CHAPTER 4

Fire as an Ecological Process

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> Removing fire from . . . ecosystems would be among the greatest upsets in the environmental system that man could impose—possibly among the most severe stresses since the evolution of the fire-dependent biota evolved. I cannot predict the outcome, but a fundamental reordering of the relationships between all plants and animals and their environments would occur. Many species could be lost through extinction.
>
> M.L. HEINSELMAN, 1981

Fire is an integral part of California ecosystems; for without fire, few of the state's native ecosystems, habitats, or even species, would persist as we know them today. Fire's dynamic nature and great complexity are amplified by the state's diverse topography, climate, and vegetation. For millennia, California ecosystems have developed in tandem with fire. Long-term alterations of fire patterns have occurred with climatic changes and with interactions with humans. In the past two centuries, the pace of human-induced alteration has accelerated, resulting in a number of changes in species and ecosystems. Many of these species and ecosystem changes occurred previously, some are currently occurring, and others are yet to manifest themselves. To understand the importance of the changing ecological role of fire, it is necessary to understand fire as an ecosystem process.

Fire can be viewed within two distinct time frames: individual fires and repeated patterns of fire occurrence. When an individual fire is seen as a discrete event, its physical characteristics are important to understanding how fire functions as an ecosystem process. Individual fires range from simple to extremely complex in their behavior, size, pattern of burning, and ecosystem effects. Individual fires in a limited area affect fuel dynamics, the physical attributes of the ecosystem, and the biological systems at the individual, species, population, and community levels. These direct influences are discussed in detail in subsequent chapters in Part I of this text.

Landscapes have repeated patterns of fire occurrence, fire magnitude, and fire type that vary over space and time. When fire is considered over centuries or millennia and on large landscapes, this repeated pattern of fire occurrence and its properties affect ecosystem function. Compounding the influences of individual fires, existing patterns greatly influence the dynamics of species composition, vegetation structure, and subsequent fire patterns. While recognizing that the patterns of fire occurrence over large expanses of space and long periods of time are extremely complex, they can be distilled into useful summaries known as *fire regimes*.

Fire is an integral part of ecosystems, and there is a continuous feedback of fire, fuels, and vegetation within the ecosystem. Fire interacts with, and is affected by, species composition, vegetation structure, fuel moisture, air temperature, biomass, and many other ecosystem components and processes over several scales of time and space. These ecosystem components are so interdependent that changes to one, including fire, often result in significant changes to others. This dynamic view of ecosystems is the key to understanding fire as an ecosystem process.

In this chapter we explore fire as a dynamic ecosystem process by first examining fire in the context of general ecological theory, then discussing the concept of fire regimes, and finally by developing and applying a new framework for classifying fire regimes that better allows us to understand the patterns of fire as processes within ecosystems. This fire regime framework will be used in the bioregional chapters that follow in Part II.

Fire in the Context of Ecological Theory

As ecological theory has evolved, so has the manner in which fire along with climate, insects, fungi, and weather are considered in that theory. We first look at succession theory and then proceed through ecosystem, disturbance, and hierarchical theory. Finally we present our view of fire as an ecological process.

Succession Theory

Classical succession is an ecological concept that was developed and championed by Clements (1916) in the early 1900s. Since it was first published, his framework for viewing plant communities as complex entities that develop over time has

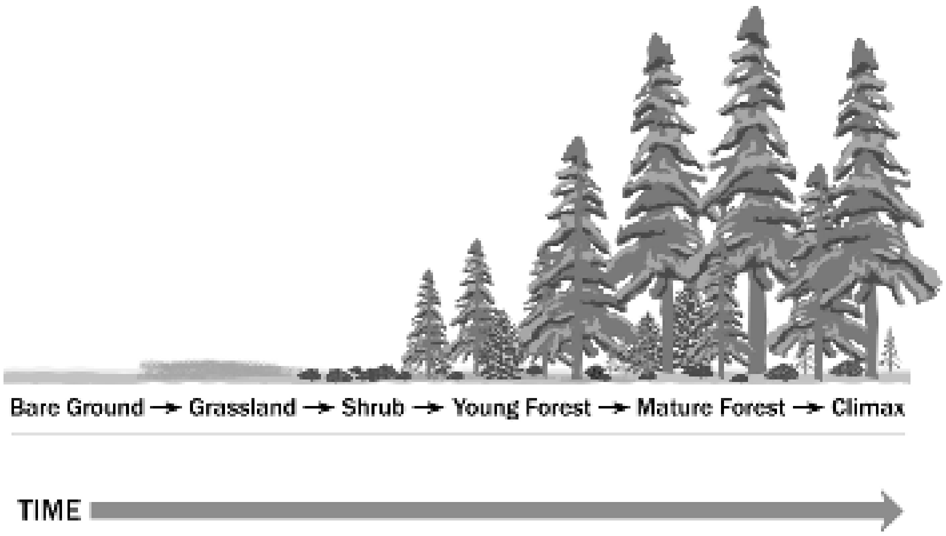

FIGURE 4.1. Clements viewed succession as a stepwise, predictable, directional process. As time passes, bare ground eventually becomes covered with a mature climax vegetation.

served as a basis from which successional ecology theory has developed. Clements (1936) defined *succession* as a predictable, directional, and stepwise progression of plant assemblages that culminates in a self-perpetuating *climax* community controlled by climate. For example, bare ground might first be colonized by grasses, followed by shrubs, and then by a young forest, and finally be covered by a mature forest (Fig. 4.1). According to Clements, the climatic climax is stable, complex, self-perpetuating, and considered to be the adult version of the "complex organism" or plant community.

Clements (1916) considered bare areas created by lightning fires as one of the natural sources for the initiation of succession. He expressed the view that lightning fires were numerous, and often very destructive, in regions with frequent dry thunderstorms. In fact, the early twentieth century witnessed some of the most destructive wildland fires known in this country. Clements considered areas where such fires maintained vegetation that differed from the climatic climax to be *subclimax,* because they were continually reset to seral plant assemblages by recurrent fire before they reached climax conditions. He cited chaparral in California and lodgepole pine *(Pinus contorta* ssp. *murrayana)* in Colorado as examples of fire subclimaxes (Clements 1916). Fire was viewed as a retrogressive process that sets back the directional, stepwise progression of succession toward the stable climactic climax. Clements (1936) refined his ideas about the nature and structure of the climax and developed a complex terminology for classifying units of vegetation. Fire subclimaxes were still part of this complex system, and he added California's Monterey pine *(Pinus radiata)*, Bishop pine *(Pinus muricata)*, and knobcone pine *(Pinus attenuata)* as examples. He used the term *disclimax* for communities that had been degraded by human activities such as logging, grazing, and burning, but seemed to not apply the term to natural fires (Clements 1936).

Gleason (1917) reacted to Clements' theory by proposing the individualistic concept of the plant association. He argued that succession was not inherently directional, but was the result of random immigration of species into a variable environment. As the environment changes, the assemblage of associated species changes based on individual attributes of each species. As an example, he cited the gradual replacement of grasslands by California oak *(Quercus* spp.*)* forests as one ascends the foothills and precipitation increases (Fig 4.2). Similarly, Gleason (1917) argued that entirely different plant associations might occupy physiographically and climatically identical environments. For instance, the alpine areas of the Sierra Nevada have essentially the same environment as in the Andes, but their floras are entirely different. Although Gleason (1926) felt that the environment had a strong influence on plant community development, he referred to fire as an unnatural disturbance that limited the duration of the original vegetation.

Daubenmire (1947) was one of the first ecologists to recognize fire as an ecological factor rather than as an allogenic factor. With regard to succession, however, he followed the same terminology as Clements (1916) but considered fire to be one of five different climaxes. *Primary* climaxes included climatic, edaphic, and topographic climaxes, whereas fire and zootic climaxes were termed *secondary* climaxes (Daubenmire 1968). Specific examples included the forests of the Sierra Nevada where episodic fires replaced fire-sensitive species with fire-tolerant pines. Daubenmire (1968) felt that the fire climax could appropriately be called a disclimax because its maintenance depended on continued disturbance.

