theme in forest ecology and management literature for almost two decades now (Aplet and Keeton 1999, Caraher and Knapp 1994, Christensen et al. 1996, Dodson et al. 1998, Egan and Howell 2001, Kimmins 1997, Manley et al. 1995, Millar 1997, Morgan 2004, Morgan et al. 1994, Morgan and Parsons 2001, Parsons et al. 1999, Quigley and Arbelbide 1997, Swanson et al. 1994, USDA Forest Service 1992).

"Considerable attention has been focused on natural disturbance processes as a guide for forest management. Concepts such as the historic range of variability (Landres et al. 1999) and coarse filter conservation strategies (Haufler et al. 1996, Hunter 1990) suggest that successful management of ecosystems may best be achieved by mimicking natural disturbance patterns and processes" (Wright and Agee 2004:443; Arno and Fiedler 2005, Perera et al. 2004).

Terminology note: Some sources refer to RV as the natural range of variability (Hessburg et al. 1999, Swanson et al. 1994) or the historical range of variability. Natural is an ambiguous but frequently used term to signify something of esthetic or spiritual importance (Christensen et al. 1996). Primarily to avoid this ambiguity, I use the term 'range of variation,' although this usage also agrees with Forest Service handbook and manual direction (see FSH 1909.12, section 43.13 – Range of Variation; and FSM 1920, section 1921.73a – Ecosystem Diversity). And in response to concerns about climate change, some sources suggest that the historical range of variability is irrelevant (deBuys 2008, Fulé 2008) and should be abandoned altogether, or perhaps replaced with 'future range of variability' (Duncan et al. 2010).

This report has six objectives:

1. Provide background and context explaining how an RV approach has been used in the Pacific Northwest Region of the U.S. Forest Service.
2. Describe certain concepts and principles related to the range of variation.
3. Describe how RV could support Forest Service planning processes.
4. Provide ranges of variation for species composition, forest structure, stand density, and related components (ranges are expressed as percentages and presented in a table for each component).
5. Provide a glossary of terms related to the RV concept.
6. Provide references and literature citations related to the range of variation.

Background and Context for This White Paper

In July 1992, a report was released called "Restoring Ecosystems in the Blue Mountains: A Report to the Regional Forester and the Forest Supervisors of the Blue Mountains" (Caraher et al. 1992). This document, often referred to as the Caraher Report, was prepared by a panel of scientists who used nine indicators to assess ecosystem restoration needs for the Blue Mountains.

The Caraher Report was probably the first example in the Pacific Northwest to demonstrate how a concept called the historical range of variability (HRV) could be applied. The Northern Region of the Forest Service initially incorporated the HRV concept in their Sustaining Ecological Systems (SES) process (USDA Forest Service 1992); the Caraher panel adopted HRV and other SES principles for their Blue Mountains restoration assessment.

In March 1993, the Natural Resources Defense Council (NRDC) petitioned the Pacific Northwest Region of the U.S. Forest Service to halt all timber harvest activity in old growth forests on national forest lands located east of the Cascade Mountain crest in Oregon and Washington (this geographical area is traditionally referred to as the Eastside).

A month later in April 1993, a group of university and U.S. Forest Service research scientists released an "Eastside Forest Ecosystem Health Assessment;" this assessment is known as the Everett Report because it was directed by Dr. Richard Everett (Everett et al. 1994).[1] In response to both the NRDC petition and the Everett report, U.S. Forest Service Regional Forester John Lowe issued interim direction in August 1993 requiring that timber sales prepared and offered by Eastside national forests be evaluated to determine their potential impact on riparian habitat, historical vegetation patterns, and wildlife fragmentation and connectivity.

[1] The Everett Report was prepared in response to a May 1992 request from U.S. House Speaker Tom Foley and U.S. Senator Mark Hatfield for a scientific evaluation of the effects of Forest Service management practices on the sustainability of forest ecosystems in eastern Oregon and eastern Washington. Over 100 scientists worked for more than a year on the assessment; final results were published as a series of general technical reports by the Pacific Northwest Research Station in 1994 and 1995.

This interim direction, known as the Eastside Screens, was used to amend Eastside forest plans when Regional Forester John Lowe signed a Decision Notice on May 20, 1994 to implement Regional Forester's Forest Plan Amendment #1 (USDA Forest Service 1994). A slightly revised version of the Eastside Screens was issued as Regional Forester's Forest Plan Amendment #2 when Lowe signed a Decision Notice on June 12, 1995 (USDA Forest Service 1995).

The Screens' ecosystem standard requires a landscape-level assessment of the historical range of variability[2] for structural stages, including a determination of how existing structural stage percentages compare with their historical ranges. To my knowledge, the Eastside Screens are the first instance of the RV approach being used as a mandatory requirement for land and resource management planning. I believe the RV concept is well suited for this role.

Concepts and Principles Related to RV

The RV concept is used to characterize fluctuations in ecosystem conditions and processes over a period of time (fig. 1). It is now understood that ecosystem conditions change as disturbance processes affect them; when disturbances act with a characteristic frequency and intensity (severity), ecosystems respond by exhibiting a predictable behavior and complexity (Aplet and Keeton 1999, Morgan et al. 1994).

Figure 1 demonstrates that the effects of repeated disturbance events cause conditions to fluctuate between upper and lower limits, suggesting that nature does not function with perfect replication from one disturbance event to another. Assume the trend line in figure 1 shows fluctuations in old forest structure within a watershed. Over time as stands mature, old-forest acreage increases toward the upper limit until a disturbance process eventually transforms some of it into another structural stage, at which point the old-forest acreage declines toward the lower limit.

Fine-scale disturbance processes such as root disease cause small reductions in old-forest acreage; broad-scale processes such as crown fire or bark beetle outbreaks often result in dramatic old-forest declines. In the hypothetical example portrayed in figure 1, the dynamics produced by disturbance processes describe a range of variation for old-forest structure.

As a concept, RV recognizes that ecosystem components have a range of conditions in which they are resilient and self-sustaining, and beyond which they move into a state of disequilibrium (Egan and Howell 2001, Holling and Meffe 1996).

If an ecosystem component should diminish to a point that never occurred historically, then it is assumed that natural processes alone will not be able to recover or sustain this component in the future (USDA Forest Service 1992). Holling and Meffe

[2] The historical range of variability (HRV) and the range of variation (RV) are used somewhat interchangeably in this white paper. HRV has longer tenure, dating back to the early 1990s, but the Forest Service recently adopted RV as its term of choice for describing the variability of reference ecosystems (see FSH 1909.12, section 43.13).

(1996) expressed this concept well when they noted that "management should strive to retain critical types and ranges of natural variation in resource systems in order to maintain their resiliency."

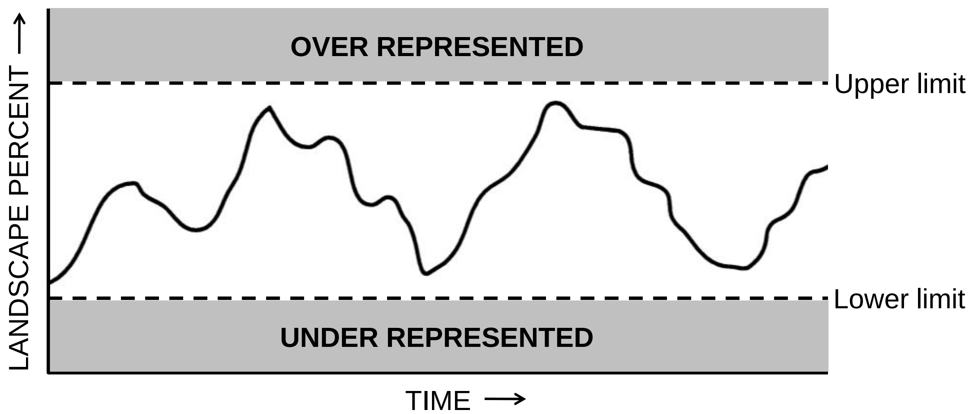


Figure 1 – The range of variation (RV) helps us decide whether existing amounts of vegetation composition, structure, and density, when summarized for a landscape-scale analysis area, are occurring within a characteristic range (Aplet and Keeton 1999, Morgan et al. 1994, Swanson et al. 1994). This diagram shows the ecological trajectory of an ecosystem component (the solid line) varying through time because the phrase 'range of variation' is meant to encompass more than just the extreme values (the upper and lower limits, shown as dashed lines) (diagram modified from Morgan et al. 1994).

RV is a good example of the dynamic equilibrium concept because modal or central-tendency conditions obviously vary over time (shown by the squiggly solid line in the center), and yet they vary within an equilibrium zone whose limits (the dashed lines) are confined within a range of potential ecological expressions. Note that conditions occurring above the upper limit are considered to be over-represented; conditions below the lower limit are considered to be under-represented (the representation zones are gray).

RV is an analytical technique to characterize inherent variation in composition, structure, and density, reflecting recent evolutionary history and the dynamic interplay of biotic and abiotic factors. "Study of past ecosystem behavior can provide the framework for understanding the structure and behavior of contemporary ecosystems, and is the basis for predicting future conditions" (Morgan et al. 1994).

RV is meant to reflect ecosystem properties free of major influence by Euro-American humans, providing insights into ecosystem resilience (Kaufmann et al. 1994, Landres et al. 1999). RV helps us understand what an ecosystem is capable of, how historical disturbance regimes functioned, and inherent variation in ecosystem conditions and processes – the patterns, connectivity, seral stages, and cover types produced by ecological systems at a landscape scale (USDA Forest Service 1997).

Ecosystem Variation as a Foundation of RV

RV is not intended to portray a static, unchanging condition. Ecosystems of the interior Pacific Northwest evolved with a steady diet of wildfire, insect outbreaks, disease epidemics, floods, landslides, human uses, and weather cycles. Change was, and still is, the only constant in their development. RV is designed to characterize the range of vegetation composition, structure, and density produced by these agents of change (Morgan et al. 1994).

The first generation of American ecologists was led at the start of the twentieth century by Nebraska scientist Frederic Clements. Clements and his University of Nebraska collaborators (particularly Charles Bessey and Rosco Pound) believed that plant succession caused ecosystems to develop in a predictable sequence of steps – much the same way as a human infant matures into an adult. Proponents of this super-organism philosophy maintained that individual species were linked together in mutually beneficial systems exhibiting properties greater than the sum of their parts (Clements 1916, Egerton 1973, Wu and Loucks 1995).

Clements contended that nature was orderly, and that its order was for the most part stable and self-regulating. He assumed that the normal condition of ecosystems was a state of homeostasis or equilibrium – a forest grows to a mature climax stage that becomes its naturally permanent condition (Clements 1916). Many contemporary ideas about the environment are based on Clements' notion that nature is capable of retaining its inherent balance more or less indefinitely if only humans could avoid disturbing it (Cronon 1996, Shugart and West 1981).

Contrary to Clements' claims, subsequent work has shown that the normal state of nature is not one of balance; the normal situation is to be recovering from the last disturbance. Change and turmoil, rather than constancy and balance, seems to be the rule. We now know that the concept of a forest evolving to a stable (climax) stage, which then becomes its naturally permanent condition, is incorrect (Botkin 1990, Stevens 1990). In many areas and particularly in the interior Pacific Northwest, large-scale disturbances are common and development to a truly stable climax is rare or absent (Kipfmuller et al. 2005, O'Hara and others 1996).

"As Clementsian climax theory fell out of favor, ecologists increasingly resorted to concepts such as the historical range of variability to bound their understanding of a system's innate potential. But for HRV to have utility, the range of variability must have reasonably fixed boundaries, which are largely determined by climate and edaphic factors. When climate changes substantially, the boundaries can weaken and ranges of variability can wobble off course" (deBuys 2008).

Historical ecology can teach us what worked and what lasted – how resilient ecosystems sustained themselves through time (Swetnam et al. 1999). The type and frequency of presettlement disturbances can serve as a management template for maintaining sites within their historical range of plant composition and vegetation structures – if landscapes can be maintained within RV, then they stand a good chance of maintaining their biological diversity and ecological integrity through time (Aplet and Keeton 1999, Holling and Meffe 1996).

An RV approach ensures that management activities are consistent with the conditions under which native species, gene pools, communities, landscapes, and ecosystem processes evolved (DeLong and Tanner 1996). It is typically assumed that presettlement conditions represent optimum habitats for native plants and animals, and that the best way to recover an endangered or threatened species is to restore its habitat to some semblance of presettlement conditions (Botkin 1995).

