



# Cumulative Watershed Effects of Fuel Management in the Western United States

## CHAPTER 2.

# Fire Regimes and Ecoregions<sup>1</sup>

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## Introduction

The public land management agencies are phasing in a radically new approach to land management. They are shifting from their focus on individual resources to a more holistic approach of managing *whole ecosystems*. Fire-excluded systems are prone to changes in composition and density and are susceptible to catastrophic fire and invasion by non-native species. The cause of the problem in many areas includes more than a century of fire exclusion and suppression along with increased human development at the wildland-urban interface. Grazing and logging have also contributed to this problem.

To correct this problem, fire and land management must return ecosystems to a healthier, *sustainable* condition. One way to do this is to modify the current structure of ecosystems to mimic natural structures (Bailey 2002).

## Ecosystem Structure and Process

Ecosystem structure and process are related. For example, riparian forests evolved with flooding, and fire-adapted forests evolved with fire of varying frequency and intensity. For ecosystems to be able to sustain natural structures, they will need to experience the same kinds of processes in which they evolved (Allen and others 2002; Savage 2003).

## Range of Variation

Restoration works best if ecosystems are returned to within a “natural range of variation” (Landres and others 1999). Ecosystems, for example, have variability not only through time because of climate change, but across the landscape and the nation because of disturbance events, successional processes, and natural climatic variation in addition to climate change. From forests, to desert, to steppe, the continent’s ecosystems vary vastly. It is not possible to reconstruct how each system looked in the past. Instead, we can reset altered ecosystems back to within a range of natural variability. As Melissa Savage (2003) puts it, “If we can restore the natural processes, the natural structure should follow.”

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# Climate, Ecoregions, and Fire Regimes

To restore altered systems and to understand how and why they are distributed, we must understand the processes of how they form. Climate largely determines ecosystem differences. As it varies, the other components vary in response. As a result, ecosystems of different climates differ significantly (Bailey 1996).

The most important climatic factor in determining the distribution of ecosystems is the climatic regime, defined as the daily and seasonal fluxes of energy and moisture. For example, tropical rainforest climates lack seasonal periodicity, whereas mid-latitude steppes have pronounced seasons. As the climatic regime changes, so does the hydrologic cycle, as reflected in the streamflow of rivers located in different climatic regions. For example, no water flows in creeks located in the warm, dry summer region of California during summer and fall, but in winter and early spring, groundwater contributes to streamflow. Climate profoundly affects landforms and erosion cycles. Such effects are evident when we contrast the angularity of arid land topography of the Colorado Plateau with the rounded slopes of the humid Blue Ridge Mountains. Plants and animals have adjusted their life patterns to the basic environmental cycles produced by the climate. Whenever a marked annual variation occurs in temperature and precipitation, a corresponding annual variation occurs in the life cycle of the flora and fauna. Climate also determines the distribution, frequency, and density of natural ignitions.

Controls over the climatic effect change with scale. At the macroscale, ecosystem patterns are controlled by macroclimate (in other words, the climate that lies above the local modifying effects of landform and vegetation). Based on macroclimatic conditions, I subdivided the continents into ecoclimatic zones, also known as ecosystem regions, or *ecoregions*. They were mapped at a scale of 1:30,000,000 (Bailey 1989). Three hierarchical levels of macroclimatic differentiation are shown (in order that reflect finer scale climatic differences: *domain*, *division*, and *province*). The domains and divisions are based largely on the climatic zones of Köppen (1931) as modified by Trewartha (1968). While the Köppen-Trewartha system is based on climate, there is good correspondence between its climatic types and the natural climax vegetation types and soils within them (Bailey 1996)<sup>3</sup>. Because of this, it was considered a logical basis for ecological zoning. A major advantage to using the system is it is based on quantitative definitions and as such, can be applied to any part of the Earth where climatic data are available<sup>4</sup>. The zoning was made hierarchical using Köppen-Trewartha's climatic groups and climatic types as ecoregion domains and divisions, respectively, (table 1). At the second level (division), further differentiation was made according to landform—distinguishing mountains with altitudinal zonation from lowland plains.

The climate is not completely uniform within level 2 (division), so a further subdivision was undertaken. Within the dry climates, for example, there is a wide range of degree of aridity, ranging from very dry deserts through transitional levels of aridity in the direction of adjacent moist climates. We refer to these as climate subtypes. The subtypes largely correspond to major plant formations (for example, broadleaved forest), which are delimited on the basis of macro features of the vegetation by concentrating on the life-form of the plants. They form the basis for subdividing ecoregion divisions into provinces, and are based on a number of sources, including a world map of landscape types (Milanova and Kushlin 1993). Of course, not all the space is taken up by the formation, because the nature of the topography will allow the differentiation into many habitats. One ignores these local variations in mapping climatic regions (and therefore ecoregions).

<sup>3</sup> This is largely because Köppen derived his climate classes from observations on the distribution of vegetation types on various continents.

<sup>4</sup> Others have followed this precedent for using Köppen-Trewartha in global ecological zoning. One good example was carried out by the United Nation's Foreign Agricultural Organization (FAO), who developed an ecological zone map for the Forest Resource Assessment 2000 (FAO 2001) using a combination of vegetation characteristics and Köppen-Trewartha.