Whittaker (1953) examined both the organismic (Clements 1916) and individualistic (Gleason 1926) concepts of the climax community and proposed an alternative approach that views the climax as a pattern of vegetation resulting from environmental variables. He postulated that: (1) the climax is a steady state of community productivity, structure, and population, with a dynamic balance determined in relationship to its site; (2) the balance among plant populations shifts with changes in the environment; and (3) the climax composition is determined by all factors of the mature ecosystem. A major

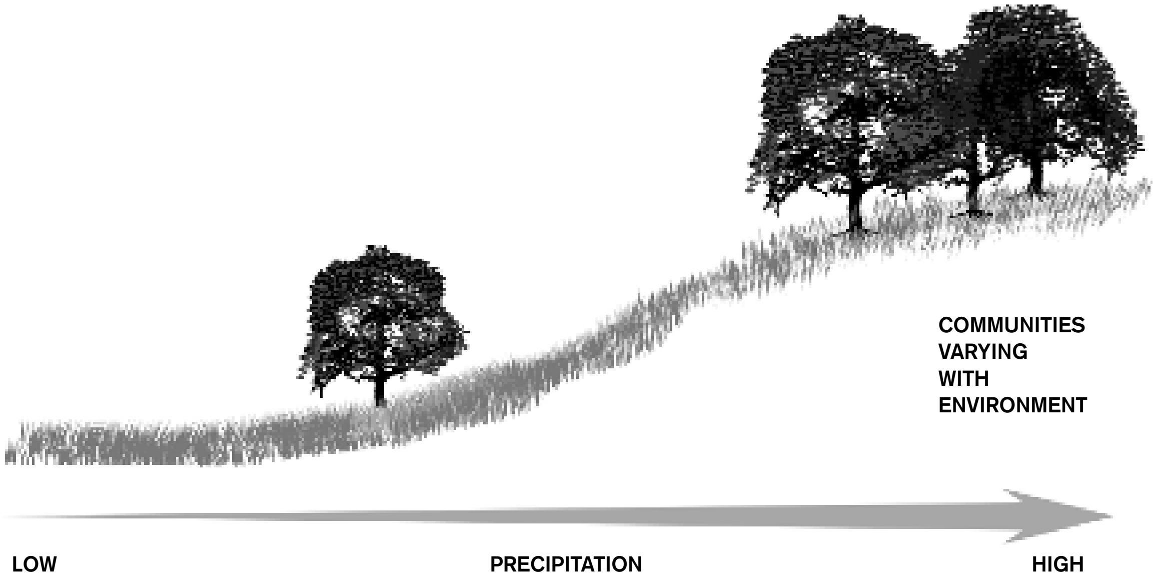

FIGURE 4.2. Gleason considered plant communities to be distributed according to environmental gradients, such as grasses being gradually replaced by oaks as precipitation increases with elevation.

contribution that Whittaker (1967) made to ecological theory was his use of gradient analysis to delineate how plant assemblages change in space and time. Whittaker (1953) considered periodic fire to be one of the environmental factors to which some climaxes are adapted. In the absence of fire, the climax plant populations might develop into something entirely different, but that development might never occur. A key point he makes is that burning may cause population fluctuations that make it difficult to distinguish between fire as an environmental factor and fire as a disturbance introduced from outside the ecosystem. For example, in climates between forests and deserts, fire could shift the balance among woodlands, shrublands, and grasslands (Whittaker 1971).

Ecosystem Theory

Tansley (1935) refuted the organism concept of a plant community put forward by Clements (1916) and proposed that succession in a community is a trajectory of a dynamic system with many possible equilibria. That is, depending on the environment, a plant community could develop in one of many different directions and reach a point of equilibrium regardless of which trajectory was followed. He also introduced the term *ecosystem* to describe the entire system to include not only the biotic components but also the abiotic factors that make up the environment. In the ecosystem, these components and factors are in a dynamic equilibrium. Succession leads to a relatively stable phase termed the *climatic climax*. He recognized other climaxes determined by factors such as soil, grazing, and fire. Tansley (1935) considered vegetation that was subjected to constantly recurring fire to be a fire climax, but thought that catastrophic fire was destructive and external to the system.

Odum (1959) defined ecology as the study of structure and function of ecosystems and emphasized that the ecosystem approach had universal applicability. He related the ecosystem concepts of nutrient and energy flow to evolutionary ecological growth and adaptation (Odum 1969). Fire was seen as an important ecological factor in many terrestrial ecosystems, as both a limiting and as a regulatory factor (Odum 1963). He cited examples of fire consuming accumulated undecayed plant material and applying selective pressure favoring the survival and growth of some species at the expense of others.

A systems approach was advocated by Schultz (1968), applying the concepts of energy dissipation to ecosystem function. He described ecosystems as open systems with material being both imported and exported. Rather than reaching an equilibrium, an open system attains a steady state with minimum loss of energy. Fire is considered a negative feedback mechanism that prevents the complete destruction of natural ecosystems by returning some of the energy to the system (Schultz 1968).

Disturbance Theory

Traditional theories of natural disturbance considered that disturbance must be a major catastrophic event and that it must originate in the physical environment (Agee 1993). Much discussion has centered on these points and various definitions and thresholds have been applied to distinguish disturbances from processes. Watt (1947) introduced the concept that plant communities were composed of patches in various stages of development that were dynamic in time and space. The patches were initiated by some form of disturbance, be it the death of a single tree or larger factors such as storms, drought, epidemics, or fires. Other than mentioning size differences, he did not distinguish among factors that were internal or external to an ecosystem. Similarly, White (1979) urged that the concept of disturbance not be limited to large catastrophic events that originate from within the physical environment but also include external factors. White and Pickett (1985) define disturbance as "any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment." They included disasters and catastrophes as subsets of disturbance. Fire was specified as a source of natural disturbance. Agee (1993) proposed that disturbance comprises a gradient that ranges from minor to major; he did not differentiate between internal and external sources. He did distinguish between fires of natural origin and fires set by Native Americans or European Americans, calling the former *natural disturbances*.

Walker and Willig (1999) follow the terminology of White and Pickett (1985) and treat fire as a natural disturbance. They go on to state that disturbances that originate inside the system of interest are considered to be endogenous. Fire is driven by an interplay of *exogenous* factors from outside of the system such as climate and topography and *endogenous* factors such as soil and biota. In this sense, Walker and Willig (1999) consider fire to be an inherent ecological process. They characterize disturbances by their frequency, size, and magnitude. These characteristics are used for grouping disturbances into disturbance regimes.

Turner and Dale (1998) state that large, infrequent disturbances are difficult to define because they occur accoss a continuum of time and space. One definition they propose is that disturbances should have statistical distributions of extent, intensity, or duration greater than two standard deviations (SDs) of the mean for the period and area of interest. Romme et al. (1998) distinguish large, infrequent disturbances from small, frequent ones by a response threshold—when the force of the disturbance exceeds the capacity of internal mechanisms to resist disturbance or where new means of recovery become involved. For example, an area that burns with a very high-severity fire as a result of unnaturally heavy accumulations of fuels would be qualitatively different from an area that burns with frequent, low-severity fires. However, not all high-severity fires cross the response threshold. Romme et al. (1998) cite the example of jack pine *(Pinus banksiana)*, an ecological equivalent of lodgepole pine, that re-establishes itself after stand-replacing fires, regardless of size, through the dispersal of seed thoughout the area from serotinous cones. These criteria (Turner and Dale 1998, Romme et al. 1998) form a basis for separating endogenous fires from those arising from outside the environment of the ecosystem.

Hierarchical Theory

O'Neill et al. (1986) proposed a hierarchical concept of the ecosystem to reconcile the species-community and process-function schools of thought. The authors define the ecosystem as being composed of plants, animals, incorporated abiotic components, and the environment. In their view, the ecosystem is a dual organization determined by structural constraints on organisms and functional constraints on processes. These dual hierarchies have both temporal and spatial components.

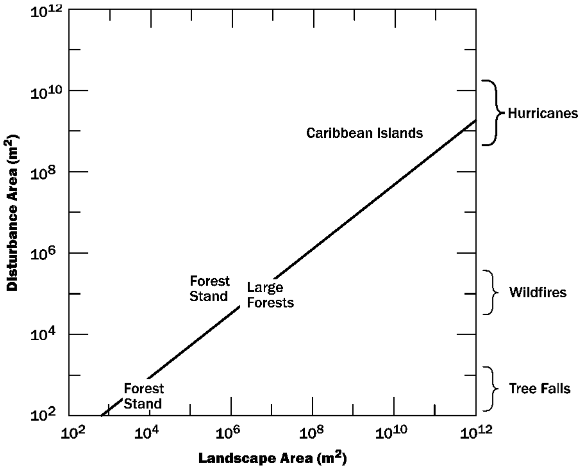

FIGURE 4.3. Relative size of disturbance area and landscape units. Landscapes above the diagonal line are in disequilibrium because they are smaller than the characteristic perturbations. (Redrawn from Shugart and West 1981.)

Disturbances are termed *perturbations* and are associated with a particular temporal and spatial scale. O'Neill et al. (1986) describe fire as a perturbation that ensures landscape diversity and preserves seed sources for recovery from any major disturbance. They state that viewing ecosystems on the arbitrary scale of the forest stand results in seeing fire as a catastrophic disturbance. If, however, fire is viewed at the scale appropriate to the frequency of occurrence, it can be seen as an essential ecosystem process that retains the spatial diversity of the landscape and permits reaching a dynamic equilibrium after disturbance. O'Neill et al. (1986) consider a perturbation to be *incorporated* if the ecosystem structure exerts control over some aspect of the abiotic environment that is uncontrolled at a lower level of organization.