Since a key premise of RV is that native species have evolved with, and are adapted to, the historical disturbance regimes of an area, ecosystem components occurring within their historical range are believed to represent sustainable conditions (Aplet and Keeton 1999, Swanson et al. 1994). At a landscape scale, for example, a forest might be considered healthy and sustainable if the spatial and temporal patterns of its composition, structure, and density are within RV.

RV is used as a tool to help us understand present forests and why they respond as they do when exposed to management practices – it uses the past to help us understand the present, to understand which forces affect vegetation response, to gain insight into possible trajectories of future forests, and to integrate this information when proposing management alternatives (Millar and Woolfenden 1999).

RV as a Planning Tool

Beginning in the early 1990s, a long-standing debate intensified about the purpose of national forests and their contribution to American society. This debate demonstrates that certain segments of American society prefer federal forests to function primarily as old-growth reserves, or to provide essential wildlife habitat. Other Americans believe that public wildlands should offer recreational opportunities as their primary purpose, whereas some feel they should be managed to supply commodities such as timber, livestock forage, minerals, and water.

The purposes for which national forests are managed are broadly established in federal law, and then refined for each individual unit through a planning process incorporating public input. But the goals and objectives for which a national forest is to be managed cannot be exclusively a matter of public (societal) preference.

Biophysical factors dictate a range of ecosystem states that are possible for an area, historical factors such as wildfire and timber harvest determine what is present there now, and both sets of factors ultimately control the societal choices available at any point in time (fig. 2). Forests adapted to a dry temperate climatic regime, for example, cannot be made to take on the characteristics of moist tropical forests, even if they are highly desired by society – in this instance, the biophysical site potential would obviously trump societal desires.

A good example of the biophysical potential concept is provided by the open and parklike forests historically created and maintained by surface fire (fig. 3). On warm dry sites such as those in figure 3, an historical process (frequent fire) maintained large, widely-spaced, fire-tolerant trees over an undergrowth so free of brush and small trees that settlers could often drive their wagons through the forest as if it was a carefully manicured park (Evans 1991, Munger 1917).

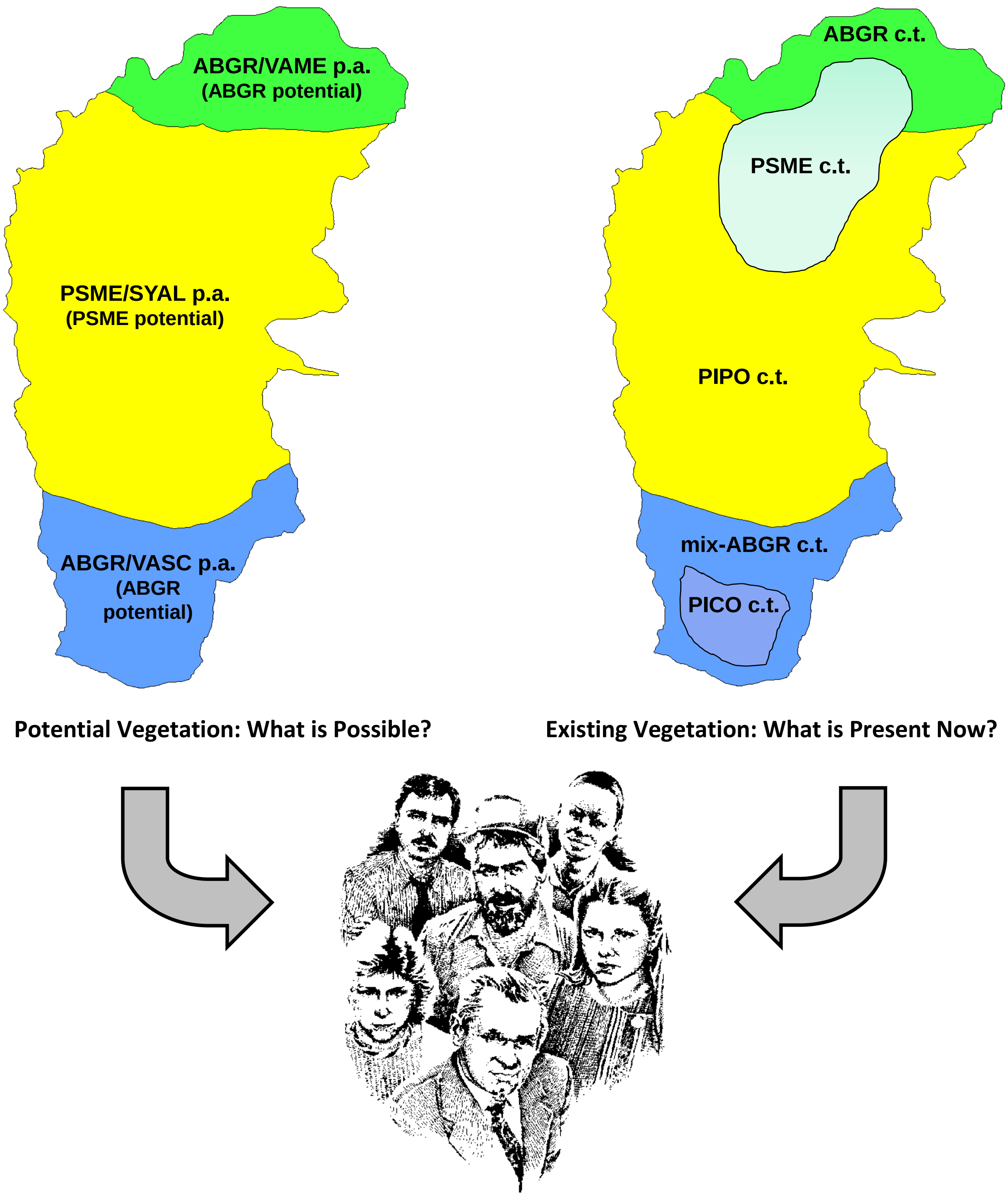


Figure 2 – Developing desired conditions for land management planning is a societal process. RV should not be used as a desired condition, but it can function as a baseline to help society understand the biophysical potential of ecosystems (upper left, showing three plant associations (p.a.) and their tree species potential: ABGR is grand fir; PSME is Douglas-fir; PIPO is ponderosa pine; PICO is lodgepole pine). After establishing a biophysical template, existing conditions for composition (upper right; c.t. is cover type), structure, density, and other ecosystem components can be compared with reference conditions (the RV). Using RV in this manner could help society develop desired conditions because it integrates potential vegetation (what is possible) with existing vegetation (what is present now).

By disrupting the short-interval fire regime on dry sites, society unintentionally decided to replace the open, parklike condition with a dense, multi-layered structure. It is possible for dense forest to exist on warm dry biophysical environments, but only at a high potential cost in terms of future susceptibility to uncharacteristic fire effects and insect or disease impact (Agee 1994, Hessburg et al. 1994, Huff et al. 1995, Lehmkuhl et al. 1994, Mutch et al. 1993, Wickman 1992).

And if land management policy continues to emphasize systematic fire exclusion for dry-forest sites, society should acknowledge that when fire returns to them, as it inevitably will, it is ready and willing to accept the consequences of an exclusion policy, including the attendant side effects of uncharacteristic fire behavior and undesirable fire effects.

It is likely "that the high costs and consequences of excluding necessary ecological processes (e.g., fire) will soon shape human desires and decisions more than they have in the past" (Swetnam et al. 1999). Now that large fires are occurring at an unprecedented rate (Bennett 2000), and are consuming steadily increasing proportions of the Forest Service's annual budget allocation, it appears that the "high costs and consequences" of fire suppression are finally being realized at the federal government level (GAO 1999).

When considering that dense, dry-site forests have existed for more than a half-century in many portions of the western United States, society is now faced with the following dilemma:

- If the current cohort of natural resource managers has grown accustomed to dense, mixed-species forests on dry sites, perhaps now accepting them as the norm and assuming they can be perpetuated into the future;
- Then society must acknowledge that if we can successfully restore the short-interval fire regime and its historically open stand density, these conditions will be ill suited for providing wood, elk cover, and many other services that society has come to expect from dense dry forests (Gruell 2001, Moore et al. 1999).

In contrast to the dry-forest situation, forests with a moist biophysical potential cannot be sustained in a parklike condition without constant tending by using activities such as timber harvest or biomass removal. The biophysical factors influencing moist environments would allow some of them to be maintained in a parklike condition if this is society's objective, but only with substantial human intervention because the native disturbance regime created little or none of this condition on its own (and never across substantial acreages).

These examples are designed to demonstrate that society must first strive to learn what the normal or characteristic 'state of being' is for an ecosystem type (in the context of biophysical potential and associated ranges of variation), and then to use this knowledge to inform natural resource policy and decision making (fig. 2).

Figure 3 – Open ponderosa pine forest with herbaceous undergrowth (stand of old-growth *P. ponderosa* near Whitney, Oregon, ca. 1900 [J. W. Cowden]; courtesy Gary Dielman, Baker City library). Pioneer journals (Evans 1991), early surveys (Gannett 1902, Munger 1917), and fire history studies (Heyerdahl 1997, Maruoka 1994) suggest that many dry-forest sites in the Blue Mountains had presettlement conditions resembling this image, particularly for the Douglas-fir/pinegrass and grand fir/pinegrass plant associations (Weaver 1967). The combination of a warm dry temperature-moisture regime and a disturbance regime featuring surface fire created the distinctive composition and structure shown here. Some studies concluded that this ecosystem condition is the result of a sustainable cultural practice because traditional human uses (Native American burning and associated plant species utilization) were important for sustaining the biodiversity and productivity of these ecological settings (Boyd 1999, Vale 2002).

One rule of thumb for hierarchical analysis during planning is to look up in scale for context, and to look down in scale to understand process (Haynes et al. 1996, O'Neill et al. 1986). As an example of hierarchical analysis, let's say that a range of variation (RV) analysis has identified a particular watershed as a candidate for harvest of old forest structure because it is currently 'above RV' with respect to this structural stage (i.e., old forest abundance exceeds the upper limit of RV – see fig. 1).

Continuing with this example, however, it would be important to evaluate RV at the next highest hierarchical level (the subbasin scale in this example) because without such information, an analyst would be unaware of the watershed's contribution to old-forest structure in the context of the subbasin – and such knowledge might have an important influence on the tree harvest decision-making process.

If it turns out that the subbasin also exceeds RV for old-forest structure, or if it occurs within the range but at the high end, then targeting the watershed for tree harvest might be an appropriate and reasonable approach. On the other hand, if the subbasin is below RV for old-forest structure, then deferring tree harvest in the watershed may be prudent until old forest abundance at the subbasin scale is restored to an ecologically appropriate level.

This same approach can be used through all hierarchical levels – RV could be assessed at the broadest scale first, then stepped down to the next lowest level, reassessed, and so on down to the site or stand level. It can also be used with a full suite of ecosystem components or categories of interest – a forest landscape in synchrony with RV would not only provide old forest at an appropriate abundance and configuration, but it would also contain young and mid-age patches with size, shape, composition, and structure all occurring within RV for these ecosystem elements (Aplet and Keeton 1999, Morgan et al. 1994).

When we think about scale, a spatial example typically comes to mind. But temporal scales are also important. The time scales associated with landscape pattern and structure range from years to centuries, but variations in stream flow or bank structure can sometimes be measured in days, and biome-level changes may span millennia. Forest vegetation often requires hundreds of years to develop to its full expression, and erosion processes frequently span thousands of years (Eng 1998).

An appropriate temporal perspective is important because "how can human communities manage landscape change that takes place over a hundred years or more, when people's perceptions and priorities change from generation to generation, or even from election to election? Humans may not have the right 'attention span' to manage environmental change, and this may be the species' fatal flaw. Perhaps this is the value of history – as an attempt to extend the time frame of our memory beyond the human lifetime. The only problem is that history represents selective memory" (Spirn 1996).

RV as a Baseline

RV can appropriately serve as a baseline from which change can be measured; it is not designed to provide a specific condition for active restoration purposes, although RV could provide a useful framework for evaluating restoration alternatives (USDA Forest Service 1997).

A common misconception is that it might be appropriate to use RV as a management objective by linking desired conditions directly to RV, but a better approach is to let reference conditions and historical data inform an analyst about the potential behavior and expected consequences of restoration treatments (Millar 1997).