**Table 1.** Ecoregion global framework.

Ecoregion Level 1 – Domain		Ecoregion Level 2 – Division		
Name	Criteria (equivalent to Köppen- Trewartha <sup>a</sup> climatic groups)	Name	Code	Criteria (approximate equivalent Köppen- Trewartha <sup>a</sup> types, in combination with vegetation physiognomy)
Polar	No more than 3 months over 10 °C	Icecap	11	All months below 0 °C. Perpetual snow and ice.
		Tundra	12	All months below 10 °C. Vegetation physiognomy: tundra.
		Subarctic	13	Up to 3 months over 10 °C. Vegetation physiognomy: dense coniferous forest dominant.
Humid Temperate	Eight months or less over 10 °C	Warm continental	21	Same as 220, warmest below 22 °C.
		Hot continental	22	4-7 months over 10 °C, coldest month below 0 °C, warmest above 22 °C.
		Subtropical	23	Same as 260, no dry season.
		Marine	24	4-7 months above 10 °C, coldest month over 0 °C.
		Prairie <sup>b</sup>	25	Sub-humid. Vegetation physiognomy: grasslands.
Dry	Evaporation > precipitation	Mediterranean	26	8 months over 10 °C, coldest below 18 °C, dry summer.
		Tropical/subtropical steppe	31	Semi-arid: all months above 0 °C.
		Tropical/subtropical desert	32	Arid: ½ precipitation of steppes, all months above 0 °C.
		Temperate steppe Temperate desert	33 34	Semi-arid: cold month below 0 °C. Arid: All months dry, cold month below 0 °C.
Humid Tropical	All months without frost: in marine areas over 18 °C	Savanna	41	Same as 420, with 2 months dry <sup>c</sup> in winter
		Rainforest	42	Wet: no dry season

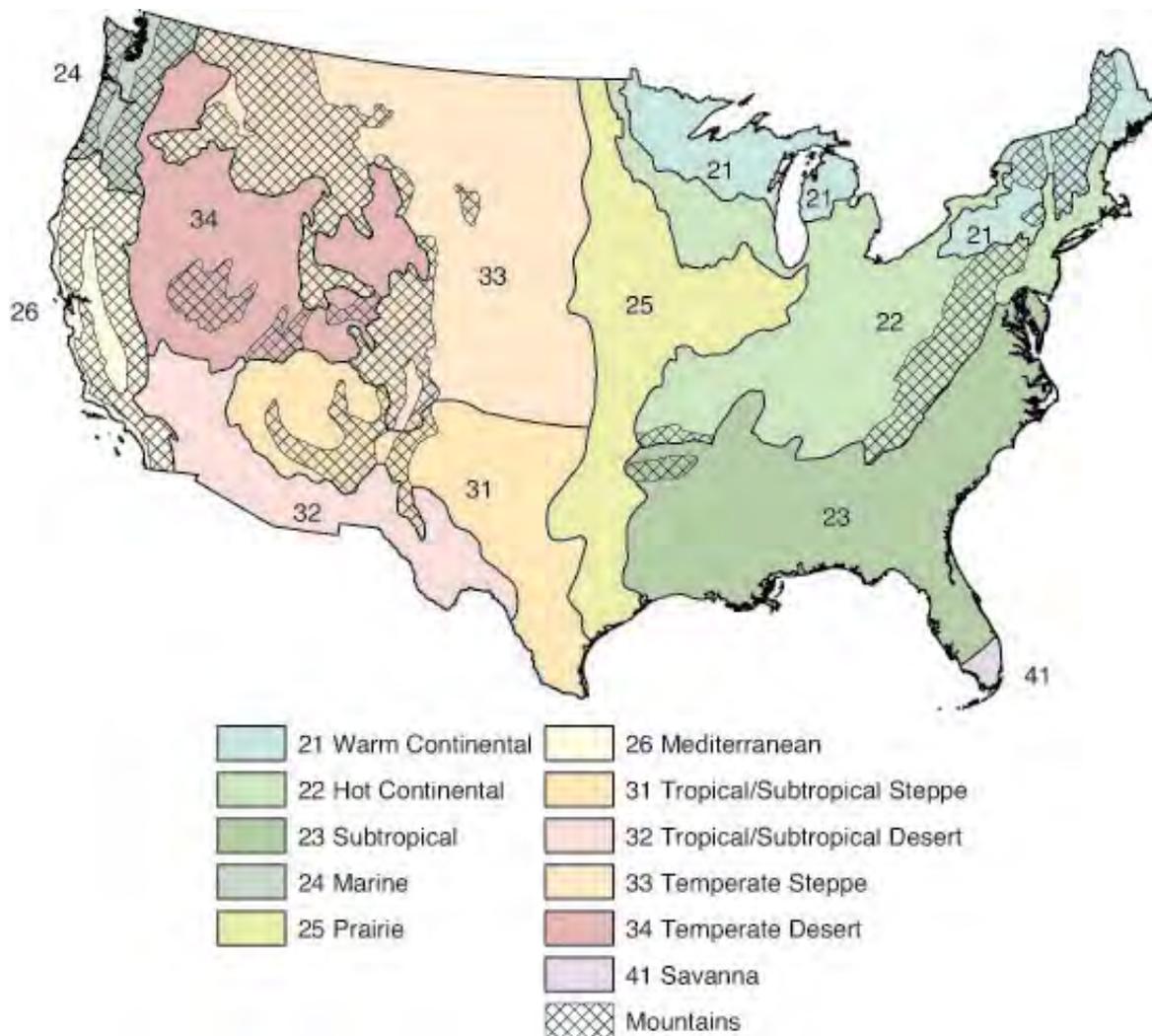
<sup>a</sup> Köppen (1931), as modified by Trewartha (1968)

<sup>b</sup> Köppen (1931) did not recognize the prairie as distinct climatic type. Geographer's recognition of the prairie climate (Borchert 1950) has been incorporated into the system presented here. The ecoregion classification system represents it at the arid side of the 210, 220, and 230 types.