Systems that are large relative to their perturbations maintain a relatively constant structure (O'Neill et al. 1986). For example, ponderosa pine *(Pinus ponderosa)* forests are usually larger than the fires that burn within them; therefore the perturbation is incorporated in the sense that the fires do not threaten the survival of the ecosystem but are in fact necessary to perpetuate the spatial diversity of the landscape. This concept is illustrated in Figure 4.3 (Shugart and West 1981). Above the diagonal line are disequilibrium systems that are the same size or smaller than their characteristic perturbations. Wildland fires would be considered a perturbation in forest stands but would be an incorporated process in large forests.

Pickett et al. (1989) linked the hierarchical organization of ecosystem components with the concept of disturbance. They state that any persistent ecological object such as a tree will have a minimal structure that permits its persistence, and that disturbance is a change in that structure caused by a factor external to the level of interest. Disturbance, then, is identified with specific ecological levels, or hierarchies, of the organization (Pickett et al. 1989). In this view, periodic fire perpetuates a variety of structures that allow the ecosystem to persist.

Our View of Fire

Each of the aforementioned views is based on careful observation and carry something of the truth. In developing our view of fire, we synthesize and build on previous theory. We consider fire to be an incorporated ecological process rather than a disturbance. In its natural role, fire is not a disturbance that impacts ecosystems; rather it is an ecological process that is as much a part of the environment as precipitation, wind, flooding, soil development, erosion, predation, herbivory, carbon and nutrient cycling, and energy flow. Fire resets vegetation trajectories, sets up and maintains a dynamic mosaic of different vegetation structures and compositions, and reduces fuel accumulations. Humans have often disrupted these processes, and the result can be that fire behavior and effects are outside of their range of natural variation. At that point, fire is considered an exogenous disturbance factor.

Fire Regimes

It is relatively simple to understand the influence of a single fire on specific ecosystem properties, but the importance of fire as an ecosystem process becomes greatly amplified by the complex pattern of fire effects over long time periods, multiple fire events, and numerous ecosystem properties. To synthesize these patterns of fire occurrence, ecologists use the concept of *fire regimes*. Fire regimes are a convenient and useful way to classify, describe, and categorize the pattern of fire occurrence for scientific and management purposes. Like any classification, a fire regime classification necessarily simplifies complex patterns. Although fire regimes are typically assigned to ecosystems defined by either land areas or vegetation types, or to some combination of area and vegetation, they often vary greatly within a vegetation type and over time on the same piece of land.

Previous Fire Regime Descriptions

Fire regime classification systems have been based on a very small number of attributes that could be described and used to explain basic patterns of ecosystem change. The classifications offer a variety of information ranging from simple, single-attribute descriptions (e.g., mean fire return interval) to a few attributes, but usually have not provided descriptions of the patterns of fire over time and space, and by magnitude. Recent fire history studies have focused on the importance of multi-scaled spatial and temporal variation of fire. As our knowledge of ecosystems and complex processes such as fire grows, our need for more sophisticated descriptive tools such as fire regime classifications expands. It is important to recognize that any classification system is an oversimplification of some portion of nature for the convenience of humans, and there is no single "complete" or "right" way to describe fire regimes. The appropriate system to use for classification of fire regimes depends on the character of the ecosystems, the fire regimes, and the intended use of that system.

Kilgore (1981) observed that fire is known to be important in so many ecosystems that it is becoming less meaningful to merely refer to ecosystems as fire dependent or fire independent. Instead, he suggests that it is more appropriate to speak of ecosystems with varying fire regimes that are made up of such factors as fire frequency and intensity (Sando 1978, Heinselman 1981), season (Gill 1975), pattern (Keeley 1977), and depth of burn (Methven 1978).

Heinselman (1981) defined a fire regime as a summary of the fire history that characterizes an ecosystem. He distinguished seven fire regimes based on: (1) fire type and intensity (crown fires or severe surface fires vs. light surface fires), (2) size (area) of typical ecologically significant fires, and (3) frequency or return intervals typical for specific land units. Although these fire regime types described the patterns that he observed in the midwestern United States, this system has served as the basis for fire regime classification throughout the western United States. The classification was not intended to imply mutually exclusive or exhaustive categories; rather it was intended to provide a tool for discussing general fire-occurrence patterns. Heinselman (1981) states, "The purpose here is not to set up a precise classification but to make it possible to discuss important differences in the way fire influences ecosystems." His fire regimes are defined in Box 4.1.

Heinselman (1981) described multiple fire regimes that occur when there are several types of fires in a single ecosystem, and each type can be described with its own fire regime. This occurs under the following three conditions: (1) the ecosystem can have more than one type of fire, (2) the types of fires occur under different sets of conditions, and (3) the conditions allow the different types of fires to occur at different frequencies. Multiple fire regimes occur most commonly in vegetation types that have multiple fuel layers that can carry a fire. Heinselman (1981) described red pine (*Pinus resinosa*) forests in the lake states to have both a frequent light surface fire regime carried in the herbaceous layer and a regime of much-less-frequent higher-intensity fire carried in the forests canopy. Many California ecosystems including some Douglas-fir *(Pseudotsuga menziesii* var. *menziesii)*, red fir *(Abies magnifica* var. *magnifica)*, and mixed conifer forest burn with both surface and crown fires that occur at different frequencies and under different weather conditions and can be termed *multiple fire regimes* (Heinselman 1981).

After applying the Heinselman (1981) fire regimes, designed for northern forests, to the forests and scrublands of the western United States, Kilgore (1981) made a number of observations. There are complex relationships between fire and other attributes of the ecosystem on the variable topography of the western states. Fire acts with different frequencies and intensities, varying with the vegetation, topography, and climate that determine the coincidence of ignitions and burning conditions. Vegetation composition and structure depend on climate, fire frequency, and fire intensity, whereas fire frequency and intensity in turn depend on vegetation

BOX 4.1. HEINSELMAN'S FIRE REGIMES

Seven kinds of fire regimes can be distinguished for forest ecosystems:

0 = No natural fire (or very little)
1 = Infrequent light surface fires (more than 25-year return intervals)
2 = Frequent light surface fires (1- to 25-year return intervals)
3 = Infrequent severe surface fires (more than 25-year return intervals)
4 = Short return interval crown fires and severe surface fires in combination (25- to 100-year return intervals)
5 = Long return interval crown fires and severe surface fires in combination (100- to 300-year return intervals)
6 = Very long return interval crown fires and severe surface fires in combination (more than 300-year return intervals)

BOX 4.2. FIRE REGIME GROUPS USED FOR CONDITION CLASSES, BY FREQUENCY AND SEVERITY

I	0–35 years	Low (surface fires common) to mixed severity (less than 75% of the dominant overstory vegetation replaced)
II	0–35 years	High (stand-replacement) severity (greater than 75% of the dominant overstory vegetation replaced)
III	35–100+ years	Mixed severity (less than 75% of the dominant overstory vegetation replaced)
IV	35–100+ years	High (stand-replacement) severity (greater than 75% of the dominant overstory vegetation replaced)
V	200+ years	High (stand-replacement) severity

structure, topography, and climate. Kilgore (1981) concluded that because of almost annual coincidence of ignitions with suitable burning conditions, western forests, such as some of those found in the Sierra Nevada, have frequent fires of low intensity. Although ignitions are as frequent in many Rocky Mountain forests, they do not coincide as often with dry fuel conditions. These Rocky Mountain forests tend to have less frequent, high-intensity crown fires.

Hardy et al. (2001) modified Hienselman's (1981) six original regimes by replacing types of fire with levels of fire severity. They grouped regimes into three levels of frequency and three levels of severity (Box 4.2). These groups are currently being used to determine natural fire regime condition classes across the landscape (Hann and Bunnell 2001). Departures from natural fire regime conditions form the basis for fire- and fuel-management programs.

Vegetation types can be combined into fire regime groups based on the response of dominant plant species to fire, potential frequency of fire, and similarity in post-fire succession. Davis et al. (1980) defined fire regime groups in Montana, as did Bradley et al. (1992) for eastern Idaho and western Wyoming. Agee (1993) considers fire regime groups to be a useful way to catalog fire and ecological information when a management system is based on similar vegetation units, such as habitat types; but the simplicity of the system begins to bog down when one considers the literally hundreds of fire groups, or vegetation communities, across the western United States. Agee (1993) considers fire regime groups to be best applied on a local basis as in the Pacific Northwest.