"If ecosystems are necessarily dynamic, then it may be misguided and fruitless to choose a single fixed point or period of time in the past for establishing a static, desired future condition" (Sprugel 1991, Swetnam et al. 1999).

Not only is selecting a single temporal point inconsistent with the RV concept (Powell 2000), but choosing a single target condition (e.g., “50% of dry-forest sites should occur in the old forest single stratum (OFSS) structural stage”) is also a misguided strategy because a range of conditions better reflects a dynamic equilibrium (e.g., “30-70% of dry-forest sites should occur in the OFSS stage”).

Helping to identify opportunities to restore an ecosystem’s resilience and integrity – its capacity for regeneration and renewal – is perhaps the most important contribution that RV information can offer to an assessment or planning effort. But this recommendation presumes that past conditions and processes, as reflected by RV, provide appropriate context and guidance for management of contemporary ecological systems (Landres et al. 1999).

Even if land managers wish to turn the clock back to some nostalgic preconception of the presettlement era, our current reality of dams, roads, cities, fire suppression, climate change, and escalating human demands on natural resources would render this goal problematic. Clearly, we cannot turn our wheat fields back into properly functioning bluebunch wheatgrass steppes, no matter how inadequate they might now seem. We simply cannot go back in time and undo all that has happened and, in this sense at least, we are prisoners of our own history (Worster 1996).

A recent scientific assessment for the interior Columbia River basin suggests it would be difficult, if not impossible, to restore presettlement conditions for many portions of the western United States, even if this was an explicit policy objective (Quigley and Arbelbide 1997).

What Time Period Should RV Represent?

Human history is dwarfed when compared with the Earth’s geological history. When considering the vast changes occurring over geologic time, ecological history seems inconsequential. But ecosystems do change, albeit slowly. Some vegetation changes are so difficult for people to recognize that they have been referred to as the ‘invisible present’ (Magnuson 1990), evoking a perception of forest tranquility due to the seemingly timeless nature of large trees (Shugart and West 1981).

As commonly used in the interior Pacific Northwest, RV refers to a range of reference conditions existing prior to Euro-American emigration. This timeframe is often defined as the early to mid 1800s because it coincides with the Oregon Trail era when Euro-American influences began in the Blue Mountains (Evans 1991).

The temporal baseline for which ranges are pertinent should be established carefully. This decision is easier for the western United States than for other parts of the world because the West was settled relatively recently.

In the British Isles, for example, the shieling system was a kind of mixed agriculture practiced in Scotland from prior to 1000 AD to the late 1700s, when it was largely abandoned due to poor harvests, famine, bouts of human disease, and a variety of other factors. Currently, only the occasional stone wall or drainage ditch provides clues that a widespread and persistent pastoral society once existed in areas managed by using the shieling system (Holl and Smith 2007).

Any attempt to base historical ranges on conditions existing on Scotland's moors in the mid 1800s would need to account for the persistent ecological effects of a long-term human influence called the shieling system. Otherwise, it is likely that RV ranges would not reflect 'pristine' (non-anthropogenic) conditions if this were an explicit objective of adopting the RV concept (Holl and Smith 2007).

RV and Climate Change

Substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and temperature (Milly et al. 2008). "Climate change suggests that planning must not depend on expectations that the past will provide a template for the future. But if not the past, then what? For the present, no one seems to know. Like the often-quoted investment advice, it now seems that past performance is no guarantee of future results" (deBuys 2008).

Some people believe that the presettlement era, which overlaps with a time period called the Little Ice Age (1300-1850), should no longer be used as a reference baseline because future conditions could be much warmer and drier than the mid 1800s due to climate change. Recent efforts to map changes in biophysical regimes for the United States, for example, found that half of the area could have shifts in moisture, temperature, and soil conditions such that it would be difficult to sustain 'historic' (presettlement) ecosystems there (Harris et al. 2006, Saxon et al. 2005).

Continuing with the RV approach, however, may still be the best option, as described here: "Some feel that HRV may no longer be a viable concept for managing lands in the future because of expected climate warming and increasing human activities across the landscape. Today's climates might change so rapidly and dramatically that future climates will no longer be similar to those climates that created past conditions. Climate warming is expected to trigger major changes in disturbance processes, plant and animal species dynamics, and hydrological responses to create new plant communities and alter landscapes that may be quite different from historical analogs" (Keane et al. 2009:1033-1034).

"At first glance, it may seem obvious that using historical references may no longer be reasonable in this rapidly changing world. However, a critical evaluation of possible alternatives may indicate that HRV, with all its faults and limitations, might be the most viable approach for the near-term because it has the least amount of uncertainty" (Keane et al. 2009:1034), particularly as compared to the uncertainty associated with the magnitude, timing, scale, and spatial extent of climate change impacts.

"Given the uncertainties in predicting climatic responses to increasing CO_2 and the ecological effects of this response, we feel that HRV time series derived from the past may have significantly lower uncertainty than any simulated predictions for the future. We suggest it may be prudent to wait until simulation technology has improved to include credible pattern and process interactions with regional climate dynamics and there has been significant model validation before we throw out the concept and application of HRV. In the meantime, it is doubtful that the use of HRV to guide management efforts will result in inappropriate activities considering the large genetic variation in most species and the robustness inherent in regional landscapes that display the broad range of conditions inherent in HRV projections" (Keane et al. 2009:1034).

"Historical reference conditions remain useful to guide management because forests were historically resilient to drought, insects, pathogens, and severe wildfire. Adaptation of reference information to future climates is logical: historical characteristics from lower, southerly, and drier sites may be increasingly relevant to higher, northerly, and currently wetter sites" (Fulé 2008). "The study of past forest change provides a necessary historical context for evaluating the outcome of human-induced climate change and biological invasions. Retrospective analyses based on fossil and genetic data greatly advance our understanding of tree colonization, adaptation, and extinction in response to past climatic change" (Petit et al. 2008).

This section demonstrates that although the RV approach has recently been questioned, especially in the context of climate change, it is still believed to function as a useful tool for informing management practices, rather than being used to set firm targets (Thompson et al. 2009). It also illustrates the importance of establishing a relevant reference period, which is the time period or era used to estimate the range of variation under historic disturbance regimes, including indigenous (American Indian) influences.

Ecosystem Components Associated With an RV Analysis

Vegetation reflects the integration of ecosystem components called composition, structure, and process (function); ecosystem components occur as multi-level hierarchies (table 1).

Composition refers to the relative abundance of ecosystem components such as water, nutrients, and species. Structure refers to the physical arrangement of composition in an ecosystem, and function refers to the processes through which composition and structure interact, including predation, decomposition, and disturbances such as wildfire (Aplet and Keeton 1999).

Composition

Composition is the kinds and numbers of organisms that make up an ecosystem (Manley et al. 1995). Depending on the hierarchical level being considered, forest composition includes individual trees, aggregations of tree species called cover types, or combinations of cover types called life forms (table 1).

Table 1: Examples of forest ecosystem components.

COMPONENTS	ECOSYSTEM SCALE (HIERARCHICAL LEVEL) FINE	MID	BROAD
Composition	Individual tree	Cover type	Lifeform (tree/shrub/herb)
Structure	Tree size class	Structural stage	Physiognomic class
Process/Function	Photosynthesis	Disturbance	Climate

Sources/Notes: Although they are shown individually in this table, ecosystem components are interrelated – from an ecological perspective, they do not operate independently.

Structure

Structure includes the physical arrangement or spatial distribution of ecosystem composition (Manley et al. 1995). Structure occurs both horizontally (the spatial distribution of structure classes across an area) and vertically (trees of varying height growing in a multi-layered arrangement). Depending on the hierarchical level being considered, examples of forest structure include size classes, structure classes, or physiognomic classes (table 1).

Process/Function

Processes are the flow or cycling or energy, materials, and nutrients through space and time (Manley et al. 1995). Forest processes can include everything from photosynthesis and nutrient cycling to stand-initiating wildfires and climatic cycles (table 1). In the interior Pacific Northwest, disturbance processes have influenced forest vegetation conditions to a greater degree than other ecosystem processes (Clark and Sampson 1995, O'Hara et al. 1996, Oliver and Larson 1996).

Processes have an important influence on species diversity. Recent studies of British plants and birds found that different processes are likely to determine species diversity (biodiversity) at different spatial scales, and that the species richness pattern at a fine scale was statistically unrelated to the pattern at a coarse scale (Whittaker et al. 2001, Willis and Whittaker 2002).

Conducting an RV Analysis

Apparently, there is no limit to the number of ecosystem characteristics that could be assessed using the range of variation concept – Manley et al. (1995) identified more than 36 such characteristics and, in theory at least, all pertinent ecosystem metrics could be assessed and interpreted using an RV approach (Egan and Howell 2001).

Broad-scale assessments completed for the Blue Mountains physiographic province and the interior Columbia River basin suggest that upland forest ecosystems could be characterized as healthy, sustainable, and resilient if three of their ecosystem components – species composition, forest structure, tree density – are within RV

(Caraher et al. 1992; Gast et al. 1991; Lehmkuhl et al. 1994; Quigley et al. 1996; USDA Forest Service 2002).

It is recommended that an RV analysis for upland-forest biophysical environments include at least three ecosystem components: species composition, forest structure, and tree density.

RV results are typically presented for an entire analysis area, but they can also be reported for subdivisions (such as combinations of subwatersheds) when an analysis area is especially large. Subdivisions of a large watershed (fifth code hydrologic unit) or a subbasin (fourth code hydrologic unit) might be especially useful for supporting fine-scale project planning efforts.

Subdividing an RV analysis area into smaller units must be done carefully. Some areas have a strong elevational gradient resulting in equivalent proportions of biophysical environments (Desolation Creek watershed on the North Fork John Day Ranger District is an example of this situation). If not done carefully, subdividing these areas can essentially disrupt this equivalence, resulting in inconsequential or minor amounts of one or more biophysical environments, in which case it might be advisable to conduct an RV analysis for the whole area as one integrated unit.

The results of an RV analysis are generally presented in a table showing the existing percentages and RV percentages for each ecosystem component, and stratified using categories of potential vegetation such as potential vegetation groups (PVG).

Please consider the following recommendations when conducting an RV analysis.

1. Before initiating a planning process, an analyst should develop an understanding of reference conditions for ecosystem components in the planning area (e.g., soil conditions, animal population sizes, plant species or seral stage composition, stream sediment loads, air quality, forest structural stages, etc.). Developing an awareness of reference conditions is best accomplished by consulting historical data sources, particularly maps depicting species composition, forest structure, and stand density.

   The Umatilla National Forest made considerable investments over the last 20 years to locate and digitize relevant historical mapping, including maps derived from General Land Office survey notes collected in the 1880s (Powell 2008); thematic maps depicting forest conditions in 1900, 1914-16, 1935-36, 1953-60, and 1987-88 (Powell 2009c); and topical maps portraying wildfires, insect outbreaks, and other disturbance processes (Powell 2009b, 2009c).

2. Use an appropriate size of analysis area.
   a. It is recommended that an RV analysis be conducted for land areas no smaller than 15,000 to 35,000 acres (this recommended size range was taken from the May 1994 Environmental Assessment for the Eastside Screens).

b. Areas larger than 35,000 acres are appropriate and preferable for an RV analysis; areas smaller than 15,000 acres should be avoided since vegetation patterns might not be consistent with those created by the historical disturbance regimes of the analysis area.

3. Stratify the vegetation data into potential vegetation groups.
   a. It is important that an RV analysis use a consistent stratification of potential vegetation. Before conducting an RV analysis, the acreage should be summarized into potential vegetation groups (PVG). Generally, a potential vegetation type (ecoclass) code is available for each polygon in an analysis database, and a cross-walk process can be used to assign PVG by using ecoclass (Powell et al. 2007).
   b. PVG information for the Blue Mountains is provided in a report entitled "Potential vegetation hierarchies for the Blue Mountains section of northeastern Oregon, southeastern Washington, and west-central Idaho" (Powell et al. 2007). Copies of this report are available from the Supervisor's Office, or from the Pacific Northwest Research Station website.
   c. If less than 1,000 acres of a PVG occurs in a planning area, it should be ignored during analysis because a full complement of cover types, structural stages, or tree density classes would not be expected for such a small amount of acreage; do not add the acreage to another PVG because it is not appropriate to combine ecosystem components produced by different disturbance regimes.