<sup>c</sup> A dry month is defined as the month in which the total precipitation, P, expressed in millimeters, is equal to less than twice the mean temperature (°C).

I also used this approach to construct a 1:7,500,000-scale map of ecoregions for the United States (Bailey 1976, revised 1995). A simplified, reduced-scale map of the second highest of three hierarchical levels (division) appears in (fig. 1). They were delineated using both macroclimate data and a map of existing climax or potential vegetation by Küchler (1967). More information on the rationale I used for identifying ecoregion boundaries on maps of the United States and the world's continents is presented elsewhere (Bailey 2005). In 1993, as part of the National Hierarchical Framework of Ecological Units (Cleland and others 1997), the Forest Service adopted the ecoregion classification system for use in ecosystem management.

It seems reasonable that regions that differ substantially in background climate should have different fire regimes. In fact, fires burn with more or less regular rhythms. The simplest means to reveal a fire regime is to consider the distribution of water within an ecosystem. If they are too wet, they won't burn. The ecosystem's moisture changes with the daily and seasonal fluxes of the moisture of air masses as they move through the region. Long-term fire records around the Pacific Ocean trace nicely the pulses of the Pacific Decadal Oscillation. In this oscillation, the Pacific alternates from warm to cool phases and causes wet and dry periods on the adjacent North American continent. These wet-dry rhythms set the ecological cadence for fire regimes.



**Figure 1.** Approximate boundaries of ecoregion divisions, conterminous United States from Bailey 1996.

## Different Ecoregions, Different Fire Regimes

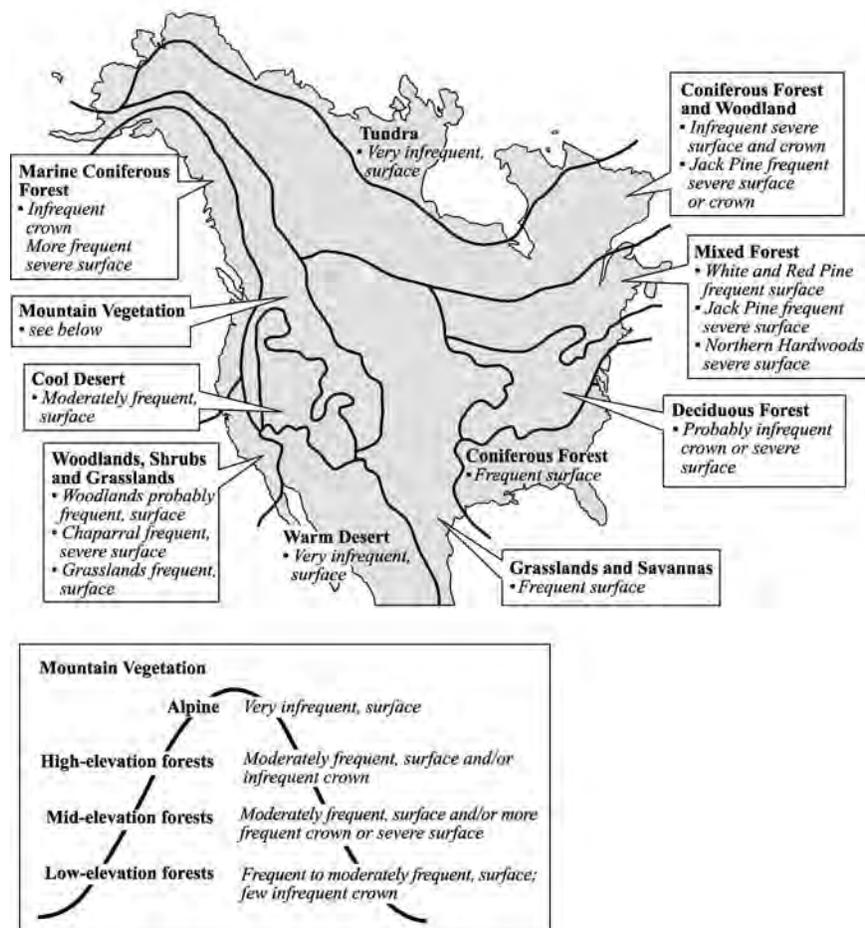
Different ecoregions produce different fire regimes. There are several studies that have looked at variation in fire regimes at the ecoregion scale. We will examine three of them.

### *Pre-Colonial Fire Regimes (Vale)*

Pre-colonial fire regimes for different vegetation types in North America have been determined by analyzing fire scars. In areas lacking trees, the development of vegetation after recent fires and early journal accounts and diaries have been used to make inferences about fire regimes. Vale (1982) synthesized this information in his book, *Plants and People*.

Vale analyzed “natural” vegetation types based on ecoregions. He characterized fire regimes from 45 published studies of fire regimes or from his estimates of the fire regimes based on the fire ecology of the plant species in the areas mapped. He found that fire regimes varied by ecoregion (fig. 2). In the northern coniferous forest and woodland (boreal forest), for example, infrequent large-magnitude fires carried the flames in the

**Figure 2.** Pre-colonial fire regimes of broad vegetation types (based on ecoregions) in North America. Only major divisions of the ecoregion map are shown (from Vale (1982); reprinted with permission of the Association of American Geographers).



canopy of the vegetation, killing most of the forest. Such fires are called “crown fires” because they burn in the upper foliage or crown of the trees.