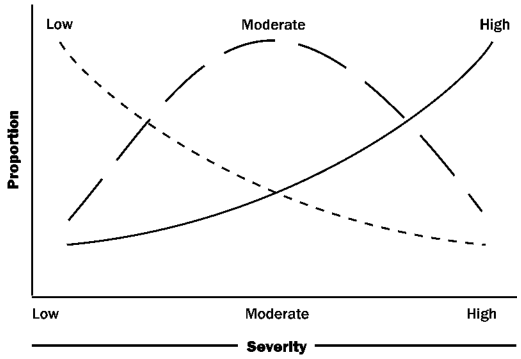

FIGURE 4.4. Variation in fire severity within a general fire regime type (redrawn from Agee 1993). Within a single fire regime type, there could be a combination of low-, moderate-, and high-severity fires.

Agee (1993) also describes another system of fire regime classification based on the severity of fire effects on dominant tree species for forests of the Pacific Northwest. To display the variability in fire that occurs within or between fires on a site, he used a set of distribution curves for illustrating fire severity patterns. The low, moderate, and high fire severity types are presented as distributions composed of different proportions of severity levels (Fig. 4.4). This allows for a range of severity variability within a regime type. The following section greatly expands on Agee's (1993) treatment of conceptual distributions to include seven fire regime attributes.

A New Framework for Defining Fire Regimes

Fire regimes distill useful information about continuous variation of fire occurrence patterns into simple categories that help us describe predominant patterns in fire and its effects on ecosystems. As land management objectives evolve, there is a need to re-evaluate what constitutes useful information. Societal objectives for land management have shifted in the past few decades, emphasizing ecosystem and biological values over consumptive uses. The amount and detail of information needed to manage fire to meet these new objectives are greater than ever before. Heinselman (1981) used various combinations of fire severity, frequency, and type to define fire regimes. Although this system could be refined to meet new management information needs, we have chosen to develop a new framework that includes and expands on his fire regime attributes.

This new framework describes fire regimes using three groups of seven attributes of fire patterns (Box 4.3). Although there are many other attributes that could be used, these seven include those that are most commonly considered to be important to ecosystem function.

Attributes are grouped into temporal, spatial, and magnitude variables. Temporal attributes include *seasonality* and *fire return interval*. Spatial attributes include *fire size* and *spatial complexity* of the fires. Magnitude attributes include *fireline intensity*, *fire severity*, and *fire type*.

Fire regimes are depicted using a set of conceptual distribution curves similar to those presented by Agee (1993) for fire severity. For each attribute, there might be several curves with different shapes representing the variability in the distribution of that attribute within different ecosystem types. A fire regime for a particular ecosystem type includes distributions for all seven attributes representing the pattern of variability within that ecosystem.

Figure 4.5 is an example of fire regime distribution curves for fire return interval. The x-axis of each distribution curve represents the range of values for fire return intervals in three different ecosystem types. The y-axis always represents the proportion of the burned area with different return interval distributions. The sum of the area underneath each curve is equal to unity and accounts for all of the area that actually burns with that regime type. The three distribution types that are illustrated are short, medium, and long, with each representing a range of short to long, but in different proportions.

The conceptual distribution curves allow us to illustrate the features of a fire regime that will affect a specific ecosystem function. For example, if a closed-cone conifer is the only species that distinguishes an ecosystem from the surrounding chaparral ecosystem, the persistence of that closed-cone conifer is key to the persistence of the ecosystem. In this case, the distribution of fire return intervals in the two ecosystems may be largely the same, differing only in the presence or absence of the low-frequency events at the extremes of the range of variability (distribution tails) (Fig. 4.6). If the fire return interval extends outside of the range of time (either shorter or longer) when the closed-cone conifer can produce seed, then there is a predicted conversion to the chaparral ecosystem type. For this example, the fire-return interval distributions for the two ecosystems have the same general shape, differing only in the absence of the tails of the distribution curve in the conifer type. The tails of the distribution are outside of the range of variability for length of fire-return interval within which the conifers can be sustained.

BOX 4.3. OVERVIEW OF FIRE REGIME ATTRIBUTES

Temporal	Seasonality Fire Return Interval
Spatial	Size Spatial Complexity
Magnitude	Fireline Intensity Fire Severity Fire Type

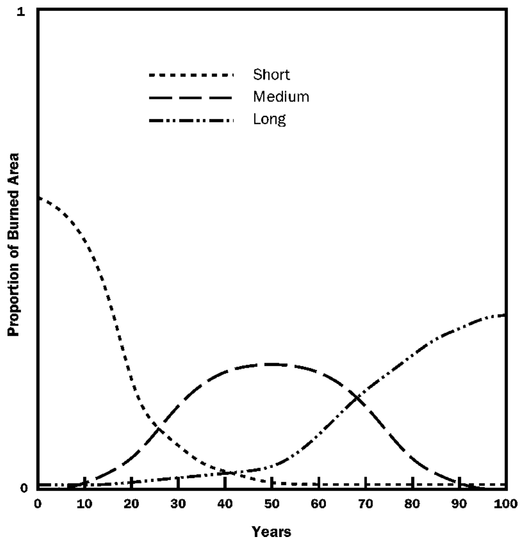

FIGURE 4.5. Example fire regime distribution curve for fire return interval. For short-return interval regimes, the majority of the burned area has intervals of only a few years. Medium-return interval regimes range from a few years to several but, the majority of the burned area has intervals in the middle range. Similarly, long fire-return interval regimes have predominantly long intervals.

Information for defining and refining the distributions can be obtained using a number of data sources including tree rings with fire scars, charcoal deposits in sediment cores, fire records, and stand-age distributions. These methods require intensive studies and, when used alone, will typically yield

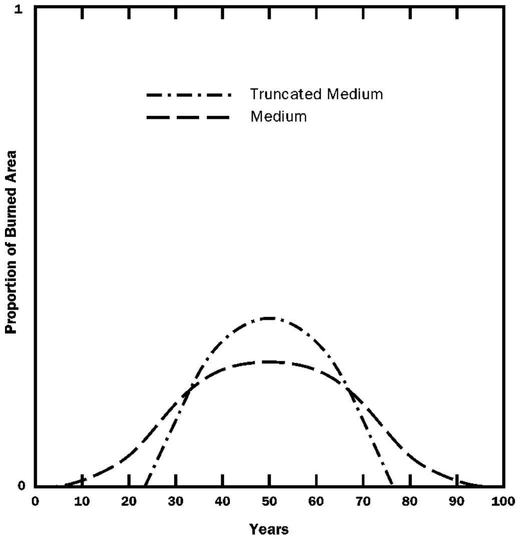

FIGURE 4.6. Example of fire regime distribution curves for fire-return interval for a closed-cone conifer ecosystem and a surrounding chaparral ecosystem. The curves are the same except for the absence of tails for the closed-cone conifer.

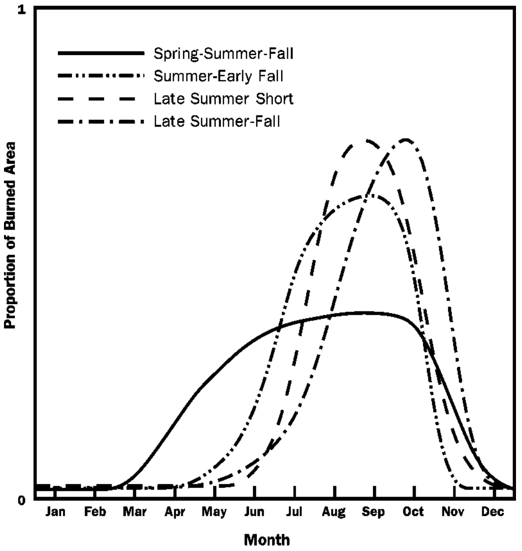

FIGURE 4.7. Fire regime distributions for seasonality. Four different distributions are displayed for fire seasons ranging from spring to fall.

only parts of the overall fire regime. Additional information can be obtained through a number of sources that are not currently used in development of fire regime descriptions. The following information should be useful in developing conceptual fire regime attribute distributions for specific ecosystems: (1) geographic location and topography; (2) plant species life history characteristics and fire adaptations; (3) spatial and temporal patterns of fuel quantity, structure, and flammability; and (4) climate and weather patterns.

Although there may be no case where we have all of the data needed to know the actual distributions of all of the fire regime attributes for any one ecosystem, we can conceptually describe the distributions of these attributes for most ecosystems. These descriptions are based on characteristics of the physical environment and knowledge of the fire relationships of the plant species composing the vegetation types, as well as other vegetation types that interface with it on the landscape. There are different combinations of fire regime attributes that are biologically important and influence stand structure and density, species composition, and distribution and stability of vegetation types with changing fire regimes. Defining the general patterns of fire regimes for ecosystems allows us to gain insight into fire's role in ecosystems. We now examine each group of fire regimes attributes and display their conceptual distribution curves.