4. Classify existing vegetation information into the same analysis categories used in tables 2-3 and 5-7, all of which qualify as derived attributes because they are calculated by using a combination of metrics from stand examination or photo interpretation surveys. Internal white papers describe how the derived fields are calculated, as demonstrated using three examples:
   a. Forest species composition is characterized using a derived field called vegetation cover type (table 2). Vegetation cover types are calculated using a three-step process described in Powell (2004, page 14).
   b. Forest structure is characterized using a derived field called forest structural stage (tables 3-4). Forest structural stages are calculated using a process described in Powell (2004, pages 11-12 and 33-34) as the first option, or in Powell (2009a, table 3 on page 6) as the second option.
   c. Forest stand density is characterized using a derived field called tree density class (table 5). Tree density classes are calculated from tabular information presented in Powell (2009d; pages 9-13 provide calculation information by PVG).

5. Calculate existing amounts of the analysis categories (such as cover type, structural stage, tree density class) for the analysis area, as stratified by potential vegetation group, and convert the acreage for each category into its corresponding percentage value (a spreadsheet will be helpful for this task).

6. Determine whether current conditions are within or outside of their range of variation (see fig. 1) by comparing the calculated existing percentages with the RV percentage ranges for each analysis category.
7. Use a spatial analysis to determine where current conditions depart from RV. A spatial analysis helps prioritize projects because we lack the institutional capacity to implement every possible project.
8. Consider how ecosystem components interact (is the OFSS structural stage associated mostly with the ponderosa pine forest cover type?), and use these insights to identify how current conditions deviate from desired conditions.
9. From a temporal standpoint, consider an area's recent disturbance history and then decide if an RV analysis is appropriate at this time. An RV analysis was not completed for the Tower Fire (Powell 1997) because much of the 52,000-acre analysis area had just experienced uncharacteristic fire effects (more stand-replacing severity than is typical for fire regime 1), so the resulting composition, structure, and density were not yet in dynamic equilibrium with the inherent disturbance regime.

Using RV to Evaluate Species Composition

Plant species occur in either pure or mixed communities called cover types. Tree species occurrence in a project planning or analysis area can be characterized using cover types, a classification of existing vegetation composition (Eyre 1980, Shiflet 1994). Cover type codes reflect majority or plurality tree species abundance, and they apply to both pure and mixed stands.

Range of variation information for species composition (vegetation cover types) is provided in table 2, and it is stratified by upland-forest potential vegetation group.

Using RV to Evaluate Forest Structure

Oliver and Larson (1996) developed a classification system for forest structure involving four structural stages (see table 4). Oliver and Larson's (1996) classification system works well for conifer forests located west of the Cascade Mountains, but it does not adequately describe forest conditions for the interior Pacific Northwest where structure is more varied. Therefore, the Oliver and Larson (1996) system was quickly expanded to eight classes to include a wider spectrum of structural variation (O'Hara et al. 1996).

When the Pacific Northwest Region of the USDA Forest Service issued two versions of the Eastside Screens between 1993 and 1995, it established a procedural requirement to use RV as an analytical technique when comparing the current percentage of each structural stage with its historical range (USDA Forest Service 1994, USDA Forest Service 1995).

Table 2: Range of variation information for species composition (vegetation cover type), expressed as percentages.

Vegetation Cover Type[1]	POTENTIAL VEGETATION GROUP Dry UF	Moist UF	Cold UF
	Range of Variation (Percentage)		
Grass-forb	0-5	0-5	0-5
Shrub	0-5	0-5	0-15
Western juniper	0-5	0	0
Ponderosa pine	50-80	5-15	0-5
Douglas-fir	5-20	15-30	5-15
Western larch	1-10	10-30	5-15
Broadleaved trees	0-5	1-10	0-5
Lodgepole pine	0	25-45	25-45
Western white pine	0-5	0-5	0
Grand fir	1-10	15-30	5-15
Whitebark pine	0	0	0-10
Subalpine fir and spruce	0	1-10	15-35

Source/Notes: Derived from disturbance process modeling using the Vegetation Dynamics Development Tool (VDDT). Potential vegetation group is described in Powell et al. (2007); UF = Upland Forest.

[1] Cover types reflect the existing vegetation composition of a polygon (Eyre 1980, Shiflet 1994). Cover type codes are described in Powell (2004); cover types consist of these coding combinations:
Grass-forb: all grass and forb codes;
Shrub: all shrub codes;
Western juniper: JUOC and mix-JUOC;
Ponderosa pine: PIPO and mix-PIPO;
Douglas-fir: PSME and mix-PSME;
Western larch: LAOC and mix-LAOC;
Lodgepole pine: PICO and mix-PICO;
Western white pine: PIMO and mix-PIMO;
Grand fir: ABGR and mix-ABGR;
Whitebark pine: PIAL and mix-PIAL;
Broadleaved trees: POTR, POTR2, mix-POTR, and mix-POTR2;
Subalpine fir and spruce: ABLA, PIEN, mix-ABLA, and mix-PIEN.

After fire suppression allowed interior Douglas-fir and grand fir to invade dry sites because surface fire was prevented from fulfilling its role as a tree-thinning process, vertical forest structure was transformed when leaf area (foliage biomass) shifted downward from one high canopy layer such as the old forest single stratum structural stage, to multiple low layers such as the understory reinitiation structural stage (Agee 1996; Arno et al. 1995; Brown et al. 2003; Graham et al. 1999, 2004).

The transformation of vertical forest structure is an important issue because it created understory layers functioning as ladder fuel, increasing the probability that surface fire would transition to crown fire (Fiedler et al. 2004, Graham et al. 2004, Mason et al. 2003, Peterson et al. 2005, Stephens 1998). For this reason, forest structure is often included in a fuels analysis to assess ladder-fuel changes through time.

RV estimates for forest structural stages, as derived from VDDT modeling, were compared with other RV sources to determine if the VDDT values are consistent with what has been traditionally used in the Blue Mountains during the last 20 years. The other sources used for this comparison are:

- Caraher Report (Caraher et al. 1992).
- Eastside Forest Ecosystem Health Assessment (Lehmkuhl et al. 1994).
- Eastside Forests Scientific Society Panel (Henjum et al. 1994).
- Ecosystem components assessment for the interior Columbia Basin ecosystem management project (ICBEMP) (Quigley and Arbelbide 1997).
- Landscape-level comparison of historical and current conditions for ICBEMP area (Hessburg et al. 1999b).
- Terrestrial vertebrate source habitat assessment for ICBEMP area (Wisdom et al. 2000).
- Historical range of variability estimates for central Idaho (Morgan and Parsons 2001).
- Analysis of pre-management era patterns of forest structure for mixed-conifer forests (Hessburg et al. 2007).
- Simulation modeling for the upper Grande Ronde River sub-basin (INLAS project) (Hemstrom et al. 2007).
- Fire and fuel model scenario planning for northeastern Oregon (Wales et al. 2007).

The RV comparison focused on the abundance and distribution of old-forest (late-old) structure by potential vegetation group. The other sources found that the estimated RV for historical levels of old forest on dry upland sites in the Blue Mountains varied from 10-80%; the VDDT estimate of 45-75% is within this range. The other sources found that the estimated RV for historical levels of old forest on moist upland sites in the Blue Mountains varied from <10-60%; the VDDT estimate of 25-40% is within this range (Countryman and Justice 2010).

As an example of the comparison process, Hemstrom et al. (2007) used VDDT to simulate landscape composition for dry upland forests under a natural fire regime. They found that the mean percentage of forested land in the old forest single stratum structural stage was just under 20%, whereas the mean percentage in the old forest multi-strata structural stage was less than 5%. When Wimberly and Kennedy (2008) completed a similar modeling exercise for warm dry forests of the Blue Mountains, they found that about 15% was in the old forest single stratum structural stage, and 4% was in the old forest multi-strata structural stage.

Range of variation information for forest structural stages is provided in table 3, and it is stratified by potential vegetation group.

Table 3: Range of variation information for forest structural stage, expressed as percentages.

Potential Vegetation Group	FOREST STRUCTURAL STAGE SI	SE	UR	OFSS	OFMS
	Range of Variation (Percentage)				
Cold Upland Forest	20-45	10-30	10-25	5-20	10-25
Moist Upland Forest	20-30	20-30	10-20	10-20	15-20
Dry Upland Forest	15-25	10-20	5-10	40-60	5-15

Source/Notes: Derived from disturbance process modeling using the Vegetation Dynamics Development Tool (VDDT). Potential vegetation group is described in Powell et al. (2007). Forest structural stages are described in table 4.

Using RV to Evaluate Tree (Stand) Density

Tree density is a characterization of tree stocking for an area. It expresses the number of tree stems occupying a unit of land. Stocking can be expressed as a 'stand density index' or in some other measure of relative density, or it can be quantified in absolute terms as a number of trees per acre or as the amount of basal area, wood volume, or canopy cover on an area (Powell 1999).

Published stocking guidelines are available for evaluating tree density levels (Cochran et al. 1994; Powell 1999, 2009d). By using the stocking guidelines in conjunction with potential vegetation groups, it is possible to estimate how much forestland acreage is currently overstocked and how it compares to a range of variation for this ecosystem component.

Range of variation information for tree density classes is provided in table 5, and it is stratified by upland-forest potential vegetation group.

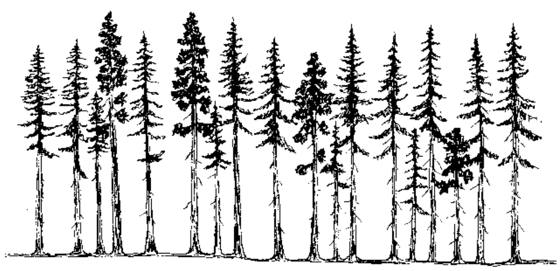
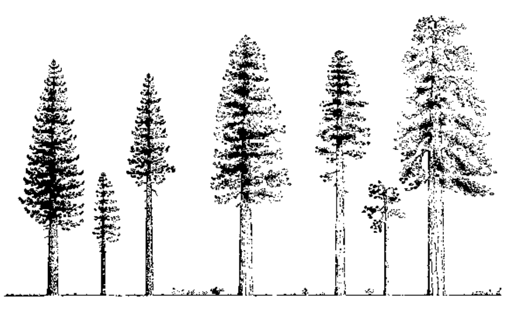
Using RV to Evaluate Forest Canopy Fuel Loading

When considering fire effects on vegetation and other ecosystem components, crown fire is acknowledged to be the most severe of three fire types, which consist of ground fire, surface fire, and crown fire (Pyne et al. 1996). Although crown fire is normal and expected for fire regimes III, IV, and V (Schmidt et al. 2002), a large amount of crown fire is neither normal nor expected for the dry forests of fire regime I (Agee 1993).

Because dry forests are affected by crown fire with increasing regularity (Mutch et al. 1993), and as treatments are being planned for the wildland-urban interface where crown fire can seldom be tolerated regardless of fire regime, fire managers need tools to help them evaluate crown fire susceptibility for all forested lands.

To help meet this need, range of variation information was developed for three classes of canopy fuel loading (canopy biomass), and it is stratified by potential vegetation group (and PVG is broadly correlated with fire regime) (table 6).

Table 4: Description of forest structural stages.

	**Stand Initiation (SI)**. Following a stand-replacing disturbance such as wildfire or tree harvest, growing space is occupied rapidly by vegetation that either survives the disturbance, or colonizes the area afterward. Survivors survive the disturbance above ground, or they initiate new growth from underground organs or from seeds on the site. Colonizers disperse seed into disturbed areas, it germinates, and then new plants establish and develop. A single canopy stratum of tree seedlings and saplings is present in this stage.
	**Stem Exclusion (SE)**. In this structural stage, trees initially grow fast and quickly occupy all of their growing space, competing strongly for sunlight and moisture. Because trees are tall and reduce light, understory plants (including smaller trees) are shaded and grow more slowly. Species needing sunlight usually die; shrubs and herbs may go dormant. In this stage, establishment of new trees is precluded by a lack of sunlight (stem exclusion closed canopy) or by a lack of soil moisture (stem exclusion open canopy).
	**Understory Reinitiation (UR)**. As the forest develops, a new age class of trees (cohort) eventually gets established after overstory trees begin to die, or because they no longer fully occupy their growing space. This period of overstory crown shyness occurs when tall trees abrade each other in the wind (Putz et al. 1984). Regrowth of understory seedlings and other vegetation then occurs, and trees begin to stratify into vertical layers. This stage consists of overstory trees at a low to moderate density, with small trees underneath.
	**Old Forest (OF)**. Many age classes and vegetation layers mark this structural stage containing large, old trees. Snags and decayed fallen trees may also be present, leaving a discontinuous overstory canopy. The drawing shows a single-layer stand of ponderosa pine reflecting the influence of frequent surface fire on dry-forest sites (old forest single stratum; OFSS). Surface fire is not common on cold or moist sites, so these areas generally have multi-layer stands with large trees in the uppermost stratum (old forest multi strata; OFMS).