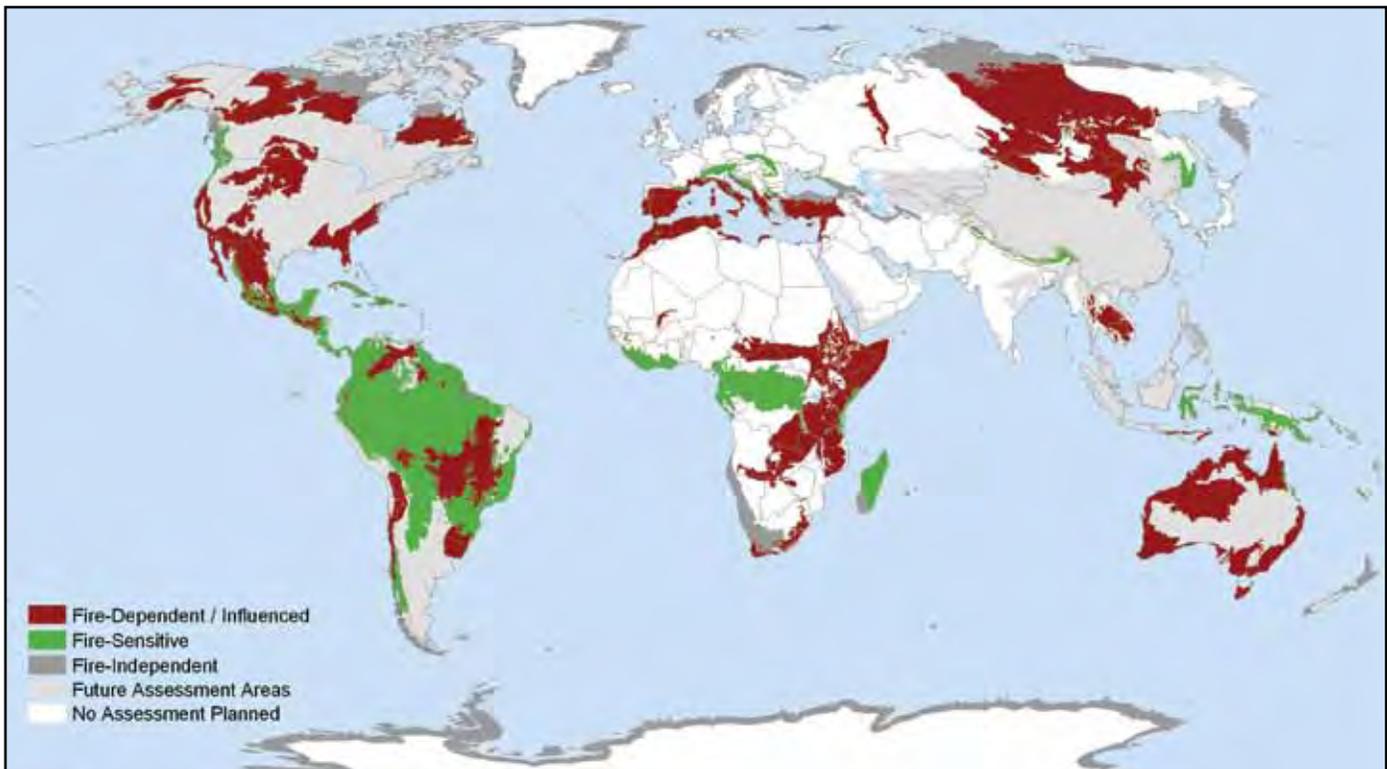
Other environments, such as the deciduous forests of the east, probably had infrequent crown or severe surface fires. These areas are typically cool or wet and consist of vegetation that inhibits the start or spread of fire.

In mountainous regions, fire frequency is related to altitude, or elevation. The lower-elevation forests in the western United States had a regime of frequent, small-magnitude, surface fires. Here, the burning was restricted to the forest floor and most mature trees survived. Ponderosa pine (*Pinus ponderosa*) forests are good examples of this kind of forest.

## Fire Regime Types (*The Nature Conservancy*)

The Nature Conservancy (2004), working in cooperation with the World Wildlife Fund and the International Union for Conservation of Nature, has recently completed a global assessment of fire regime alteration on an ecoregional basis. The assessment identified three broad fire regime types (fig. 3). The report reveals that, among globally important ecoregions for conservation, 84 percent of the area is at risk from altered fire regimes. Almost half of priority conservation ecoregions can be classified as “fire-dependent” (shown in reddish brown).

In *fire-dependent systems*, fires are fundamental to sustaining native plants and animals. Many of the world’s ecosystems, from taiga forest to chaparral shrublands to the savanna, have evolved with fires. What characterizes all of these ecosystems is resilience and recovery following exposure to fires. In the case of chaparral, fire does not kill most of the shrub layer, they sprout back from root crowns.



**Figure 3.** Dominant fire regimes in priority ecoregions for biodiversity conservation. Reddish brown areas are fire dependent; green areas are fire sensitive; and gray areas are fire independent (Copyright, The Nature Conservancy; reproduced with permission).

Thirty-six percent of these important ecoregions are *fire-sensitive*. In these regions, frequent, large and intense fires were, until recently, rare events. In these systems, plants lack adaptations to allow them to rapidly rebound from fire. These areas are typically cool or wet and consist of vegetation that inhibits the start or spread of fire. Examples include the tropical moist broadleaf forest and temperate rainforests.

Eighteen percent are classified as *fire-independent ecosystems*. Here, fires are largely absent because of a lack of vegetation or ignition sources, such as in Africa's Namibian Desert or in tundra ecosystems in the arctic.