Temporal Fire Regime Attributes

The temporal attributes of fire regimes are described in two ways: seasonality and fire return interval. *Seasonality* is a description of *when* fires occur during the year; *fire return interval* describes *how often* fires occur over several years. The patterns that are described here for ecosystems are not static on landscapes and can migrate or change in response to changing climate, fuel, continuity, ignition, or species composition. When temporal fire patterns change, there is commonly a change in vegetation type or the distribution of vegetation types.

SEASONALITY

Although California in general can be described as having warm, dry summers and cool, moist winters, season alone does not determine when ecosystems are likely to burn. Other factors, including elevation, coastal influences, topography, characteristics of the vegetation, ignition sources, and seasonal weather patterns, also influence the fire season. Season of burning is especially important biologically because many California ecosystems include species that are only adapted to burning during a fairly limited part of the year. Figure 4.7 illustrates the four conceptual seasonality patterns that occur in California ecosystems with proportion of the burned area on the y-axis and the annual calendar on the x-axis.

Spring–Summer–Fall Fire Season The longest fire season type that occurs in California has fire burning well distributed from May to November. It occurs in ecosystems with early spring warming and drying and in which fire is primarily carried in rapidly curing herbaceous layer fuels. The spring–summer–fall fire season type occurs in low elevations and deserts that cure early in the spring and persists until wetting rains occur in the late fall. This fire season type is characteristic of many low-elevation grasslands and oak woodlands, and the Mojave, Colorado, and Sonoran deserts.

Summer–Fall Fire Season This is the characteristic fire season type for many of the lower- and middle-elevation, montane conifer forests of California such as mixed conifer and ponderosa pine forests. Fires are primarily carried in herbaceous, duff, and needle layers. Most of the area burns from July to October.

Late Summer, Short Fire Season This is the shortest fire season type that occurs in California. It is characteristic of alpine and subalpine ecosystems where there is a very short period late in the summer when the vegetation is dry enough to burn. The climate excludes fire for the remainder of the year. Although lightning is abundant, fuels are mostly sparse and discontinuous, resulting in few fires.

Late Summer–Fall Fire Season This is the characteristic fire season type for central and south coastal California chaparral. Fire occurrence and size are greatly influenced by Santa Ana and north winds that most commonly occur in the late summer and early fall. This is the end of the dry season and live fuel moisture levels are lowest at this time of year. Most of the area that burns does so from September to early November.

FIRE-RETURN INTERVAL

Fire-return interval is the length of time between fires on a particular area of land. Fire rotation (Heinselman 1973) and fire cycle (Van Wagner 1978) are related concepts that display the average time required for fire to burn over an area equivalent to the total area of an ecosystem. Fire-return interval distributions illustrate the range and pattern of values that are characteristic of an ecosystem and are critical in determining the mixture of species that will persist as the vegetation of a given area. A species cannot survive if fire is too frequent, too early, or too infrequent to allow that species to complete its life cycle (Hendrickson 1991). For example, survival of a nonsprouting species in a given area may be threatened by fires that occur before there has been time for a seed pool to accumulate or after the plant's longevity has been exceeded and the store of seed is lost (Bond and vanWilgen 1996). The significance of fire-return interval in determining the species composition or vegetation structure through time is illustrated when fire burns often enough to prevent Oregon white oak *(Quercus garryana)* woodlands from changing to a Douglas-fir forest, which can tolerate a wider range of return intervals (Sugihara and Reed 1987). Figure 4.8 illustrates six conceptual fire-return interval patterns occurring in California ecosystems with proportion of the burned area on the y-axis and the fire-return interval on the x-axis.

Truncated Short Fire-Return Interval All of the area that burns does so with short fire-return intervals. Long intervals allow the establishment and growth of species that will convert these ecosystems to another type. Many oak woodlands, montane meadows, grasslands, and other Native American–maintained ecosystems are typical of this fire-return interval pattern.

Short Fire-Return Interval Most of the area burns at short fire-return intervals, but there is a wide range including a small proportion of longer intervals. Ponderosa pine forests typify this pattern with the short intervals maintaining the open nature of the stand and ponderosa pine as the dominant species. The occasional low-probability long intervals promote the establishment of a mixture of canopy species but do not prevent ponderosa pine from maintaining dominance as long as short intervals are typical.

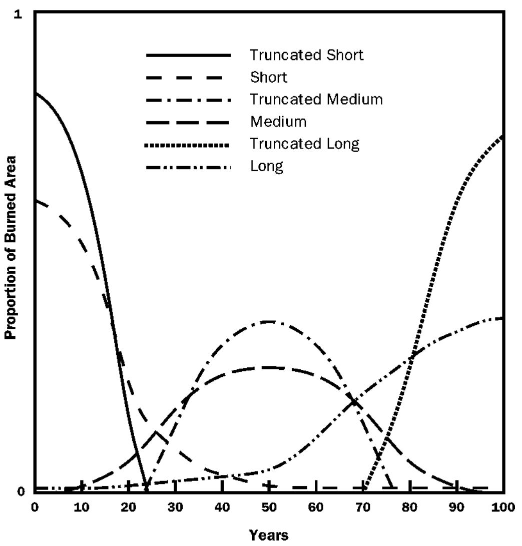

FIGURE 4.8. Fire regime distributions for fire return interval. Six different distribution curves describe the variety of possible return interval regimes.

Truncated Medium Fire-Return Interval The area that burns does so within a range of fire-return intervals that has both upper and lower limits that are defined by the life histories of characteristic species. Intervals outside of that range result in conversion to another ecosystem. This is a variation of the previous pattern with upper and lower boundaries on the length of fire-return intervals. Many of the closed-cone pine and cypresses *(Cupressus* spp.*)* are examples of ecosystems in which fires must occur within a specific range of intervals for the characteristic species to regenerate. If fires are too close or too far apart in time, the conifers cannot persist.

Medium Fire-Return Interval Most of the area burns at medium-return intervals, but occasional strong deviation will not usually facilitate conversion to another ecosystem type. This set of fire-return interval distributions includes a variety of means, ranges, and shapes. Although the distribution on Figure 4.8 shows a symmetrical shape, this is not always the case. The presence of a relatively wide range of intervals within the regime is characteristic. This pattern includes many chaparral types, live oak forests, and upper-montane forest types including red fir and white fir *(Abies concolor)* forests.

Truncated Long Fire-Return Interval In all of the burned area, intervals are long (typically greater than 70 years), and fires burning over the same area within a few years or even decades do not occur without conversion to another ecosystem type.

This return interval pattern is characteristic of ecosystems with discontinuous fuels or very short burning seasons such as most very arid deserts, sand dunes, and alpine and subalpine ecosystems. Plant species are generally not adapted to fire. Mountain hemlock *(Tsuga mertensiana)*, whitebark pine *(Pinus albicaulis)*, foxtail pine *(Pinus balfouriana* ssp. *balfouriana)*, bristlecone pine *(Pinus longaeva)*, Sitka spruce *(Picea sitchensis)*, and alpine meadows have this return interval pattern.

Long Fire-Return Interval In most of the burned area, fire-return intervals are long. Fires burning over the same area at shorter intervals can occur within this ecosystem type but account for only a small proportion of the overall burned area. This pattern is characteristic of ecosystems that are geographically isolated, do not normally have a fuel layer that will typically carry a fire, have discontinuous fuels or very short burning seasons, or lack ignition sources. Ecosystems in which this pattern is typical include some desert scrubs that only develop herbaceous layers in wet years, low-density Jeffrey pine *(Pinus jeffreyi),* or lodgepole pine on glaciated bedrock that will not support continuous vegetative cover, and singleleaf pinyon pine *(Pinus monophylla)* and beach pine *(Pinus contorta* spp. *contorta)* forests.

Spatial Fire Regime Attributes

The spatial attributes of fire regimes are described in two ways: fire size and spatial complexity. *Fire size* is the characteristic distribution of area within the fire perimeter. *Spatial complexity* describes pattern of area burned at different levels of fire severity. Although we have little direct evidence of pre–fire-suppression-era spatial patterns for most of California's vegetation types, much information can be inferred from the structure of the vegetation and typical burning patterns and conditions.

FIRE SIZE

Fire size is displayed as the distribution of burned area in fires of various sizes. The size of an individual fire is the area inside the perimeter of the fire. This is not the same as the total amount of area burned by the fire because it also includes unburned islands and the entire mosaic of burned and unburned areas. The size a fire attains is determined by fuel continuity, site productivity, topography, weather, and fuel conditions at the time of the fire. Figure 4.9 illustrates four different fire size patterns that occur in California ecosystems, with proportion of the burned area on the y-axis and fire size on the x-axis. Care should be taken to interpret each curve separately. Small fires do not necessarily burn more area than large fires; the range of fire sizes is less for small fire regimes than for medium or large regimes, and therefore the proportion is larger.