Sources: Based on O'Hara and others (1996), Oliver and Larson (1996), and Spies (1997).

Table 5: Range of variation information for tree density class, expressed as percentages.

Tree Density Class (expressed as basal area, in ft^2/acre at 10″ QMD)	**Potential Vegetation Group**		
	Dry UF	**Moist UF**	**Cold UF**
	Range of Variation (Percentage)		
Low (dry: <45; moist: <90; cold: <70)	40-85	20-40	15-35
Moderate (dry: 45-70; moist: 90-135; cold: 70-110)	15-30	25-60	20-40
High (dry: >70; moist: >135; cold: >110)	5-15	15-30	25-60

Source/Notes: Derived from Powell (2009d). Potential vegetation group is described in Powell et al. (2007). QMD is quadratic mean diameter. Note that basal area values for the low, moderate, and high categories are provided as examples – Powell (2009d) provides additional density-class metrics in the form of stand density index, trees per acre, and canopy cover.

Table 6: Range of variation information for canopy biomass classes, expressed as percentages.

Potential Vegetation Group	**Fire Regime[2]**	**CANOPY BIOMASS CLASS[1]**		
		Low (≤.05 kg/m^3 CBD)	**Moderate** (.06-.09 kg/m^3 CBD)	**High** (≥.10 kg/m^3 CBD)
		Range of Variation (Percentage)		
Dry Upland Forest	I	60-90	20-60	10-20
Moist Upland Forest	III	20-50	50-70	20-50
Cold Upland Forest	IV	10-20	20-60	60-90

Source/Notes: Based on Agee (1998). Potential vegetation group is described in Powell et al. (2007).

[1] Canopy biomass class is a derived database field; it can be calculated using queries contained in Powell (2010). CBD is crown bulk density, expressed as kilograms per cubic meter of crown volume. Class break-points are as follows: .05 kg/m^3 = CBD threshold below which crown fire is unlikely; .10 kg/m^3 = CBD threshold above which crown fire is easily sustained (Powell 2010).

[2] Fire regime describes the fire environment by characterizing fire frequency, fire intensity, fire severity, fire extent, fire timing, and historical burned area (Schmidt et al. 2002). For forest environments in the Blue Mountains, three fire regimes are most important: Fire regime I: surface;Fire regime III: mixed; Fire regime IV: replacement.

Using RV to Evaluate Insect and Disease Susceptibility

RV is not intended to portray a static, unchanging condition. It should relate to ecological processes with important implications on ecosystem behavior, such as the capacity to function effectively in a constantly changing environment. Ecosystems of the interior Pacific Northwest evolved with a steady diet of fires, insect outbreaks, disease epidemics, floods, landslides, human uses, and weather cycles. Change was, and still is, the only constant in their existence. RV is designed to characterize the range of vegetation composition and structure resulting from these agents of change (Morgan et al. 1994).

Do insect outbreaks and disease epidemics indicate that ecosystems are unhealthy? And what do large, landscape-scale fires indicate in an ecological sense? Since ecosystems are constantly changing, we need to evaluate their health in a similar context. Resilient forests not only tolerate periodic disturbance, they may depend on it for rejuvenation and renewal (Johnson et al. 1994). Significant changes in the magnitude (extent), intensity, or pattern of disturbance, however, may be indicators of impaired ecological integrity (Sampson and Adams 1994).

Perhaps the most effective framework for evaluating forest health is the range of variation – are changes caused by insects, diseases, and wildfire consistent with what would be expected (the RV) for similar ecosystems and vegetative conditions? Recent forest health assessments for the Blue Mountains, for example, suggest it would be appropriate to characterize dry forest ecosystems as out-of-balance. When dry forests are evaluated in this context, high levels of insect and disease activity are not unexpected, but they are still a symptom of the underlying problem – the composition and structure of these ecosystems are currently outside their RV (Caraher et al. 1992, Gast et al. 1991, Hessburg et al. 1994, Mutch et al. 1993, Oliver et al. 1994, Sampson and Adams 1994, Shlisky 1994, Wickman 1992).

Since the composition and structure of a forest ecosystem changes as development progresses, it is important that land managers understand how forest succession influences susceptibility to ensure that management activities are placed on a sound ecological foundation: "manipulation of a forest ecosystem should work within the limits established by natural disturbance patterns prior to extensive human alteration of the landscape" (Hunter 1999, page 29).

Susceptibility is defined as a set of conditions that make a forest stand vulnerable to substantial injury from insects or diseases. Susceptibility assessments do not predict when insects or diseases might reach damaging levels; rather, they indicate whether stand conditions are conducive to declining forest health, as indicated by increasing levels of tree mortality from insect and disease organisms.

Drought, ecological site potential (potential vegetation type), species composition and abundance, tree size, forest structure (canopy layering, structural stage), stocking (tree density), intra-stand variability (clumpiness), and other biophysical factors influence susceptibility and vulnerability to insect and disease disturbances (Hessburg et al. 1999, Lehmkuhl et al. 1994, Schmitt and Powell 2005).

Trees with increased insect or disease susceptibility often occur in dense forests where they face greater competition for soil moisture, nutrients, and other resources. Ponderosa pines in high-density stands, for example, have lower xylem water potentials and rates of photosynthesis, indicating greater drought stress (in this instance, high density causes physiological drought, rather than climatic drought caused by lack of rainfall). These trees also have decreased resin production and foliar toughness, suggesting an increased susceptibility to insect and pathogen attack (Kolb et al. 1998).

To provide a process for evaluating insect and disease susceptibility, range of variation information was developed for nine insect and disease agents, and three classes of susceptibility (high, moderate, low), and it is stratified by potential vegetation group (table 7).

Table 7: Range of variation information for insect and disease susceptibility.

Insect and Disease Agents[1]	POTENTIAL VEGETATION GROUP Dry UF	Moist UF	Cold UF
	Range of Variation (Percentage)		
Defoliating insects			
Low susceptibility	40-85	5-20	40-95
Moderate susceptibility	15-30	20-30	15-25
High susceptibility	5-15	35-80	5-10
Douglas-fir beetle			
Low susceptibility	35-75	30-60	45-95
Moderate susceptibility	15-30	20-40	10-25
High susceptibility	10-25	10-30	5-10
Fir engraver			
Low susceptibility	45-95	30-70	35-75
Moderate susceptibility	10-25	10-20	20-45
High susceptibility	5-10	20-40	5-10
Spruce beetle			
Low susceptibility	0-0	50-95	10-30
Moderate susceptibility	0-0	10-25	30-50
High susceptibility	0-0	0-10	20-50
Bark beetles in ponderosa pine			
Low susceptibility	35-75	30-65	55-95
Moderate susceptibility	15-35	15-30	5-30
High susceptibility	10-20	15-35	0-5
Mountain pine beetle in lodgepole pine			
Low susceptibility	55-90	30-60	30-50
Moderate susceptibility	5-35	25-40	15-40
High susceptibility	0-5	5-30	15-40
Douglas-fir dwarf mistletoe			
Low susceptibility	30-60	30-65	40-90
Moderate susceptibility	10-35	20-45	20-30
High susceptibility	20-35	10-20	0-10
Western larch dwarf mistletoe			
Low susceptibility	55-95	5-20	10-20
Moderate susceptibility	5-30	15-40	20-50
High susceptibility	0-5	40-70	30-60
Root diseases			
Low susceptibility	35-75	5-25	30-65
Moderate susceptibility	20-35	20-40	20-45
High susceptibility	5-20	35-65	10-15

Sources/Notes: Derived from Schmitt and Powell (2012). Queries for calculating susceptibility ratings for forest polygons are available from Schmitt and Powell (2005). Potential vegetation group is described in Powell et al. (2007).

[1] Defoliating insects includes western spruce budworm and Douglas-fir tussock moth; bark beetles in ponderosa pine includes western and mountain pine beetles; root diseases include laminated root rot and Armillaria root disease.

GLOSSARY

Biophysical environment. Landscape-level unit of composition and structure, with its associated environmental gradients and processes of change (Quigley and Arbelbide 1997).

Cover type. The plant species forming a plurality of the composition across a given land area, e.g., the Engelmann spruce-subalpine fir, ponderosa pine-Douglas-fir, or lodgepole pine forest cover types (Helms 1998). Forest cover types of the United States and Canada are described in Eyre (1980). Rangeland cover types of the United States are described in Shiflet (1994).

Disturbance. A relatively discrete event that disrupts the structure of an ecosystem, community or population, and changes resource availability or the physical environment. Disturbances include processes such as fires, floods, insect outbreaks, disease epidemics and windstorms (Dodson et al. 1998).

Disturbance regime. The spatial and temporal dynamics of disturbance events over a long time period. Description of a disturbance regime would include characteristics such as the spatial distribution of disturbance events; disturbance frequency (number of disturbance events in a specified time interval, or the probability of a disturbance event occurring within a particular time interval); return interval (average time between successive disturbance events); rotation period (length of time until an area equivalent to the size of an analysis area would be affected in one disturbance event); disturbance size; and the magnitude, or intensity, of a disturbance event (Dodson et al. 1998).

Ecosystem. A set of interacting species and their local, non-biological environment, functioning together to sustain life (Botkin 1990). This term was first used by A.G. Tansley in 1935 to describe a discrete unit consisting of living and non-living components, interacting to form a stable system (Allaby 1998).

Landscape. A heterogeneous land area composed of interacting ecosystems that are repeated in similar form throughout. Landscapes can vary in size, ranging down to a few kilometers in diameter (Forman and Godron 1986).

Plant association. A plant community with similar physiognomy (form and structure) and floristics; commonly it is a climax community (Allaby 1998). It is believed that (1) the individual species in the association are, to some extent, adapted to each other; (2) the association is made up of species that have similar environmental requirements; and (3) the association has some degree of integration (Kimmins 1997).

Potential vegetation. The vegetation that would develop if all successional sequences were completed under present site conditions (Dunster and Dunster 1996).

Potential vegetation group (PVG). An aggregation of plant association groups with similar environmental regimes (temperature or moisture relationships) and dominated by similar types of plants (Powell et al. 2007).

Range of variation (historical range of variability). A characterization of fluctuations in ecosystem conditions or processes over time; an analytical technique used to define the bounds of ecosystem behavior that remain relatively consistent through time (Morgan and others 1994). "The range of variation under historic disturbance regimes is an important context to evaluate current and desired conditions; however, it should not necessarily be used as the desired condition itself" (FSH 1909.12, Land Management Planning Handbook, section 43.13 – Range of variation).

Resilience. Rate at which a system returns to its reference state in the face of a perturbation (Chapin et al. 2002); i.e., the 'bounce-back' capacity of an ecosystem.

Resistance. Resistance refers to the ability of a system to remain unchanged (i.e., maintain its stability) in the face of external forces such as disturbance.

Seral stage: a stage of secondary successional development (secondary succession refers to an ecological process of progressive changes in a plant community after stand-initiating disturbance). Four seral stages are recognized: early seral, mid seral, late seral, and potential natural community (Hall et al. 1995).

> **Early seral**: clear dominance of pioneer species (western larch, ponderosa pine, lodgepole pine, etc.); PNC species absent, or present in very low numbers.
>
> **Mid seral**: PNC species are increasing in the forest composition as a result of their active colonization of the site; PNC species are approaching equal proportions with the early-seral species.
>
> **Late seral**: PNC species are dominant, although long-lived, early-seral species (ponderosa pine, western larch, etc.) may still be present in low numbers.
>
> **Potential natural community** (PNC): the biotic community presumably established and maintained under present environmental conditions; early- or mid-seral species are scarce or absent entirely in the plant composition.

Species composition. Identity of species in an ecosystem (Chapin et al. 2002).