According to The Nature Conservancy (2004), fire regimes are degraded in over 80 percent of globally important ecoregions. The majority of North American forests and grasslands are adapted to fire of varying frequencies and intensities. Fire-excluded systems are prone to changes in composition and density, and are susceptible to catastrophic fire and invasion by non-native species. Fire-loving invasive alien plants can drastically change the fire regimes of both fire-dependent and fire-sensitive ecosystems (fig. 4).

### ***Characterizing U.S.A. wildfire regimes (Malamud, Millington, and Perry)***

Researcher Bruce Malamud and colleagues report that the spread of wildfires and their severity patterns show distinct regional styles across the United States (Malamud and others 2005). Using high-resolution Forest Service wildfire statistics, this study was based on 31 years (1970-2000) of wildfire data consisting of 88,916 fires  $\geq 1$  acre on the National Forest System. To allow spatial analysis with regard to the biophysical factors that drive wildfire regimes, the researchers classified the wildfire data into ecoregion divisions (areas of common climate, vegetation, and elevation). In each ecoregion, they asked: What is the frequency-area distribution of wildfires? The study compared area

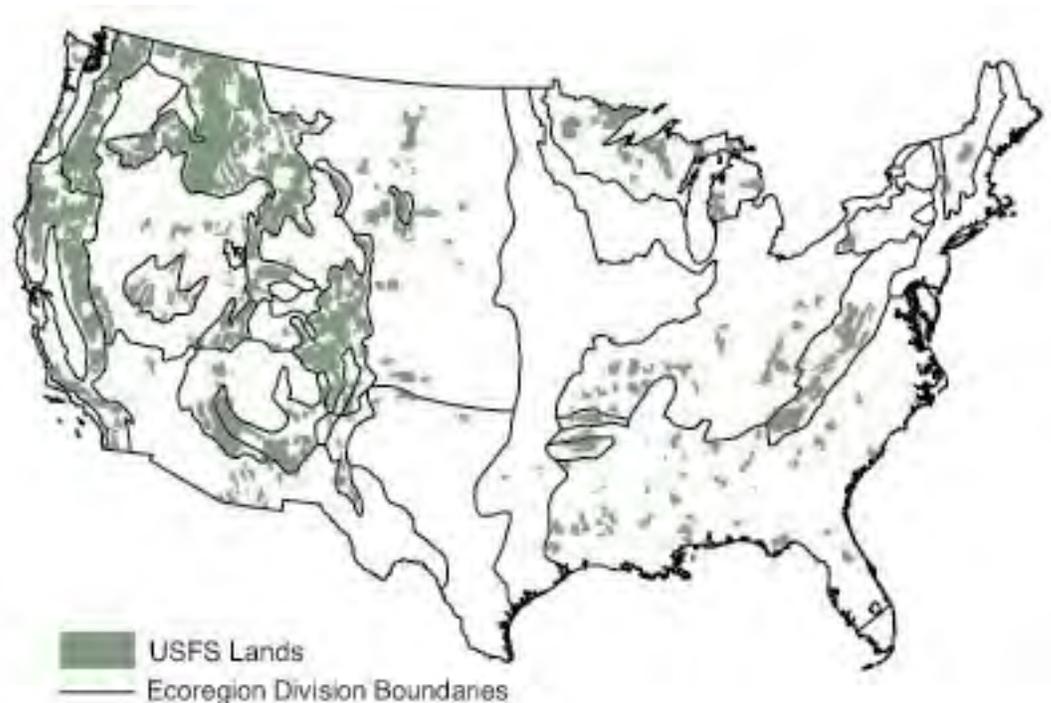
**Figure 4.** Non-native cheatgrass (*Bromus tectorum*) is invading sagebrush steppe in the western United States (photograph copyright, The Nature Conservancy; reproduced with permission).

