ONE

Wildland Fire in the West

The Big Picture

Scientific understanding of wildland fire has grown exponentially during the past few decades. Fire ecology has developed into a viable field of study. Scientists and land managers increasingly recognize the complexity and uncertainty involved in fire management, and alternatives to fire suppression have gained popularity. Today we can identify three major methods for managing fire: First, we can suppress it directly, to the best of our ability. This is the method that has predominated since the mid-twentieth century. We can manage it indirectly, by physically removing the fuels necessary for fires to ignite and spread. Physical fuel reduction is most often accomplished by selective cutting, although the use of cattle or goats for removing finer fuels also has many proponents. Finally, we can use fire to our advantage, either by setting prescribed fires or by letting lightning-sparked fires burn.[1] Fire use also changes the behavior of future fires by removing fuels, and many land managers and policy makers consider fuel reduction through physical removal to be roughly functionally

Copyrighted Material

equivalent to reduction by fire. As we will see, however, the results of these two methods can be very different in practice. In any case, fire suppression, fuel reduction, and fire use are the primary tools available to fire managers today. We discuss these tools and their applications in much greater detail in chapter 5.

Throughout most of the last century, fire use has been highly contentious. The idea of using fire to accomplish specific management goals is quite old (many Native American cultures were frequent burners, as were early white settlers), but it has only recently gained ground as an alternative to suppression, at least in the eyes of the federal government. In what became known as the Leopold Report, several ecologists in 1963 famously endorsed the idea of letting fires burn under well-defined conditions.[2] The National Park Service accepted the practice as a management technique shortly afterward, but was slow to put it into widespread use.

From publication of the Leopold Report through the 1980s, debate raged over the wisdom of allowing some lightning-ignited fires to burn.[3] Research on historical fire cycles and fuels suggested that it might be beneficial in some areas to allow fires to burn unchecked in circumstances where they were unlikely to grow large and intense. Land managers began tentatively allowing fires to burn, especially early and late in the fire season and during relatively cool, humid, and calm conditions. They hoped that allowing numerous small fires to burn might head off very large, intense fires by keeping fuels from building up. As the use of those managed fires gained in popularity, this practice also promised land managers an opportunity to safely burn up more fuels every year without having to budget for costly prescribed fires.

Copyrighted Material

By the late 1980s, the National Park Service seemed to be doing everything right at Yellowstone National Park. In response to scientists' recommendations, particularly the influential Leopold Report, Yellowstone had developed a policy that allowed some lightning-caused fires to burn unchecked. Managers recognized the key role fire played in park ecosystems, especially in forests dominated by lodgepole pine (*Pinus contorta* var. *latifolia* Englem.), a species that both facilitates and depends upon fire. (Some populations of lodgepole pine produce closed cones that are not viable until they are opened by fire.)[4] The Park Service had allowed 235 fires to burn 33,759 acres in Yellowstone between 1972 and 1987; all of them were extinguished naturally. Only a few ever covered more than a hundred acres.[5] It looked for some time as if the reintroduction of fire might be a fairly straightforward process there, and using naturally ignited fire as a management tool started to gain political acceptability, both within Yellowstone and nationally.[6] Managers believed that fires were unlikely to grow large except in Yellowstone's old-growth pine and older spruce-fir forests, and these occurred in wilderness areas that seemed large enough to contain nearly any fire. In retrospect, it seems likely that a string of wetter-than-average summers through the early and mid-1980s unduly influenced these perceptions.[7]

As the summer of 1988 began, the Park Service's assumptions were put to the test. After an unusually wet spring, the normal summer rains virtually stopped. The Yellowstone area entered a severe drought and grew increasingly parched as dry thunderstorms began to spark fires. Early in the summer, lightning-strike fires were allowed to burn, provided they fit within preestablished parameters. By July 15, drought conditions had worsened enough

Copyrighted Material

that the Park Service began to aggressively suppress all new fires. After July 21, the service actively fought all existing fires.[8] A total of 248 fires started that summer in the greater Yellowstone area, and several of them burned through the summer and into the fall. High winds and dry fuels made firefighting a losing battle, and the situation seemed to many observers to be totally out of control. The fires became manageable only when snow started falling in mid-September. By that time, fires had burned across about 1.5 million acres of the greater Yellowstone area, including about 36 percent of the park itself. The National Park Service reported that "more than 25,000 firefighters, as many as 9000 at one time, attacked [the fires] at a total cost of about $120 million."[9]

Media coverage of the fires was emotional, hyperbolic, and unrelenting. It also was very often misleading. Live coverage of flames and charred forests was everywhere. The alarming images and rhetoric, along with outright disinformation, led the public to believe that intense fires had completely destroyed the park's beauty and wonder. They also suggested that the Park Service had, based on a contentious and misguided theory of forest management, allowed America's most prized national park to burn to the ground. The public had come to expect quick and effective suppression of all fires, and there was little patience for the argument that some fires simply couldn't be suppressed. Even as park officials were spending three million dollars per day on fire suppression, they continued to insist to the media that only winter could extinguish the fires.[10] Still, most Americans seemed determined to believe that modern technology, coupled with sufficient personnel, should be able to extinguish any forest fire.