Small Fire Size Most of the area that burns does so in fires smaller than 10 ha (25 ac) with larger fires accounting for much less of the total area burned. Open Jeffrey pine woodlands on glaciated surfaces with discontinuous fuels are examples.

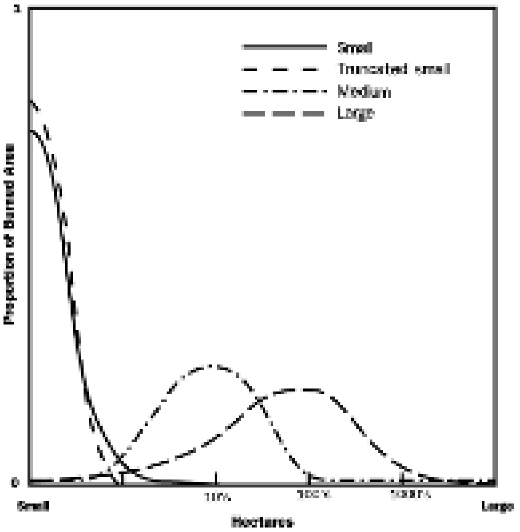

FIGURE 4.9. Fire regime distributions for size. Small, truncated small, medium, and large fire size regimes are displayed.

Truncated Small Fire Size All of the burned area is in small fires, usually less than 1 ha (2.5 ac). This is characteristic of areas with very discontinuous fuels such as whitebark pine, foxtail pine, bristlecone pine, and alpine meadow ecosystems.

Medium Fire Size Most of the area that burns does so in medium-sized fires that range from 10 to 1,000 ha (25 to 2,500 ac). Smaller and larger fires do occur but account for a small proportion of the total area burned in these ecosystems. This fire size pattern is characteristic of ecosystems that occur with patchy fuel conditions and have limited stand size, limited burning periods, or limited fuel continuity. Many red fir and white fir forests are examples of this fire size pattern.

Large Fire Size Most of the area that burns is in large fires that are greater than 1,000 ha (2,500 ac) in size with smaller fires accounting for a lower proportion. This pattern is characteristic of ecosystems occurring over extensive areas with fires typically spreading in continuous fuel layers. Many of California's grassland, chaparral, and oak woodland ecosystems fit into this category.

SPATIAL COMPLEXITY

Spatial complexity, or patchiness, is the spatial variability in fire severity within the fire perimeter. Figure 4.10 illustrates four distribution curves for spatial complexity patterns that occur in California ecosystems, with the proportion of the burned area on the y-axis and spatial complexity ranging from low to high on the x-axis.

Low Spatial Complexity Most of the area within the perimeter of the fire is homogeneous with few unburned islands and a relatively narrow range of severity producing a course-grained vegetation mosaic. Oak woodlands, grasslands, and chamise *(Adenostoma fasiculatum)* chaparral are often examples of this spatial type.

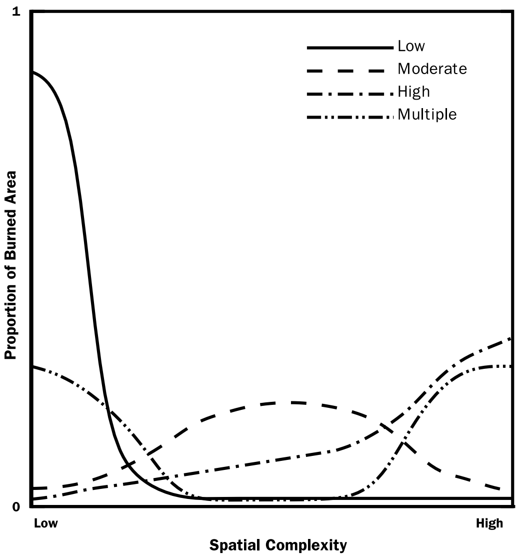

FIGURE 4.10. Fire regime distributions for spatial complexity. Burned areas can have low to high spatial complexity as well as a mixture of multiple complexities.

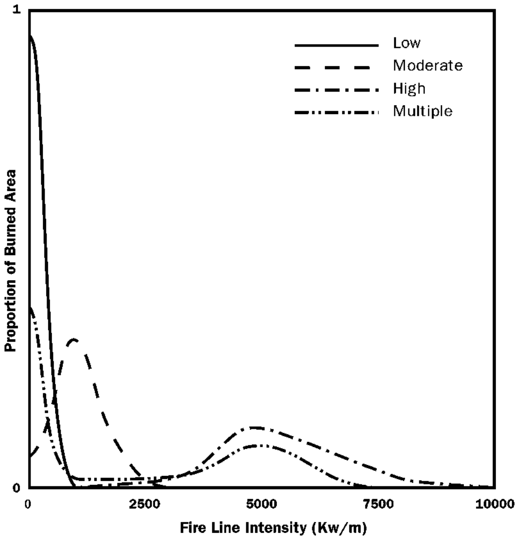

FIGURE 4.11. Fire regime distributions for fireline intensity. Fire regimes include low-, moderate-, high-, and multiple-intensity distribution curves.

Moderate Spatial Complexity Most of the area within the burn perimeter has an intermediate level of complexity. Burned and unburned areas and severity levels produce a mosaic of fine- and coarse-grained vegetation pattern. Douglas-fir and ponderosa pine are examples.

High Spatial Complexity Most of the area burns in a highly complex pattern of burned and unburned areas and severity levels producing a fine-grained vegetation mosaic. Mixed conifer and giant sequoia *(Sequoiadendron giganteum)* forests are examples.

Multiple Spatial Complexity Most of the area burns in fires that are of two distinct types: one has a complex burn pattern of burned and unburned areas and severity levels producing a fine-grained vegetation mosaic; the other has a mostly uniform pattern of burned area and severity levels and produces a coarse-grained vegetation mosaic. This is characteristic of ecosystems in which two distinct fire types occur with flaming fronts in two different fuel layers. Red fir and white fir forests are examples in which complex surface fires and homogenous crown fires result in two very different spatial complexity patterns.

Magnitude Fire Regime Attributes

Fire magnitude is separated into three separate attributes: fireline intensity, fire severity, and fire type. *Fireline intensity* is a description of the fire in terms of energy release pattern. *Fire severity* is a description of fire effects on the biological and physical components of the ecosystem. *Fire type* is a description of different types of flaming fronts. Although fire severity is related to fire intensity and fire type, their relationship is very complex depending on which elements of severity are assessed and how they are directly and indirectly influenced by fire intensity and type. Similarly, fire severity is interrelated with fire seasonality and fire-return interval through fire intensity.

FIRELINE INTENSITY

Fireline intensity is a measure of energy release per unit length of fire line. Intensity is described in detail in Chapter 3 and summarized here as it applies to fire regimes. Figure 4.11 illustrates four different fire intensity distribution patterns that occur in California ecosystems with proportion of the burned area on the y-axis and level of intensity on the x-axis.

Low Fireline Intensity Most of the area that burns does so in fires that are low intensity with flame lengths less than 1.2 m (4 ft) and fireline intensities less than 346 kW m^{-1} (100 Btu ft^{-1} s^{-1}). A smaller proportion of the area burns at moderate to high-intensity levels. Persons using hand tools can generally attack the fire at the head or flanks. Fire remains on the surface and occasionally consumes understory vegetation. Annual grasslands and blue oak *(Quercus douglasii)* woodlands are examples of ecosystems that typically burn with this intensity pattern.

Moderate Fireline Intensity Most of the area burned does so in fires of moderate intensity with flame lengths from 1.2 to 2.4 m (4 to 8 ft) and fireline intensities between 346 and 1,730 kW m^{-1} (100 and 500 Btu ft^{-1} s^{-1}). Fire is too intense for direct attack at the head by persons using hand tools. Fire usually remains on the surface, although there could be complete consumption of understory vegetation. Mixed conifer and giant sequoia forests are examples of ecosystems that typically burn with this intensity pattern.

High Fireline Intensity Most of the area that burns has fires that are of high to very high intensities greater than 1,730 kW m^{-1} (500 Btu ft^{-1} s$^{-1)}$ with flame lengths over 2.4 m (8 ft). A smaller proportion of the area burns at low to moderate intensity levels. Some crowning, spotting, and major runs are probable. These intensities usually result in complete consumption and mortality of vegetation, and consumption of entire individual plants occurs. Lodgepole pine and many chaparral ecosystems often burn with this intensity pattern.