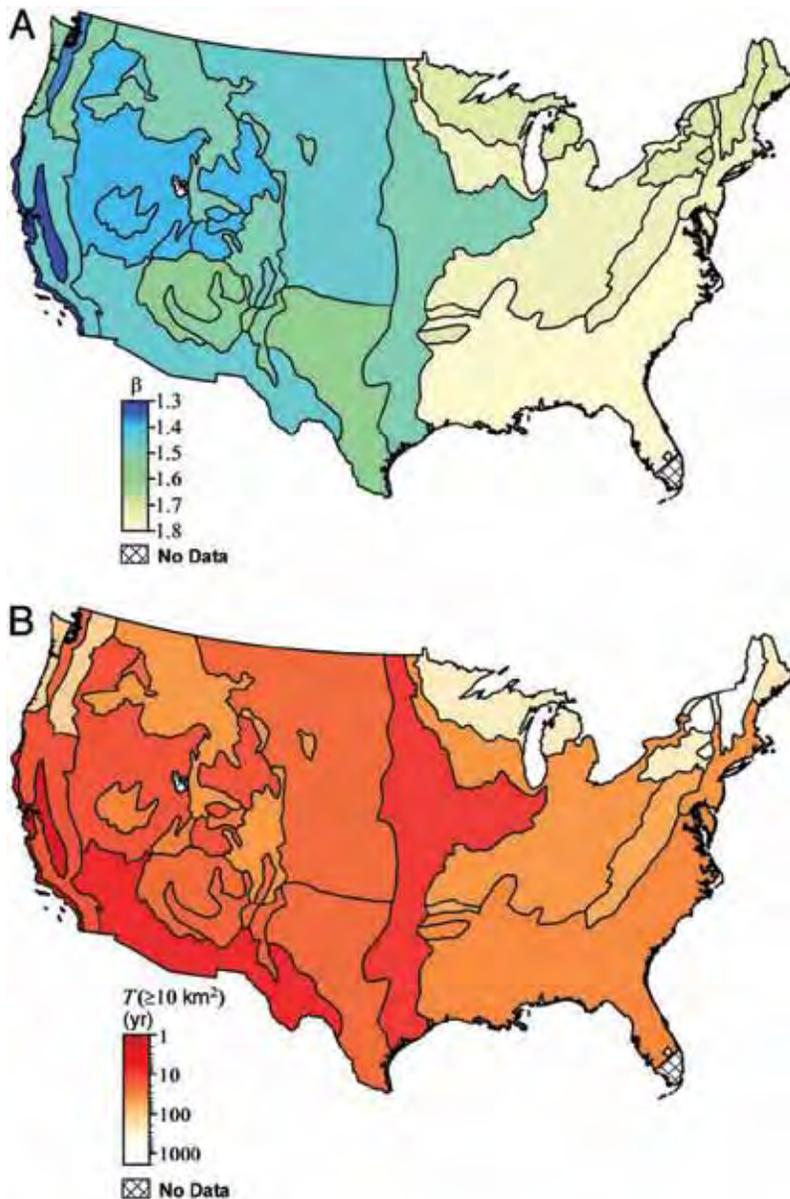


burned, number of fires, and the wildfire recurrence interval. These parameters were calculated at the ecoregion division level (fig. 5). The study created maps to display wildfire patterns and risk for the entire continental United States.

The authors found that the ratio of large to small wildfires decreases from east to west (fig. 6B). There is a relatively higher proportion of large fires in the west compared to the east. This may be due to greater population density and increased forest fragmentation. Alternatively, the observed gradient may be due to natural drivers, with climate, vegetation, and topography producing conditions more conducive to large wildfires.

**Figure 5.** Ecoregion divisions and U.S. Forest Service lands.





**Figure 6.** Maps of wildfire patterns across the conterminous United States for years 1970 to 2000 for U.S. Forest Service wildfires classified by ecoregion division. (A) Ratio of large to small wildfires. The darker the color, the greater the number of large fires. (B) Fire recurrence interval. The legend goes from dark red to white, representing “high” to “low” hazard (from Malamud and others 2005).

The fire recurrence interval differs markedly between ecoregions. For example, the fire cycle values ranged from 13 years for the Mediterranean Mountains Ecoregion to 203 years for the Warm Continental Ecoregion (fig. 6B). Note the term “fire cycle” does not mean that a fire will occur “every” 13 years, or “every” 203 years. It is a probabilistic hazard. For example, a recurrence interval of 100 years would mean that in ANY year, we have a 1 in 100 chance of a fire of a given size.

## Other Studies

In other studies, gradients similar to those observed by Malamud and others (2005) have been described and related to climate and vegetation. Turner and Romme (1994) describe wildfire occurrence gradients as a function of altitude and latitude. They attribute these gradients to broad climatic variation and note western and central regions tend to have frequent fires with forest stand structures dominated by younger trees, whereas the eastern region experiences longer inter-fire intervals and older stand structures. A

statistical forecast methodology developed by Westerling and others (2002) exploits these gradients to predict area burned by western United States wildfires, by ecoregion, a season in advance.

Littell et al. (2009) found that climate drivers of synchronous fire differ regionally. They identified four distinct geographic patterns of ecoregion provinces (ecoprovinces) across the West, each associated with a unique set of climate drivers of annual area burned by wildfire. For example, in northern mountain ecoprovinces, dry, warm conditions in the seasons leading up to and including the fire season are associated with increased area burned, suggesting that fuel condition that is dry vs. wet, was the key determinant of regionally synchronous fires. In contrast, in the southwestern dry ecoprovinces, moist conditions the seasons prior to the fire season are more important than warmer temperatures or drought conditions in the year of the fire, suggesting that fuel abundance determined large fire years.

## Use of Fire Regime at the Ecoregion Scale

The results of these studies can be used to assess burn probabilities across the nation to identify areas with high risk. This helps government agencies to better plan for wildfire hazards. They can also be used as a baseline from which to assess natural fire regimes, which can be used to abate the threat of fire exclusion and restore fire-adapted ecosystems. In fact, these baseline reference conditions are currently being developed as part of the LANDFIRE project (<http://www.landfire.gov>) by the United States Forest Service (Missoula Fire Sciences Laboratory), the U.S. Geological Survey (EROS Data Center), and The Nature Conservancy for all biophysical systems across the United States. In addition, an understanding of fire regimes at the ecoregion scale can provide valuable insights important for designing fuel treatments by helping to identify high from low hazard situations.

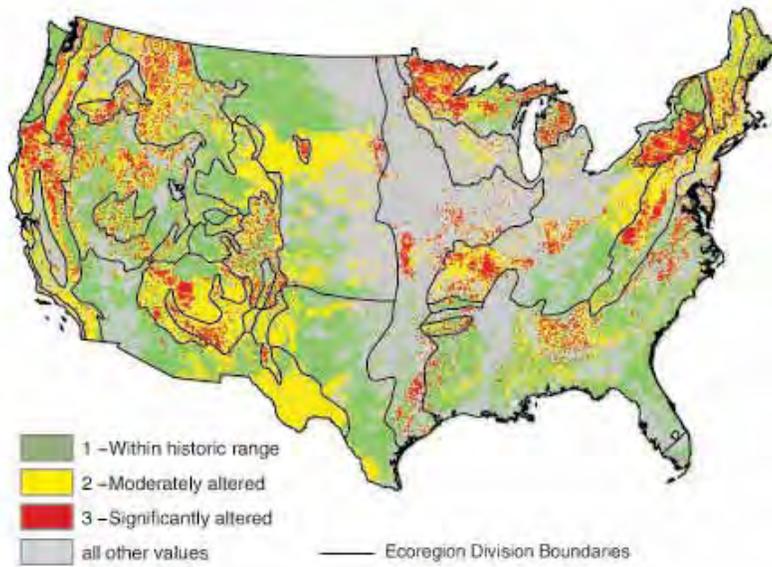
Finally, what can be done to reduce the risk of fire? Savage (2003) and Allen and others (2002) suggest several principles to guide the implementation of ecologically justifiable restoration projects. Two of the most important principles are:

1. Restoration of natural fire regimes (for example, in southwestern ponderosa pine forests to reduce the widespread risk of crown fires by return to low-intensity surface fire);
2. Pay attention to both structure and process (for example, thinning young trees to reduce the fuel load may not work unless low-intensity surface fires are also reintroduced).

Recent data from the Forest Service reflects the scale of the challenge. Schmidt and others (2002) mapped fire regime condition class (FRCC), which is an ecological metric used by federal agencies, The Nature Conservancy (2004), and others to determine the degree to which the vegetation and fire regimes of a given area have changed compared to reference conditions. As shown on the Schmidt and others (2002) map (fig. 7), fire management has significantly changed the fuel levels of many forests, and concurrently, the frequency and intensity of fire. About 30 percent of all ownerships (except those related to agricultural, barren, and urban land) are in high risk categories (shown in yellow and red). In many ecoregions, this percentage is much higher. For example, in the mountains of the southwest, as much as 83 percent is moderately to severely altered<sup>5</sup>.

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<sup>5</sup> Finer resolution and more accurate FRCC maps are being produced by the LANDFIRE project. For more information, see <http://www.landfire.gov>.



**Figure 7.** Fire regime condition class (as mapped by Schmidt and others 2002) with ecoregion division boundaries (thick black lines). Green areas (condition class 1) are largely intact and functioning; yellow areas (condition class 2) are moderately altered; red areas (condition class 3) are significantly altered; and gray areas are non-vegetated, agricultural, or urban.

## Why Ecoregions Are Needed

The same forest type can occur in different ecoregion divisions. For example, ponderosa pine forests occur in the northern Rockies and the Southwest. This does not imply that the climate, topography, soil, and fire regime are necessarily the same. In the Southwest, the historical fire regime is of frequent, low-intensity surface fires that tend to maintain open, multi-age forests. Farther to the north in the Rockies, cooler conditions mean moister forests in which fires burn less readily. This distinction is important because fire management strategies and restoration protocols are often applicable only to the region in which they were developed. Therefore, management strategies planned to address the fire and fuel issue, such as those documented in the interagency National Fire Plan, should take into consideration ecoregional variation in fire regimes. This 10-year comprehensive strategy can be viewed online at: <http://www.fireplan.gov>.

## Use of Ecosystem Patterns Within Ecoregions

Macroclimate accounts for the largest share of systematic environmental variation at the macroscale or ecoregion level. At the mesoscale level, physiography (geology and landform) modifies the macroclimate and exerts the major control over ecosystem patterns and processes within climatic zones. With this in mind, Bailey and others (1994) used physiographic factors to subdivide the ecoregion provinces of the United States into subregional areas, or sections that have different landform characteristics<sup>6</sup>. These differences are important because the character of the landform with different geology will vary in the climatic zone. In the same climatic zone, different geologies, such as granitic mountains or volcanic plateaus, will weather and erode differently forming different landform relief. Where this occurs, the spread of a disturbance such as wildfire may differ among landforms. Swanson and others (1990) hypothesized that in forested, steep-mountain landforms along the northwest coast of the United States, where landform relief does not exceed several tree heights (for example, Coast Ranges), disturbance agents such as fire and wind can readily move through the forest with little regard for topography. Landforms may have a greater effect on the spread of disturbance and mosaic

<sup>6</sup> Cleland and others (2005) developed another approximation of section boundaries as shown on a revised version of the ecological subregions map.

structure where relief substantially exceeds tree height (for example, Cascade Range). The classification and mapping of physiography, as was done to delineate ecological subregions at the section level, should provide an important means of discriminating broad areas with differing fire regimes within a particular ecoregion.

At finer scales, one finds considerable variation in fire regimes in response to local topography, vegetation, and microclimate (Cleland and others 2004). As we have seen, local ecosystems occur in predictable patterns within a particular ecoregion. Similar fire regimes occur on similar sites within an ecoregion. Knowledge about fire regimes on similar sites allows ecological restoration so as to incorporate the natural variability of fire regimes across the ecoregion.

## Future Range of Variation

The range of variation concept is a useful starting point, but it is limited for a number of reasons. First, many systems have been fragmented because of human disturbance. Because of this, fires will not carry the way they did historically. Second, the introduction of non-native species (for example, cheatgrass) has made permanent changes in fire frequencies. Third, fire size and intensity of the past are clearly not acceptable in developed areas. And fourth, system boundaries and fire regimes will change as the climate changes (McKenzie and others 1996). Therefore, only where possible, we need to restore the natural range of variation. We must also determine our feasible alternatives for the “Future Range of Variation.”