Structural stage. A stage or recognizable condition that relates to the physical orientation and arrangement of vegetation; the size and arrangement (both vertical and horizontal) of trees and tree parts. The following structural stages have been described (O'Hara et al. 1996, Oliver and Larson 1996; also see table 4):

> **Stand initiation**: one canopy stratum of seedlings and saplings is present; grasses, forbs, and shrubs typically coexist with the trees.
>
> **Stem exclusion**: one canopy stratum comprised mostly of pole-sized trees (5-8.9" DBH) is present. The canopy layer may be open (**stem exclusion open canopy**) on sites where moisture is limiting, or closed (**stem exclusion closed canopy**) on sites where light is a limiting resource.
>
> **Understory reinitiation**: two canopy strata are present; a second tree layer is established under an older overstory. Overstory mortality creates growing space for establishment of understory trees.
>
> **Old forest**: a predominance of large trees (>21" DBH) is present in a stand with one or more canopy strata. On warm dry sites with frequent, low-intensity fires, a single stratum may be present (**old forest single stratum**). On cool moist sites without recurring underburns, multi-layer stands with large trees in the uppermost stratum may be present (**old forest multi strata**).

REFERENCES

This section contains cited literature, along with other references pertaining to the range of variation concept.

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p. isbn:1-55963-229-1

Agee, J.K. 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. Gen. Tech. Rep. PNW-GTR-320. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 52 p. http://www.treesearch.fs.fed.us/pubs/6225

Agee, J.K. 1996. Fire in the Blue Mountains: a history, ecology, and research agenda. In: Jaindl, R.G.; Quigley, T.M., eds. Search for a solution: sustaining the land, people, and economy of the Blue Mountains. Washington, DC: American Forests: 119-145.

Agee, J.K. 1998. The landscape ecology of western forest fire regimes. Northwest Science. 72(Special Issue): 24-34.

Allaby, M., ed. 1998. The concise Oxford dictionary of ecology. 2nd edition. New York: Oxford University Press. 440 p. isbn:0-19-280078-7

Aplet, G.H.; Keeton, W.S. 1999. Application of historical range of variability concepts to biodiversity conservation. In: Baydack, R.K.; Campa, H.; Haufler, J.B., eds. Practical approaches to the conservation of biological diversity. Washington, DC: Island Press: 71-86. isbn:1-55963-544-4

Arno, S.F.; Fiedler, C.E. 2005. Mimicking nature's fire: restoring fire-prone forests in the West. Washington, DC: Island Press. 242 p. isbn:1-55963-143-0

Arno, S.F.; Harrington, M.G.; Fiedler, C.E.; Carlson, C.E. 1995. Restoring fire-dependent ponderosa pine forests in western Montana. Restoration and Management Notes. 13(1): 32-36. doi:10.3386.er.13.1.32

Bennett, R.S. 2000. Extremists are destroying our national forests. 21st Century. 13(2): 66-67, 70.

Betts, M.; Loo, J. 2002. A comparison of pre-European settlement forest characterization methodologies. Forestry Chronicle. 78(3): 422-432.

Botkin, D.B. 1990. Discordant harmonies: a new ecology for the twenty-first century. New York: Oxford University Press. 241 p. isbn:0-19-507469-6

Botkin, D.B. 1995. Our natural history: the lessons of Lewis and Clark. New York: G.P. Putnam's Sons. 300 p. isbn:0-399-14048-4

Boyd, R. 1999. Indians, fire, and the land in the Pacific Northwest. Corvallis, OR: Oregon State University Press. 313 p. isbn:0-87071-459-7

Brown, J.K.; Reinhardt, E.D.; Kramer, K.A. 2003. Coarse woody debris: managing benefits and fire hazard in the recovering forest. Gen. Tech. Rep. RMRS-GTR-105. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. 16 p. http://www.treesearch.fs.fed.us/pubs/5585

Caraher, D.L.; Henshaw, J.; Hall, F.; Knapp, W.H.; McCammon, B.P.; Nesbitt, J.; Pedersen, R.J.; Regenovitch, I.; Tietz, C. 1992. Restoring ecosystems in the Blue Mountains: a report to the Regional Forester and the Forest Supervisors of the Blue Mountain forests. Portland, OR: USDA Forest Service, Pacific Northwest Region. 14 p (plus 5 appendices). Caraher Report

Caraher, D.; Knapp, W.H. 1994. Assessing ecosystem health in the Blue Mountains. In: Foley, L.H., comp. Silviculture: from the cradle of forestry to ecosystem management; proceedings of the National Silviculture Workshop. Gen. Tech. Rep. SE-88. Asheville, NC: USDA Forest Service, Southeastern Forest Experiment Station: 34-41. http://www.treesearch.fs.fed.us/pubs/132

Chapin, F.S. III; Matson, P.A.; Mooney, H.A. 2002. Principles of terrestrial ecosystem ecology. New York: Springer-Verlag. 436 p. isbn:0-387-95443-0

Christensen, G.A.; Dunham, P.; Powell, D.C.; Hiserote, B. 2007. Forest resources of the Umatilla National Forest. Res. Bull. PNW-RB-253. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 38 p. http://www.treesearch.fs.fed.us/pubs/27656

Christensen, N.L.; Bartuska, A.M.; Brown, J.H.; Carpenter, S.; D'Antonio, C.; Francis, R.; Franklin, J.F.; MacMahon, J.A.; Noss, R.F.; Parsons, D.J.; Peterson, C.H.; Turner, M.G.; Woodmansee, R.G. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications. 6(3): 665-691. doi:10.2307/2269460

Clark, L.R.; Sampson, R.N. 1995. Forest ecosystem health in the inland west: a science and policy reader. Washington, DC: American Forests, Forest Policy Center. 37 p.

Clements, F.E. 1916. Plant succession: an analysis of the development of vegetation. Pub. No. 242. Washington, DC: Carnegie Institution of Washington. 512 p.

Cochran, P.H.; Geist, J.M.; Clemens, D.L.; Clausnitzer, R.R.; Powell, D.C. 1994. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington. Res. Note PNW-RN-513. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 21 p. http://www.treesearch.fs.fed.us/pubs/25113

Countryman, B.; Justice, D. 2010. Analysis of existing versus historic condition for structural stages and potential vegetation groups within the Malheur, Umatilla, and Wallowa-Whitman National Forests. Unpub. Process Pap. Baker City, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 16 p.

Cronon, W., ed. 1996. Uncommon ground: rethinking the human place in nature. New York: W.W. Norton & Company. 561 p. isbn:0-393-31511-8

Cyr, D.; Gauthier, S.; Bergeron, Y.; Carcaillet, C. 2009. Forest management is driving the eastern North American boreal forest outside its natural range of variability. Frontiers in Ecology and the Environment. 7(10): 519-524. doi:10.1890/080088

deBuys, W. 2008. Welcome to the Anthropocene. Rangelands. 30(5): 31-35. doi:10.2111/1551-501X(2008)30[31:WTTA]2.0.CO;2

DeLong, S.C.; Tanner, D. 1996. Managing the pattern of forest harvest: lessons from wildfire. Biodiversity and Conservation. 5(10): 1191-1205. doi:10.1007/BF00051571

Dodson, S.I.; Allen, T.F.H.; Carpenter, S.R.; Ives, A.R.; Jeanne, R.L.; Kitchell, J.F.; Langston, N.E.; Turner, M.G. 1998. Ecology. New York: Oxford University Press. 433 p. isbn:0-19-512079-5

Duncan, S.L.; McComb, B.C.; Johnson, K.N. 2010. Integrating ecological and social ranges of variability in conservation of biodiversity: past, present, and future. Ecology and Society. 15(1): article 5. http://www.ecologyandsociety.org/vol15/iss1/art5/

Dunster, J.; Dunster, K. 1996. Dictionary of natural resource management. Vancouver, BC: UBC Press. 363 p. isbn:0-7748-0503-X

Egan, D.; Howell, E.A. 2001. The historical ecology handbook: a restorationist's guide to reference ecosystems. Washington, DC: Island Press. 457 p. isbn:1-55963-746-3

Egerton, F.N. 1973. Changing concepts of the balance of nature. Quarterly Review of Biology. 48(2): 322-350. http://www.jstor.org/stable/2820544

Eng, M. 1998. Spatial patterns in forested landscapes: implications for biology and forestry. In: Voller, J.; Harrison, S., eds. Conservation biology principles for forested landscapes.

Vancouver, BC: UBC Press: 42-75. isbn:0-7748-0630-3

Evans, J.W. 1991. Powerful rockey: the Blue Mountains and the Oregon Trail, 1811-1883. Enterprise, OR: Eastern Oregon State College; Pika Press. 374 p. isbn:0-9626772-0-5

Everett, R.; Hessburg, P.; Jensen, M.; Bormann, B. 1994. Volume 1: executive summary. Gen. Tech. Rep. PNW-GTR-317. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 61 p.

Eyre, F.H., ed. 1980. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters. 148 p. isbn:978-0686306979

Fiedler, C.E.; Keegan, C.E.; Woodall, C.W.; Morgan, T.A. 2004. A strategic assessment of crown fire hazard in Montana: potential effectiveness and costs of hazard reduction treatments. Gen. Tech. Rep. PNW-GTR-622. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 48 p. http://www.treesearch.fs.fed.us/pubs/7448

Forman, R.T.T.; Godron, M. 1986. Landscape ecology. New York: John Wiley. 619 p. isbn:0-471-87037-4

Frank, A.C. 2003. The restoration of historical variability in the ponderosa pine type on the Boise Basin Experimental Forest. M.S. thesis. Moscow, ID: University of Idaho. 119 p.

Fulé, P.Z. 2008. Does it make sense to restore wildland fire in changing climate? Restoration Ecology. 16(4): 526-531. doi:10.1111/j.1526-100X.2008.00489.x

Gannett, H. 1902. The forests of Oregon. Professional Paper No. 4, Series H, Forestry, 1. Washington, DC: U.S. Department of the Interior, Geological Survey. 36 p.

Gast, W.R., Jr.; Scott, D.W.; Schmitt, C.; Clemens, D.; Howes, S.; Johnson, C.G., Jr.; Mason, R.; Mohr, F.; Clapp, R.A. 1991. Blue Mountains forest health report: "new perspectives in forest health." Portland, OR: USDA Forest Service, Pacific Northwest Region, Malheur, Umatilla, and Wallowa-Whitman National Forests. Irregular pagination. Gast Report

General Accounting Office (GAO). 1999. Western national forests: a cohesive strategy is needed to address catastrophic wildfire threats. GAO/RCED-99-65. Washington, DC: U.S. General Accounting Office, Resources, Community, and Economic Development Division. 60 p. GAO Report

Graham, R.T.; Harvey, A.E.; Jain, T.B.; Tonn, J.R. 1999. The effects of thinning and similar stand treatments on fire behavior in western forests. Gen. Tech. Rep. PNW-GTR-463. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 27 p. http://www.treesearch.fs.fed.us/pubs/2979

Graham, R.T.; McCaffrey, S.; Jain, T.B., tech. eds. 2004. Science basis for changing forest structure to modify wildfire behavior and severity. Gen. Tech. Rep. RMRS-GTR-120. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 43 p. http://www.treesearch.fs.fed.us/pubs/6279

Gruell, G.E. 2001. Fire in Sierra Nevada forests: a photographic interpretation of ecological change since 1849. Missoula, MT: Mountain Press Publishing Company. 238 p. ISBN:0-87842-446-6

Hall, F.C. 1993. Structural stages by plant association group: Malheur and Ochoco National Forests. Unpub. Rep. Portland, OR: USDA Forest Service, Pacific Northwest Region. 5 p.