Multiple Fireline Intensity Most of the burned area has fires that are mostly of two types: low-intensity surface fires and high-intensity crown fires. A smaller proportion of the area burns at moderate or very high intensity levels. Red fir, white fir, and some Douglas-fir and mixed conifer forests are examples of ecosystems that commonly burn with this intensity pattern.

SEVERITY

Fire severity is the magnitude of the effect that fire has on the environment, and is applied to a variety of ecosystem components, including vegetation, soil, geomorphology, watersheds, wildlife habitat, and human life and property. Separate, and often very different, distributions are appropriate when severity is displayed for multiple ecosystem characteristics. Fire severity is not always a direct result of fireline intensity, but results from a combination of fireline intensity, residence time, and moisture conditions at the time of burning. This treatment of severity emphasizes the effect that fire has on the plant communities, especially the species that characterize the ecosystem. Figure 4.12 illustrates five severity patterns that occur in California ecosystems with proportion of the burned area on the y-axis and severity on the x-axis.

Low Fire Severity Most of the area burns in low-severity fires that produce only slight or no modification to vegetation structure; most of the mature individual plants survive. A small proportion of the area burns at higher severity levels. Interior Douglas-fir forests in the Klamath Mountains, ponderosa pine, and blue oak woodlands are often examples of this fire severity pattern.

Moderate Fire Severity Most of the area burns in fires that are moderately stand modifying, with most individual mature plants surviving. A small proportion of the area burns at lower and higher severity levels. Mixed conifer and giant sequoia are typical examples of this severity pattern.

High Fire Severity Fire kills the aboveground parts of most individual plants over most of the burned area. Most mature individual plants survive below ground and resprout. A small proportion of the area burns at lower and higher severity levels. Chamise and many sprouting chaparral types are often examples of this fire severity pattern.

Very High Fire Severity Fires are mostly stand replacing over much of the burned area. All or nearly all of the individual mature plants are killed. A smaller proportion of the area burns at lower severity levels. Lodgepole pine, mountain hemlock, knobcone pine, Monterey pine, and many cypress and nonsprouting chaparral types frequently display this fire severity pattern.

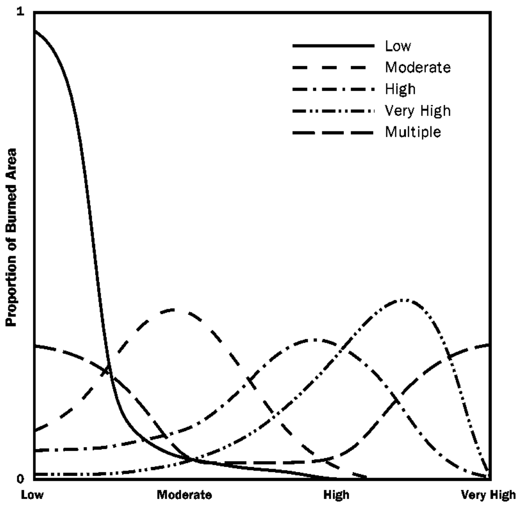

FIGURE 4.12. Fire regime distributions for severity. Five different distribution curves describe the variation in severity for different fire regimes.

Multiple Fire Severity The area burned is mostly divided between two distinct fire types: low severity and high to very high severity. A smaller proportion of the area burns at moderate severity levels. Red fir and white fir forests are often examples of this fire severity pattern.

FIRE TYPE

Fire type is a description of the flaming front patterns that are characteristic of an ecosystem. The types are defined in Chapter 3 and include surface, passive crown, active crown, and independent crown fires. Although fire type is a categorical variable, it can be expressed as a continuous variable by using fireline intensity to scale the fire types. Ground fires, although a significant contributor to fire effects, are not part of the flaming front. There are four fire regime types that represent different combinations of the fire types. These are the surface-passive crown fire regime, the passive–active crown fire regime, the active-independent crown fire regime, and the multiple-fire-type regime. Figure 4.13 illustrates the four different patterns for fire type regimes that occur in California ecosystems. The proportion of the burned area is on the y-axis, and the x-axis depicts increasing values for fireline intensity with points along the axis for fire type.

Surface-Passive Crown Fire Most of the area that is burned does so with a surface fire. Although as much as 30% of the area may experience torching of individual trees or groups of trees, the flaming front is primarily a surface fire. Organic layers are burned by ground fires, and small amounts of active crowning can burn stands of trees. Grasslands, blue oak woodlands, ponderosa pine, and low-elevation desert shrublands are typical examples of this fire-type distribution.

Passive–Active Crown Fire Most of the burned area has fire that is a combination of surface fire supported by passive and active crown fire. Active crown fire is dependent on and

SIDEBAR 4.1. FIRE REGIME EXAMPLE: OREGON WHITE OAK WOODLAND/DOUGLAS-FIR FOREST

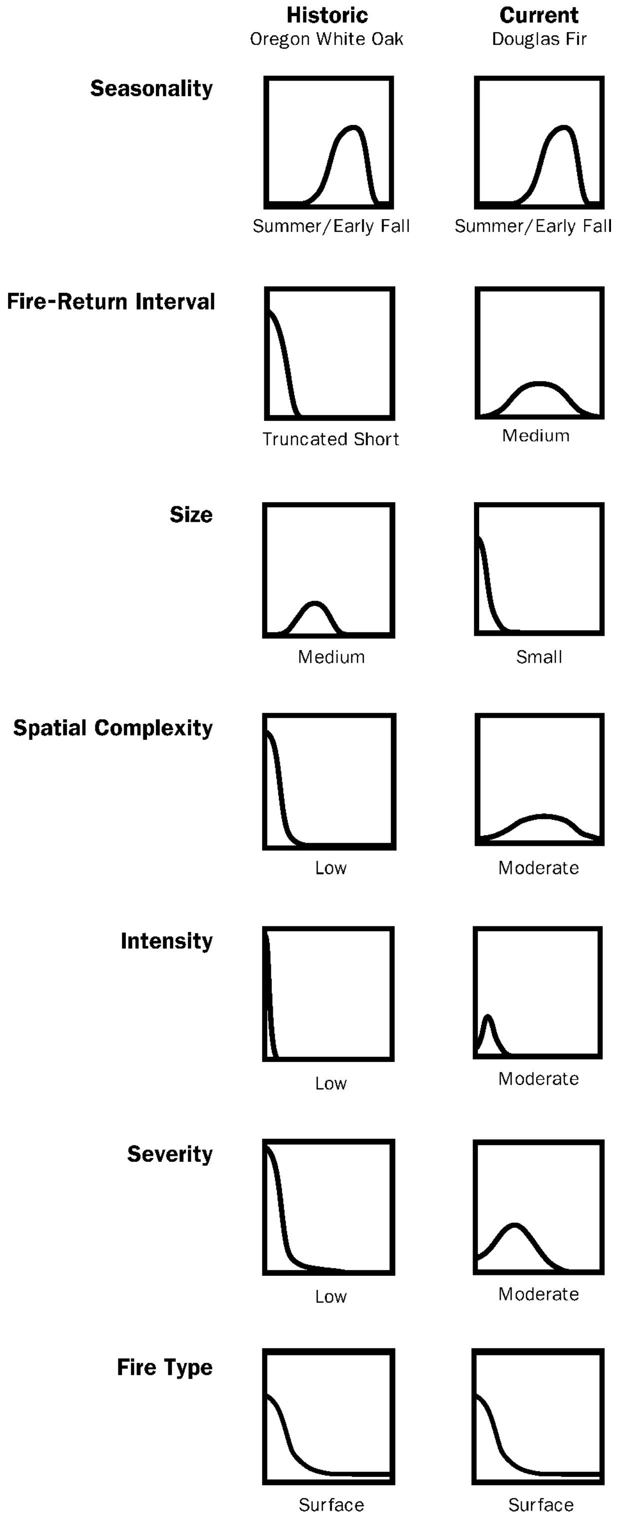

FIGURE 4.1.1. Fire regime attribute distributions for Oregon white oak/Douglas-fir forest ecosystems.

This chapter has defined fire regimes and outlined a method for describing them as a set of conceptual distributions. This example applies the description method to a California ecosystem to better illustrate this approach. We demonstrate how the persistence of this ecosystem is dependent on specific fire regime attributes.

Since the mid-1800s, there has been a general change in the fire regime patterns and a concomitant change in forest composition from Oregon white oak woodland to Douglas-fir forest. Figure 4.1.1 displays two sets of distributions that define the historic fire regime and the current fire regime that has replaced the historic one in the past 200 years. The narrative description explains the dynamics of the change and some of the options for future management. This example is intended to display the use of the fire regime distributions but not to fully describe all of the possible complexities. In-depth descriptions of the issues are developed in the chapters on bioregions.

