Abstract: The majority of American forest and grassland ecosystems are adapted to fire of varying frequencies and magnitudes. Fire is critical in maintaining ecological processes and biodiversity. 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 prevention and suppression along with increased human development at the wildland-urban interface. To correct this problem, planning for fire and land management must incorporate an improved understanding of fire regimes. This paper discusses fire regimes of different ecosystems at the scale of ecoregion, and goes on to explore how understanding fire regimes at this scale can abate the threat of fire exclusion and restore fire-adapted ecosystems.
Introduction
The public land-management agencies are phasing into 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 prevention and suppression along with increased human development at the wildland-urban interface. Grazing and logging have also contributed to this problem.

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To correct this problem, planning for 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 (cf., Bailey 2002).

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**Ecosystem structure and process**

Ecosystem structure and process are related. For example, riparian forests evolved with flooding, and 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 (Savage 2003).

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**Range of variation**

Restoration works best if ecosystems are returned to within a “natural range of variation” (Landres et al. 1999). Ecosystems, for example, not only have variability through time because of climate change, but also across the landscape and the nation. From forests, to desert, to steppe, the nation’s ecosystems vary vastly. It is not possible to reconstruct how each system looked in the past. Instead we can reset the 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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**Role of climate**
To restore these 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 changes, the other components change in response. As a result, *ecosystems of different climates differ significantly* (Bailey 1996).

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The most important climatic factor 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.

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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 (shown in green) during summer and fall, but in winter and early spring, groundwater contributes to streamflow.

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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.

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![Annual Cycles, Steppe](image)  

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.

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![Scales of Climatic Zones](image)
Controls over the climatic effect change with scale. At the macroscale, ecosystem patterns are controlled by macroclimate (i.e., the climate that lies above the local modifying effects of landform and vegetation).

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![Common macroclimate, based on Koppen-Trewartha](image)

Based on macroclimatic conditions, I subdivided the continents into eoclimatic zones, also known as ecosystem regions, or *ecoregions*. These regions are based largely on the ecological climatic zones of Koppen as modified by Trewartha.

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![Ecoregion ~ plant formation](image)

Each climate zone is associated with a single plant formation. Of course, not all the space is taken up by the formation, for the nature of the topography will allow the differentiation into many habitats. One ignores these local variations in mapping climatic
regions (and therefore ecoregions). Note that ecosystems occur in predictable patterns, i.e., similar ecosystems occur on similar sites in a particular region.

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![Ecoregion: based on macroclimate conditions and prevailing plant formations determined by those conditions](image)

Mediterranean hardleaved evergreen forests, open woodland and shrub

A more detailed map was created for the United States. Each region is characterized by a different climatic regime and associated plant formation.

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![Vertical Zonation in Different Eco-Climatic Zones along the eastern slopes of the Rocky Mountains](image)

Mountainous areas within specific ecoregions are also classified, whose character depends on the zone where they are located.

*It seems reasonable that regions which 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. These wet-dry rhythms set the ecological cadence for fire regimes.

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 (Thomas R. Vale)

Pre-colonial fire regimes for different vegetation type 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 inference about fire regime. Thomas Vale 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. In the northern coniferous forest and woodland (boreal forest), for example, infrequent large-magnitude fires carried the flames in the 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.

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These areas are typically cool or wet and consist of vegetation that inhibits the start or spread of fire.

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In mountainous regions, fire frequency is related to altitude, or elevation.

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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.

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Ponderosa pine forests are good examples of this kind of forest.

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**Fire Regime Types**


- Fire-dependent/influenced
- Fire-sensitive
- Fire-independent

*Fire regime types (The Nature Conservancy)*
The Nature Conservancy has recently completed a global assessment of fire regime alteration on an ecoregional basis. The assessment identified three types.

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The report reveals that, among globally important ecoregions for conservation: 84% 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 the plants. They sprout back from root crowns.

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Thirty-six percent are fire-sensitive. In these regions, frequent, large and intense fires, until recently were 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.

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And 18% are classified as fire-independent. 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, fire regimes are degraded (shown in yellow, orange, and red) in over 80% of globally important ecoregions.
Altered fire regimes
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. Here, non-native cheat grass (*Bromus tectorum*) is invading sagebrush steppe in the western U.S.