Hall, F.C.; Bryant, L.; Clausnitzer, R.; Geier-Hayes, K.; Keane, R.; Kertis, J.; Shlisky, A.; Steele, R. 1995. Definitions and codes for seral status and structure of vegetation. Gen. Tech. Rep. PNW-GTR-363. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 39 p. http://www.treesearch.fs.fed.us/pubs/5619

Harris, J.A.; Hobbs, R.J.; Higgs, E.; Aronson, J. 2006. Ecological restoration and global climate change. Restoration Ecology. 14(2): 170-176. doi:10.1111/j.1526-100X.2006.00136.x

Harrod, R.J.; McRae, B.H.; Hartl, W.E. 1999. Historical stand reconstruction in ponderosa pine forests to guide silvicultural prescriptions. Forest Ecology and Management. 114(2-3): 433-446. doi:10.1016/S0378-1127(98)00373-9

Haufler, J.B.; Mehl, C.A.; Roloff, G.J. 1996. Using a coarse-filter approach with species assessment for ecosystem management. Wildlife Society Bulletin. 24(2): 200-208. http://www.jstor.org/stable/3783108

Helms, J.A., ed. 1998. The dictionary of forestry. Bethesda, MD: Society of American Foresters. 210 p. ISBN:0-939970-73-2

Hemstrom, M.A.; Merzenich, J.; Reger, A.; Wales, B. 2007. Integrated analysis of landscape management scenarios using state and transition models in the upper Grande Ronde River Subbasin, Oregon, USA. Landscape and Urban Planning. 80(3): 198-211. http://www.treesearch.fs.fed.us/pubs/29354

Henjum, M.G.; Karr, J.R.; Bottom, D.L.; Perry, D.A.; Bednarz, J.C.; Wright, S.G.; Beckwitt, S.A.; Beckwitt, E. 1994. Interim protection for late-successional forests, fisheries, and watersheds; national forests east of the Cascade crest, Oregon, and Washington. Wildlife Society Tech. Rev. 94-2. Bethesda, MD: The Wildlife Society. 245 p.

Hessburg, P.F.; Mitchell, R.G.; Filip, G.M. 1994. Historical and current roles of insects and pathogens in eastern Oregon and Washington forested landscapes. Gen. Tech. Rep. PNW-GTR-327. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 72 p. http://www.treesearch.fs.fed.us/pubs/6390

Hessburg, P.F.; Smith, B.G; Salter, R.B. 1999a. Detecting change in forest spatial patterns from reference conditions. Ecological Applications. 9(4): 1232-1252. doi:10.1890/1051-0761(1999)009[1232:DCIFSP]2.0.CO;2

Hessburg, P.F.; Smith, B.G.; Kreiter, S.D.; Miller, C.A.; Salter, R.B.; McNicholl, C.H.; Hann, W.J. 1999b. Historical and current forest and range landscapes in the interior Columbia River basin and portions of the Klamath and Great basins. Part 1: linking vegetation patterns and landscape vulnerability to potential insect and pathogen disturbances. Gen. Tech. Rep. PNW-GTR-458. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 357 p. http://www.treesearch.fs.fed.us/pubs/29638

Hessburg, P.; Salter, R.; James, K. 2007. Re-examining fire severity relations in pre-management era mixed conifer forests: inferences from landscape patterns of forest structure. Landscape Ecology. 22(Supplement 1): 5-24.

Heyerdahl, E.K. 1997. Spatial and temporal variation in historical fire regimes of the Blue Mountains, Oregon and Washington: the influence of climate. Ph.D. dissertation. Seattle, WA: University of Washington, College of Forest Resources. 224 p.

Holl, K.; Smith, M. 2007. Scottish upland forests: history lessons for the future. Forest Ecology and Management. 249(1-2): 45-53. doi:10.1016/j.foreco.2007.04.042

Holling, C.S.; Meffe, G.K. 1996. Command and control and the pathology of natural resource management. Conservation Biology. 10(2): 328-337. doi:10.1046/j.1523-1739.1996.10020328.x

Huff, M.H.; Ottmar, R.D.; Alvarado, E.; Everett, R.L.; Vihnanek, R.E.; Lehmkuhl, J.F.; Hessburg, P.F. 1995. Historical and current forest landscapes in eastern Oregon and Washington; part II: linking vegetation characteristics to potential fire behavior and related smoke production. Gen. Tech. Rep. PNW-GTR-355. Portland, OR: USDA Forest

Service, Pacific Northwest Research Station. 43 p. http://www.treesearch.fs.fed.us/pubs/3063

Hunter, M.L. 1990. Wildlife, forests, and forestry: principles of managing forests for biological diversity. Englewood Cliffs, NJ: Prentice Hall. 370 p. ISBN:0-13-959479-5

Johnson, C.G. 1993. Ecosystem screens; file designation 2060 memorandum to Wallowa-Whitman, Umatilla, and Malheur Forest Supervisors. Baker City, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 4 p (and 6 exhibits).

Johnson, C.G., Jr.; Clausnitzer, R.R. 1992. Plant associations of the Blue and Ochoco Mountains. Tech. Pub. R6-ERW-TP-036-92. Portland, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest. 164 p.

Johnson, C.G., Jr.; Clausnitzer, R.R.; Mehringer, P.J.; Oliver, C.D. 1994. Biotic and abiotic processes of eastside ecosystems: the effects of management on plant and community ecology, and on stand and landscape vegetation dynamics. Gen. Tech. Rep. PNW-GTR-322. Portland, OR: U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. 66 p.

Kaufmann, M.R.; Graham, R.T.; Boyce, D.A., Jr.; Moir, W.H.; Perry, L.; Reynolds, R.T.; Bassett, R.L.; Mehlhop, P.; Edminster, C.B.; Block, W.M.; Corn, P.S. 1994. An ecological basis for ecosystem management. Gen. Tech. Rep. RM-246. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. 22 p. http://www.treesearch.fs.fed.us/pubs/7612

Keane, R.E.; Hessburg, P.F.; Landres, P.B.; Swanson, F.J. 2009. The use of historical range and variability (HRV) in landscape management. Forest Ecology and Management. 258(7): 1025-1037. doi:10.1016/j.foreco.2009.05.035

Kimmins, J.P. 1997. Forest ecology; a foundation for sustainable management. 2nd edition. Upper Saddle River, NJ: Prentice Hall. 596 p. isbn:0-02-364071-5

Kipfmueller, K.F.; Kupfer, J.A. 2005. Complexity of successional pathways in subalpine forests of the Selway-Bitterroot Wilderness area. Annals of the Association of American Geographers. 95(3): 495-510.

Kolb, T.E.; Holmberg, K.M.; Wagner, M.R.; Stone, J.E. 1998. Regulation of ponderosa pine foliar physiology and insect resistance mechanisms by basal area treatments. Tree Physiology. 18(6): 375-381. doi:10.1093/treephys/18.6.375

Landres, P.B.; Morgan, P.; Swanson, F.J. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications. 9(4): 1179-1188. doi:10.1890/1051-0761(1999)009[1179:OOTUON]2.0.CO;2

Lehmkuhl, J.F.; Hessburg, P.F.; Everett, R.L.; Huff, M.H.; Ottmar, R.D. 1994. Historical and current forest landscapes of eastern Oregon and Washington; part I: vegetation pattern and insect and disease hazards. Gen. Tech. Rep. PNW-GTR-328. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 88 p. http://www.treesearch.fs.fed.us/pubs/6407

Magnuson, J.J. 1990. Long-term ecological research and the invisible present. BioScience. 40(7): 495-501. http://www.jstor.org/stable/1311317

Manley, P.N.; Brogan, G.E.; Cook, C.; Flores, M.E.; Fullmer, D.G.; Husari, S.; Jimerson, T.M.; Lux, L.M.; McCain, M.E.; Rose, J.A.; Schmitt, G.; Schuyler, J.C.; Skinner, M.J. 1995. Sustaining ecosystems: a conceptual framework. Tech. Pub. R5-EM-TP-001. San Francisco, CA: USDA Forest Service, Pacific Southwest Region. 216 p.

Maruoka, K.R. 1994. Fire history of *Pseudotsuga menziesii* and *Abies grandis* stands in the

Blue Mountains of Oregon and Washington. M.S. Thesis. Seattle, WA: University of Washington, College of Forest Resources. 73 p.

Mason, C.L.; Ceder, K.; Rogers, H.; Bloxton, T.; Comnick, J.; Lippke, B.; McCarter, J.; Zobrist, K. 2003. Investigation of alternative strategies for design, layout and administration of fuel removal projects. Seattle, WA: University of Washington, College of Forest Resources, Rural Technology Initiative. 78 p. http://www.ruraltech.org/pubs/reports/fuel_removal/index.asp

Millar, C.I. 1997. Comments on historical variation & desired condition as tools for terrestrial landscape analysis. In: Proceedings of the sixth biennial watershed management conference. Water Resources Center Report No. 92. Davis, CA: University of California: 105-131. http://www.treesearch.fs.fed.us/pubs/31818

Millar, C.I.; Woolfenden, W.B. 1999. The role of climate change in interpreting historical variability. Ecological Applications. 9(4): 1207-1216. doi:10.1890/1051-0761(1999)009[1207:TROCCI]2.0.CO;2

Milly, P.C.D.; Betancourt, J.; Falkenmark, M.; Hirsch, R.M.; Kundzewicz, Z.W.; Lettenmaier, D.P.; Stouffer, R.J. 2008. Stationarity is dead: Whither water management? Science. 319(5863): 573-574. doi:10.1126/science.1151915

Moore, M.M.; Covington, W.W.; Fulé, P.Z. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications. 9(4): 1266-1277. doi:10.1890/1051-0761(1999)009[1266:RCAERA]2.0.CO;2

Morgan, P. 2004. Back to the future: the value of history in understanding and managing dynamic landscapes. In: Gucinski, H.; Miner, C.; Bittner, B., eds. Proceedings: views from ridge – considerations for planning at the landscape scale. Gen. Tech. Rep. PNW-GTR-596. Portland, OR: USDA Forest Service, Pacific Northwest Research Station: 78-84. http://www.treesearch.fs.fed.us/pubs/6195

Morgan, P.; Aplet, G.H.; Haufler, J.B.; Humphries, H.C.; Moore, M.M.; Wilson, W.D. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry. 2: 87-111. doi:10.1300/J091v02n01_04

Morgan, P.; Parsons, R. 2001. Historical range of variability of forests of the Idaho southern batholith ecosystem. Unpub. Rep. Moscow, ID: University of Idaho, Department of Forest Resources. 34 p. Southern Idaho HRV

Munger, T.T. 1917. Western yellow pine in Oregon. Bulletin No. 418. Washington, DC: U.S. Department of Agriculture. 48 p. Munger Bulletin

Mutch, R.W.; Arno, S.F.; Brown, J.K.; Carlson, C.E.; Ottmar, R.D.; Peterson, J.L. 1993. Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems. Gen. Tech. Rep. PNW-GTR-310. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 14 p. http://www.treesearch.fs.fed.us/pubs/9056

O'Hara, K.L.; Latham, P.A.; Hessburg, P.; Smith, B.G. 1996. A structural classification for inland Northwest forest vegetation. Western Journal of Applied Forestry. 11 (3): 97-102. http://www.treesearch.fs.fed.us/pubs/4746

Oliver, C.D.; Ferguson, D.E.; Harvey, A.E.; Malany, H.S.; Mandzak, J.M.; Mutch, R.W. 1994. Managing ecosystems for forest health: an approach and the effects on uses and values. Journal of Sustainable Forestry. 2(1/2): 113-133.

Oliver, C.D.; Larson, B.C. 1996. Forest stand dynamics. Update edition. New York: John Wiley and Sons. 520 p. isbn:0-471-13833-9

Parsons, D.J.; Swetnam, T.W.; Christensen, N.L. 1999. Invited feature: uses and limitations of historical variability concepts in managing ecosystems. Ecological Applications.

9(4): 1177-1277. doi:10.1890/1051-0761(1999)009[1177:UALOHV]2.0.CO;2

Parsons, R.; Morgan, P.; Landres, P. 2000. Applying the natural variability concept: towards desired future conditions. In: D'Eon, R.G.; Johnson, J.F.; Ferguson, E.A. Ecosystem management of forested landscapes: directions and implementation. Vancouver, BC: UBC Press: 222-237.

Perera, A.H.; Buse, L.J.; Weber, M.G., eds. 2004. Emulating natural forest landscape disturbances: concepts and applications. New York: Columbia University Press. 315 p. isbn:0-231-12916-5

Peterson, D.L.; Johnson, M.C.; Agee, J.K.; Jain, T.B.; McKenzie, D.; Reinhardt, E.D. 2005. Forest structure and fire hazard in dry forests of the western United States. Gen. Tech. Rep. PNW-GTR-628. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 30 p. http://www.treesearch.fs.fed.us/pubs/8572

Petit, R.J.; Hu, F.S.; Dick, C.W. 2008. Forests of the past: a window to future changes. Science. 320(5882): 1450-1452. doi:10.1126/science.1155457

Powell, D.C. 1994. Effects of the 1980s western spruce budworm outbreak on the Malheur National Forest in northeastern Oregon. Tech. Pub. R6-FI&D-TP-12-94. Portland, OR: USDA Forest Service, Pacific Northwest Region. 176 p.