## References

- Allen, C.D.; Savage, M.; Falk, D.A.; Suckling, K.F.; Swetnam, T.W.; Schulke, T.; Stacey, P.B.; Morgan, P.; Hoffman, M.; Klingel, J.T. 2002. Ecological restoration of southwestern ponderosa pine ecosystems: A broad perspective. *Ecological Applications*. 12(5):1418-1433.
- Bailey, R.G. 1976. Map. Ecoregions of the United States. Ogden, Utah. USDA Forest Service. Intermountain Region. Scale 1:7,500,000.
- Bailey, R.G. 1989. Ecoregions of the continents—scale 1:30,000,000. Supplement in *Environmental Conservation*. 16(4): 307-309.
- Bailey, R.G. 1995. Description of the ecoregions of the United States, 2<sup>nd</sup> ed. Misc. Pub. No. 1391 (rev.). Washington, DC. USDA Forest Service. With separate map at 1:7,500,000.
- Bailey, R.G. 1996. *Ecosystem geography*. New York. Springer Verlag. 204 p.
- Bailey, R.G. 2002. Ecoregion-based design for sustainability. New York. Springer Verlag. 222 p.
- Bailey, R.G. 2005. Identifying ecoregion boundaries. *Environmental Conservation*. 34 Suppl. 1, S14-S26.
- Bailey, R.G.; Avers, P.E.; King, T.; McNab, W.H. [Eds.]. 1994. Map. Ecoregions and subregions of the United States. Washington, DC. U.S. Geological Survey. Scale 1:7,500,000. Accompanied by supplementary table of map unit descriptions compiled and edited by W.H. McNab and R.G. Bailey.
- Borchert, J.F. 1950. The climate of the central North American grassland. *Annals of the Association of American Geographers*. 40: 1-39.
- Cleland, D.T.; Avers, P.E.; McNab, W.H.; Jensen, M.E.; Bailey, R.G.; King, T.; Russell, W.E. 1997. National hierarchical framework of ecological units. In: Boyce, M.S.; Haney, A. [Eds.]. *Ecosystem management: Applications for sustainable forest and wildlife resources*. New Haven, Connecticut. Yale University Press: 181-200.
- Cleland, D.T.; Crow, T.R.; Saunders, S.C.; Dickmann, D.I.; Maclean, A.L.; Jordan, J.K.; Watson, R.L.; Sloan, A.M.; Brosofske, K.D. 2004. Characterizing historical and modern fire regimes in Michigan (USA): A landscape ecosystem approach. *Landscape Ecology*. 19: 311-325.
- Cleland, D.T.; Freeouf, J.A.; Keys, Jr., J.E.; Nowacki, G.J.; Carpenter, C.A.; McNab, W.H. 2005. Map. Ecological subregions: Sections and subsections of the conterminous United States. CD-ROM. Washington, DC. USDA Forest Service. Scale 1:3,500,000. [Online]. <http://svinetfc4.fs.fed.us/research/section/index.html>. [July 2009].

- Foreign Agriculture Organization (FAO) of the United Nations. 2001. Global ecological zoning for the Forest Resources Assessment 2000. Rome, Italy. FAO. Forestry Department. [Online]. <http://www.fao.org/docrep/006/ad652e/ad652e00.htm> [July 2009].
- Köppen, W. 1931. Grundriss der klimakunde. Berlin: Walter de Gruyter. 388 p.
- Küchler, A.W. 1967. Potential natural vegetation of the United States. Washington, DC. U.S. Geological Survey, National Atlas: 89-90.
- 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.
- Littell, J.S.; McKenzie, D.; Peterson, D.L.; Westerling, A.L. 2009. Climate and wildfire area burned in western US ecoprovinces, 1916-2003. *Ecological Applications*. 19(4): 1003-1021.
- Malamud, B.D.; Millington, J.D.A.; Perry, G.W. 2005. Characterizing wildfire regimes in the United States. *Proceedings National Academy of Sciences*. 102: 4694-4699.
- McKenzie, D.; Peterson, D.L.; Alvarado, E. 1996. Predicting the effect of fire on large-scale vegetation patterns in North America. Res. Paper PNW-RP-489. Portland, OR. USDA Forest Service. Pacific Northwest Research Station. 38 p.
- Milanova, E.V.; Kushlin, A.V., [Eds.]. 1993. World map of present-day landscapes: An explanatory note. Moscow, Russia. Moscow State University. Separate map at 1:15,000,000. 33 p.
- Nature Conservancy, The. 2004. Fire, ecosystems and people. Tallahassee, FL. Global Fire Initiative. 9 p.
- Savage, M. 2003. Restoring natural systems through natural processes. *Quivera Coalition Newsletter*. 6(2): 1, 20-27.
- 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. RMRS GTR-87. Fort Collins, CO. USDA Forest Service. Rocky Mountain Research Station. 41 p.
- Swanson, F.J.; Franklin, J.F.; Sedell, J.R. 1990. Landscape patterns, disturbance, and management in the Pacific Northwest, USA. In: Zonneveld, I.S.; Forman, R.T. [Eds.]. *Changing landscapes: An ecological perspective*. New York. Springer Verlag: 191-213.
- Trewartha, G.T. 1968. *An introduction to climate*, 4<sup>th</sup> ed. New York. McGraw-Hill. 408 p.
- Turner, M.G.; Romme, W.H. 1994. Landscape dynamics in crown fire ecosystems. *Landscape Ecology*. 9(1): 59-77.
- Vale, T.R. 1982. *Plants and people*. Washington, DC. Association of American Geographers. 88 p.
- Westerling, A.L.; Gershunov, A.; Cayon, D.R.; Barnett, T.P. 2002. Long-lead statistical forecasts of area burned in western U.S. wildfires by ecosystem province. *International Journal of Wildland Fire*. 11: 257-266.