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**Characterizing USA Wildfire Regimes**
Malamud, BD, Millington, JDA & Perry, GLW. (2005)

- Wildfire statistics for the National Forests
  - 1970–2000
  - 88,916 wildfires ≥ 1 acre

**Characterizing USA wildfire regimes (Malamud et al.)**
Using high-resolution Forest Service wildfire statistics, this study was based on 31 years (1970-2000) of wildfires data consisting of 88,916 fires ≥ 1 acre for the National Forest System.

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In each ecoregion, what is the frequency-area distribution of wildfires?

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?

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The study compared area burned, number of fires, and the wildfire recurrence interval. These parameters were calculated at the ecoregion division level. The study created maps to display wildfire patterns and risk for the entire continental U.S.

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The authors found that the ratio of large to small wildfires decreases from east to west. The darker the color, the greater the number of large fire. 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.

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The fire recurrence interval differs markedly between ecoregions. For example, the fire cycle values ranged from 13 yrs for the Mediterranean Mountains Ecoregion to 203 yrs for the Warm Continental Ecoregion. The legend goes from dark red to white, representing ‘high’ to ‘low’ hazard. [Note: “fire cycle” does not mean that a fire will occur ‘every’ 13 years, or ‘every’ 203 years. It is a probabilistic hazard (e.g., a recurrence intervals 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


- Wildfire occurrence gradient a function of altitude and latitude
- Attributed to broad climatic variation:
  - Western and central tend to have frequent fires w/ younger trees
  - Eastern experience longer inter-fire intervals w/older trees

Other Studies

In other studies, gradients similar to those observed by Malamud et al. have been described and related to climate and vegetation. Turner and Romme 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.

Use of fire regime at the ecoregion scale

- Assess burn probabilities across the nation to identify areas with the high risk
- Baseline from which to abate the threat of fire exclusion and restore fire-adapted ecosystem
The results of these studies can be used to assess burn probabilities across the nation to identity areas with the high risk. *This could help government agencies 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.

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**What can be done?**


1. **Restoration of natural fire regimes**
   - E.g., in southwestern ponderosa pine reduce the widespread risk of crown fires by return to low-intensity surface fire

2. **Pay attention to both structure and process**
   - E.g., thinning young trees to reduce the fuel load may not work unless low-intensity surface fires are also reintroduced.

Finally, what can be done to reduce the risk of fire? Melissa Savage and her colleagues (Allen et al. 2002) suggest a couple of principles to guide the implementation of ecologically justifiable restoration projects: (1) Restoration of natural fire regimes (E.g., in southwestern ponderosa pine reduce the widespread risk of crown fires by return to low-intensity surface fire), and (2) Pay attention to both structure and process (E.g., thinning young trees to reduce the fuel load may not work unless low-intensity surface fires are also reintroduced).

**Slide 45**
Recent data from the Forest Service reflect the scale of the challenge. As shown on this map, fire management has significantly changed the fuel levels of many forests, and concurrently, the frequency and intensity of fire. About 30% of all ownerships (except agriculture, barren, and urban land) are in high risk categories (shown in yellow and red). In many ecoregions (black lines) this percentage is much higher. For example, in the mountains of the southwest, as much as 83% is moderately to severely altered. [Note: a finer resolution and more accurate FRCC map is being produced by the LANDFIRE project of the USFS (MFSL) and the USGS (EDC).]

Why ecoregions are needed

The same forest type can occur in different ecoregion divisions. For example, ponderosa pine forest occurs 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, multiage forests. Farther to the north in the Rockies, cooler conditions mean moister forests in which fires burn less readily.

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Why ecoregions are needed

- Same forest occurs in different ecoregions
  E.g., ponderosa pine

- Distinction is important because fire management strategies and restoration protocols are often applicable only to the local region in which they were developed.

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Therefore

Management strategies planned to address the fire and fuel issue such as those documented in the National Fire Plan …

should take into consideration the ecoregional variation in fire regimes.

Therefore, management strategies planned to address the fire and fuel issue such as those documented in the National Fire Plan should take into consideration ecoregional variation in fire regimes.
Use of ecosystem patterns within ecoregions

At finer scales, one finds considerable variation in fire regimes in response to local topography, vegetation, and microclimate. 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.

Limitations
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 (e.g., cheat grass) 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 will change as the climate changes.

Therefore, where possible, we need to restore the natural range of variation. We must also determine our feasible alternatives for the “Future Range of Variation.”

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For more information:

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