Powell, D.C. 1997. Forest vegetation report for the Tower Fire ecosystem analysis. Unpub. Rep. Pendleton, OR: USDA Forest Service, Umatilla National Forest, North Fork John Day Ranger District. 52 p. Tower Vegetation Report

Powell, D.C. 1999. Suggested stocking levels for forest stands in northeastern Oregon and southeastern Washington: an implementation guide for the Umatilla National Forest. Tech. Pub. F14-SO-TP-03-99. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 300 p. Stocking Guide

Powell, D.C. 2000. Potential vegetation, disturbance, plant succession, and other aspects of forest ecology. Tech. Pub. F14-SO-TP-09-00. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 88 p. Forest Ecology

Powell, D.C. 2004. Description of composite vegetation database. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 37 p.

Powell, D.C. 2008. Using General Land Office survey notes to characterize historical vegetation conditions for the Umatilla National Forest. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 50 p.

Powell, D.C. 2009a. A stage is a stage is a stage…or is it? Successional stages, structural stages, seral stages. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 9 p.

Powell, D.C. 2009b. Historical fires in the headwaters portion of the Tucannon River watershed. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 52 p.

Powell, D.C. 2009c. Historical vegetation mapping. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 53 p. Historical Mapping

Powell, D.C. 2009d. Tree density protocol for mid-scale assessments. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 45 p.

Powell, D.C. 2010. Estimating crown fire susceptibility for project planning. Fire Management Today. 70(3): 8-15. http://www.fs.fed.us/fire/fmt/fmt_pdfs/FMT70-3.pdf

Powell, D.C.; Johnson, C.G., Jr.; Crowe, E.A.; Wells, A.; Swanson, D.K. 2007. Potential vegetation hierarchy for the Blue Mountains section of northeastern Oregon, southeastern Washington, and west-central Idaho. Gen. Tech. Rep. PNW-GTR-709. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 87 p. http://www.treesearch.fs.fed.us/pubs/27598

Putz, F.E.; Parker, G.G.; Archibald, R.M. 1984. Mechanical abrasion and intercrown spacing. American Midland Naturalist. 112(1): 24-28. http://www.jstor.org/stable/2425452

Pyne, S.J.; Andrews, P.L.; Laven, R.D. 1996. Introduction to wildland fire. 2nd edition. New York: John Wiley & Sons. 769 p. isbn:0-471-54913-4

Quigley, T.M.; Arbelbide, S.J., tech. eds. 1997. An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins. Gen. Tech. Rep. PNW-GTR-405. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 4 volumes: 1-2066. http://www.treesearch.fs.fed.us/pubs/24921

Quigley, T.M.; Haynes, R.W.; Graham, R.T. 1996. Integrated scientific assessment for ecosystem management in the interior Columbia basin. Gen. Tech. Rep. PNW-GTR-382. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 303 p. http://www.treesearch.fs.fed.us/pubs/25384

Sampson, R.N.; Adams, D.L., eds. 1994. Assessing forest ecosystem health in the inland west. Binghamton, NY: Food Products Press (Haworth Press). 461 p.

Saxon, E.; Baker, B.; Hargrove, W.; Hoffman, F.; Zganjar, C. 2005. Mapping environments at risk under different climate change scenarios. Ecology Letters. 8(1): 53-60. doi:10.1111/j.1461-0248.2004.00694.x

Schmidt, K.M.; Menakis, J.P.; Hardy, C.C.; Hann, W.J.; Bunnell, D.L. 2002. Development of coarse-scale spatial data for wildland fire and fuel management. Gen. Tech. Rep. RMRS-GTR-87. Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station. 41 p (and CD). http://www.treesearch.fs.fed.us/pubs/4590

Schmitt, C.L.; Powell, D.C. 2005. Rating forest stands for insect and disease susceptibility: a simplified approach; version 2.0. Pub. BMPMSC-05-01. La Grande, OR: USDA Forest Service, Pacific Northwest Region, Wallowa-Whitman National Forest, Blue Mountains Pest Management Service Center. 20 p. Susceptibility Rating

Schmitt, C.L.; Powell, D.C. 2012. Range of variation recommendations for insect and disease susceptibility. White Pap. F14-SO-WP-Silv-22. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 12 p.

Sedell, J.R.; Luchessa, K.J. 1982. Using the historical record as an aid to salmonid habitat enhancement. In: Armantrout, N.B., ed. Acquisition and utilization of aquatic habitat inventory information. Bethesda, MD: American Fisheries Society: 210-223.

Shiflet, T.N., ed. 1994. Rangeland cover types of the United States. Denver, CO: Society for Range Management. 152 p. isbn:1-884930-01-8

Shlisky, A.J. 1994. Multiscale analysis in the Pacific Northwest. Journal of Forestry. 92(8): 32-34.

Shugart, H.H., Jr.; West, D.C. 1981. Long-term dynamics of forest ecosystems. American Scientist. 69(6): 647-652.

Spies, T. 1997. Forest stand structure, composition, and function. In: Kohm, K.A.; Franklin, J.F., eds. Creating a forestry for the 21st century: the science of ecosystem management. Washington, DC: Island Press: 11-30. isbn:1-55963-399-9

Spirn, A.W. 1996. Constructing nature: the legacy of Frederick Law Olmstead. In: Cronon, W., ed. Uncommon Ground. New York: W.W. Norton: 91-113. isbn:0-393-31511-8

Sprugel, D.G. 1991. Disturbance, equilibrium, and environmental variability: what is 'natural' vegetation in a changing environment? Biological Conservation. 58(1): 1-18. doi:10.1016/0006-3207(91)90041-7

Stephens, S.L. 1998. Evaluation of the effects of silvicultural and fuels treatments on potential fire behaviour in Sierra Nevada mixed-conifer forests. Forest Ecology and Management. 105(1-3): 21-35. doi:10.1016/S0378-1127(97)00293-4

Stevens, W.K. 1990. New eye on nature: the real constant is eternal turmoil. New York: The New York Times, science column for Tuesday, July 31, 1990. 2 p.

Swanson, D.K.; Schmitt, C.L.; Shirley, D.M.; Erickson, V.; Schuetz, K.J.; Tatum, M.L.; Powell, D.C. 2010. Aspen biology, community classification, and management in the Blue Mountains. Gen. Tech. Rep. PNW-GTR-806. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 117 p. http://www.treesearch.fs.fed.us/pubs/35257

Swanson, F.J.; Jones, J.A.; Wallin, D.O.; Cissel, J.H. 1994. Natural variability – implications for ecosystem management. In: Jensen, M.E.; Bourgeron, P.S., eds. Volume II: Ecosystem management: principles and applications. Gen. Tech. Rep. PNW-GTR-318. Portland, OR: USDA Forest Service, Pacific Northwest Research Station: 80-94. http://www.treesearch.fs.fed.us/pubs/6223

Swetnam, T.W.; Allen, C.D.; Betancourt, J.L. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications. 9(4): 1189-1206. doi:10.1890/1051-0761(1999)009[1189:AHEUTP]2.0.CO;2

Thomas, J.W., tech. ed. 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Agriculture Handbook No. 553. Washington, DC: USDA Forest Service. 512 p.

Thompson, J.R.; Duncan, S.L.; Johnson, K.N. 2009. Is there potential for the historical range of variability to guide conservation given the social range of variability? Ecology and Society. 14(1): article 18. http://www.ecologyandsociety.org/vol14/iss1/art18/

USDA Forest Service. 1990. Land and resource management plan: Umatilla National Forest. Portland, OR: USDA Forest Service, Pacific Northwest Region. Irregular pagination. Forest Plan

USDA Forest Service. 1992. Our approach to sustaining ecological systems. R1-92-23. Missoula, MT: USDA Forest Service, Northern Region. 26 p.

USDA Forest Service. 1994. Continuation of interim management direction establishing riparian, ecosystem and wildlife standards for timber sales; Regional Forester's Forest Plan Amendment #1. Portland, OR: USDA Forest Service, Pacific Northwest Region.

USDA Forest Service. 1995. Revised interim direction establishing riparian, ecosystem and wildlife standards for timber sales; Regional Forester's Forest Plan Amendment #2. Portland, OR: USDA Forest Service, Pacific Northwest Region. 14 p. Eastside Screens

USDA Forest Service. 1996. Status of the interior Columbia basin: summary of scientific findings. Gen. Tech. Rep. PNW-GTR-385. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 144 p. http://www.treesearch.fs.fed.us/pubs/25385

USDA Forest Service. 1997. Considering all things: summary of the draft environmental impact statements. R6-P&EA-UP-007-97. [Place of publication unknown]: USDA Forest Service; U.S. Department of the Interior, Bureau of Land Management. 57 p.

USDA Forest Service. 2002. Watershed prioritization. Unpub. Rep. Pendleton, OR: USDA Forest Service, Pacific Northwest Region, Umatilla National Forest. 75 p.

Vale, T.R., ed. 2002. Fire, native peoples, and the natural landscape. Washington, DC: Island Press. 315 p. isbn:1-55963-889-3

Veblen, T.T. 2003. Historic range of variability of mountain forest ecosystems: concepts and applications. Forestry Chronicle. 79(2): 223-226. doi:10.5558/tfc79223-2

Wales, B.C.; Suring, L.H.; Hemstrom, M.A. 2007. Modeling potential outcomes of fire and fuel management scenarios on the structure of forested habitats in northeast Oregon, USA. Landscape and Urban Planning. 80(3): 223-236. http://www.treesearch.fs.fed.us/pubs/29338

Weaver, H. 1967. Fire as a continuing ecological factor in perpetuation of ponderosa pine forests in western United States. Advancing Frontiers of Plant Science. 18: 137-157.

Whittaker, R.J.; Willis, K.J.; Field, R. 2001. Scale and species richness: towards a general, hierarchical theory of species diversity. Journal of Biogeography. 28(4): 453-470. doi:10.1046/j.1365-2699.2001.00563.x

Wickman, B.E. 1992. Forest health in the Blue Mountains: the influence of insects and disease. Gen. Tech. Rep. PNW-GTR-295. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 15 p. http://www.treesearch.fs.fed.us/pubs/9032

Wiersum, K.F. 1995. 200 years of sustainability in forestry: lessons from history. Environmental Management. 19(3): 321-329. doi:10.1007/BF02471975

Willis, K.J.; Whittaker, R.J. 2002. Species diversity – scale matters. Science. 295(5558): 1245-1248. doi:10.1126/science.1067335

Wimberly, M.C.; Kennedy, R.S.H. 2008. Spatially explicit modeling of mixed-severity fire regimes and landscape dynamics. Forest Ecology and Management. 254(3): 511-523.

Wisdom, M.J.; Holthausen, R.S.; Wales, B.C.; Hargis, C.D.; Saab, V.A.; Lee, D.C.; Hann, W.J.; Rich, T.D.; Rowland, M.M.; Murphy, W.J.; Eames, M.R. 2000. Source habitats for terrestrial vertebrates of focus in the interior Columbia basin: broadscale trends and management implications. Gen. Tech. Rep. PNW-GTR-485. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 3 vol. 529 p. http://www.treesearch.fs.fed.us/pubs/3081

Wong, C.; Dorner, B.; Sandman, H. 2003. Estimating historical variability of natural disturbances in British Columbia. Land Management Handbook No. 53. Victoria, BC: British Columbia Ministry of Forests, Research Branch, British Columbia Ministry of Sustainable Resource Management. 140 p.

Wong, C.; Iverson, K. 2004. Range of natural variability: applying the concept to management in central British Columbia. BC Journal of Ecosystems and Management. 4(1): art3. http://www.forrex.org/jem/ISS21/vol4_no1_art3.pdf

Worster, D. 1996. Nature's economy: a history of ecological ideas. 2nd edition. Cambridge, UK: Cambridge University Press. 507 p. isbn:0-521-46834-5

Wright, C.S.; Agee, J.K. 2004. Fire and vegetation history in the eastern Cascade Mountains, Washington. Ecological Applications. 14(2): 443-459. doi:10.1890/02-5349

Wu, J.; Loucks, O.L. 1995. From balance of nature to hierarchical patch dynamics: a paradigm shift in ecology. Quarterly Review of Biology. 70(4): 439-466. doi:10.1086/419172

Revision History

March 2012: minor formatting and text edits were made; table 7 was revised to incorporate revised RV ranges from Schmitt and Powell (2012).