Fire Regime Attributes

Seasonality Summer–Early Fall. The seasonality of fire has remained relatively unchanged from the historic to current period.

Fire-Return Interval Oregon white oak woodlands within the coast redwood *(Sequoia sempervirens)* forest were maintained by annual or nearly annual burning (truncated short fire-return interval) by the Native Americans. Douglas-fir was a constituent of the redwood forest. The interval has changed to a medium-return interval with fires occurring much less frequently.

Size Historically, fires were typically 10–100 ha (25–250 ac) due to the size and pattern of the vegetation on the landscape. Currently, the fires are mostly smaller than 10 ha (25 ac) due to the effectiveness of fire suppression.

Spatial Complexity Historically, the complexity of any particular fire was low due to the uniform herbaceous fuels in which the fires spread. As Douglas-fir becomes established and changes the fuel conditions, the spatial complexity increases to moderate.

Intensity Historically, fire was limited to low to moderate intensity due to the short fire-return intervals and the lack of opportunity for heavy fuel accumulations. With fire exclusion, the longer intervals allow more fine fuels and heavier woody fuels to accumulate. Moderate- to high-intensity fires now occur.

Severity Historically, fire severity was low, with plant species adapted to frequent fires and frequent surface fires having little effect on the Oregon white oak overstory. Douglas-fir is sensitive to low- to moderate-severity fire when it is young but is very resistant to damage from moderate-severity fire as a large tree. After long fire-free intervals, high-severity fires can eliminate Douglas-fir from the stand.

Fire Type Historically, surface fires with only occasional torching occurred. Currently, surface fire is still the most common, with more torching and some potential for active crown fires under extreme fire weather conditions.

Fire Regime Changes

Since the late 1800s, there have been changes in the fire regime largely due to elimination of the annual or nearly annual burning by Native Americans. Encroachment of Douglas-fir from the adjacent forest and invasion of non-native annual grass species have greatly influenced the ecosystem. The season during which the grasses are dry enough to burn has probably started earlier in the summer because of the change in species composition to more non-native annual grasses that cure earlier in the season. Fire-suppression efforts have reduced the opportunity for fires to burn these woodlands. Spatial complexity, intensity, and severity of the fires have all increased. Originally, surface fires were the most common fire type. Now there is mixture of surface fires and crown fires.

Plant Community Response

The changes in fire regime have resulted in conversion from Oregon white oak woodland to Douglas-fir forest. This represents a significant change in biodiversity of the area, because it represents a reduction in plant community diversity. The Oregon white oak woodlands are replaced by expansion of the adjacent Douglas-fir forests.—NGS

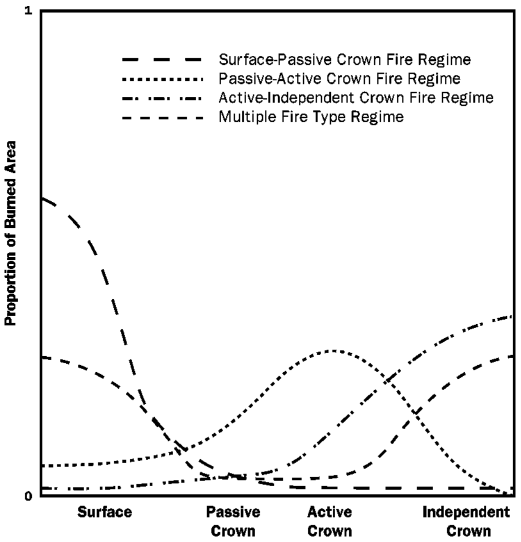

FIGURE 4.13. Fire regime distributions for type. Fire type regimes include surface fires, crown fires, and multiple type fires.

synchronous with a surface fire and is the most common type of sustained crown fire. This fire regime type occurs in north coastal pine forests, Sitka spruce, knobcone pine, coastal sage *(Salvia* spp.*)* scrub, and desert riparian woodlands and oases.

Active-Independent Crown Fire In California forests, independent crown fires are very rare but do occur occasionally in combination with active crown fires. When they do occur, the crown fire burns independently of the surface fire and advances over a given area ahead of the surface fire. Examples are lodgepole pine in northeastern California and some closed-cone conifer ecosystems. Areas supporting hardwood or conifer forests with dense canopies in very steep complex topography can also fit into this fire type distribution. In chaparral ecosystems, independent crown fires are the norm, although some active crowning might occur. Examples of vegetation types with a greater preponderance for independent crowning include knobcone pine embedded in chaparral, similarly situated Sargent cypress *(Cupressus sargentii)*, and south coast and Sierra Nevada chaparral.

Multiple Fire Type Both surface fire and crown fire are characteristic of these ecosystems with multiple fire types. Each fire type occurs in a complex spatial mosaic within the same fire under different fuel, topographic, and weather conditions. In the Sierra Nevada, red fir, lodgepole pine, and tanoak *(Lithocarpus densiflorus)*–mixed evergreen are examples of ecosystems in which this fire type pattern is characteristic. Additional types include Coulter *(Pinus coulteri)*, Bishop pine, and Monterey pine.

Combining Attributes to Develop a Comprehensive Fire Regime

Comprehensive fire regimes are developed for vegetation types by combining the appropriate attribute distribution curves for each attribute. Similar combinations could be grouped into fire regime types such as those described by Hardy et al. (2001). Sidebar 4.1 describes how all seven attributes are combined to depict the fire regime for Oregon white oak woodlands and how those attributes might change as the woodlands convert to a Douglas-fir forest as a result of fire exclusion.

Summary

Fire is an important ecological process that occurs regularly and has predictable spatial, temporal, and magnitude patterns. That is not to say, however, that we can always predict when and where a fire will occur. In the fire-prone ecosystems of California, fire is inevitable and general patterns are predictable, but the extremes are not. Species adapt to fire by having characteristics that make them competitive in the presence of recurring fire. Because fire patterns interact with biotic communities and depend on them to provide fuel, the dynamics of ecosystems are intimately tied to fire regimes. Changing fire regimes inherently affect biological change. Changes to any of the fire regime attributes are large-scale alterations to ecosystem function, producing shifts in the composition and distribution of species and ecosystems.

Fire regimes have always been dynamic at multiple scales. In addition to the scale represented by the distribution curves, fire regimes also operate at larger scales on much larger landscapes over centuries and millenia. Ecosystems and their associated fire regimes have migrated across landscapes with climate changes, human occupation, and geologic and biologic changes. Ecosystems adjust to changes in fire regime by changing composition and structure and by migrating up- and downslope, and north and south.

Although humans have altered fire regimes throughout California for thousands of years, the pace of fire regime change has accelerated over the past 200 years. Recent and current management strategies have imposed directional changes on the pattern of fires in many California ecosystems. For example, fire exclusion from some forests that historically had frequent fires has lengthened fire-return intervals, allowing greater fuel accumulations. Until 2000, the trend had been to less total area burned, with the reduction mostly in area burned by fires of low to moderate intensity and severity. Today the trend is toward more area burned by a larger number of high-severity fires. Because current technology has enabled increased human intervention in eliminating the low- to moderate-severity fires, the historic fire regime distributions have now shifted toward a greater proportion of high-severity, large, stand-replacing fires (McKenzie et al. 2004). Although it is unlikely that we will ever universally restore California's ecosystems to any historic condition, it is apparent that we cannot totally eliminate fire.

In recent decades, ecologists and land managers have become very concerned with mitigating the effects of our changes to historic fire regimes. Scientists and land managers have devoted considerable effort to improving our understanding of historic fire regimes and our changes to them. We know that fire's role in ecosystems and fire regime dynamics serve as mechanisms for driving habitat change for many species. An understanding of fire regimes is critical in assessing current conditions and developing strategies for achieving land management objectives. It is also vital in assessing the threat that wildfire poses to people on the urban–wildland interface.

The system used here for describing fire regimes allows description of the attributes involved, comparison of how they differ from those in other ecosystems, and how they change over time. Additionally, fire regime descriptions allow us to view in a structured manner how changing attributes influence fire's role as an ecological process. Knowledge of fire regime–ecosystem interactions allows us to understand mechanisms for ecosystem change due to changing fire regimes. This knowledge further allows prediction of the direction of ecological change that will occur with future planned and unplanned changes to fire regimes.

Today we have the opportunity to manage dynamic ecosystems and maintain many of their important processes and attributes. Society is redefining its land management objectives and strategies, and managing fire regimes has emerged as a major element of managing ecosystems. We must also decide where it is appropriate to manage altered fire regimes and ecosystems to meet society's desires and demands. The fire regime system described in this chapter is designed to aid in meeting these challenges by giving us a tool for assessing fire regime–ecosystem dynamics and to help us to understand the mechanisms of fire-related ecosystem change.

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