In the wake of the fires, many people, including some scientists, land managers, and members of the public, believed that the soil

Copyrighted Material

had been sterilized and the forest effectively destroyed for decades to come.[11] The Park Service's let-burn policy became a major target of public outrage, and interest in "natural" fires waned. Some fire scientists argued that a program of careful prescribed burning would have prevented the whole catastrophe, while many in the media argued for a return to total suppression.[12]

It wasn't long, though, before it became clear that Yellowstone had not simply been converted into a wasteland and a public testament to Park Service incompetence. The following spring, wildflowers bloomed on the blackened ground. Within ten years, even the most severely burned forests were scattered with small lodgepole pine seedlings.[13] Today we know that the burned landscapes have largely been recolonized by native species, that the fires led not to a homogeneous landscape but to a diverse mosaic of burned and unburned areas, and that the snags and downed logs created by the fires have decayed and formed a rich source of organic matter that boosted productivity.[14] We also know that many of the management strategies previously suggested for the Yellowstone lodgepole pine ecosystem—from total suppression to reducing fuels and creating a regime of frequent, minor ground fires—are misguided, oversimplified, and ultimately futile.

The 1988 Yellowstone Fires have many lessons to offer. First and foremost, they show us that our society has a pervasive and unfortunate tendency to misjudge wildland fire. We underestimate fire's role in ecosystems, and we seriously overestimate humans' ability to control it. This is a lesson that nearly any wildland fire, regardless of size and severity, can teach us. In later chapters, we examine our government's ill-fated attempts to gain control over fire and show the inevitable failures of that path, and we offer suggestions for living productively with fire, both as a society and as

Copyrighted Material

individuals. First, however, we examine in some detail the beautiful, astonishing complexity of wildland fire and the inherent uncertainty involved in living with it.

MAKING SENSE OF COMPLEXITY

Wildland fire is an unimaginably complex and unpredictable phenomenon influenced by countless interrelated factors, and as such, it does not submit easily to human control and planning. During the Yellowstone Fires, for example, a totally unpredictable change in winds caused a single fire, brought partially under control by firefighters, to explode, growing from 68,000 acres to almost 250,000 acres in just sixteen hours. A few days later, rain and snow brought the fire back under control.[15] Fire in its wild state is notoriously difficult to anticipate, much less control.

At the most basic level, however, we understand fire quite well. Fire requires only three things: heat, oxygen, and fuel. More specifically, it requires a heat source for ignition, an adequate supply of oxygen, and dry, fine fuel sufficient to ignite and then carry fire.[16] The environment around a wildfire transforms these three requirements into a practically infinite set of variables. Ignition can be lightning or human caused. Oxygen can be supplied under a variety of wind patterns. Winds may be calm or gale force, stable or rapidly shifting, and caused by massive, slow-moving fronts or sudden, unexpected changes in the jet stream. Large fires create their own winds and weather systems. Fuels can be fine or heavy, green or dead, and can become extremely desiccated during drought conditions. At one point early in the summer of 1988, moisture levels of some of Yellowstone's fine and dead fuels were lower than that of kiln-dried lumber.[17] Some plants, including

Copyrighted Material

several dominant species in chaparral communities, contain highly flammable volatile oils. Others, including many nonnative grasses now dominant in the southwestern United States, have a life cycle and physical structure that predispose the species to carrying fire. Moreover, the flammability of a fuel type can be radically altered by factors such as slope and exposure. The result is an amazingly diverse universe of unique combinations of ignition type, fire weather, and fuel type. Any single variable is capable of completely altering a single fire's behavior or even a specific ecosystem's entire fire cycle.

The term *fire regime* is used to express the idea that any given ecosystem has evolved with fires of a certain kind—a certain frequency, seasonality, intensity, and extent. Fire ecologists often aim to describe (and fire managers aim to re-create) the "natural" fire regime for a specific ecosystem. The term is useful to the point of being indispensable, because it gives us a framework for understanding the patterns common to fires in many different systems. But the idea of a clearly defined fire regime can also oversimplify the complexity of fire and its variations across space and time, even within a single ecosystem. The term obscures the diversity and unpredictability of fire as it interacts with and changes diverse landscapes. Even while we describe the fire regime for ponderosa pine forest or desert ecosystems, therefore, it is important to keep in mind that any such description is an oversimplification. In reality, fire regimes change over time (and may change even more quickly under human influence), just as they vary among regions, among different mountain ranges, and even from slope to slope or forest to forest.

Fire scientists describe both individual fires and fire regimes according to several different traits, including frequency, intensity,

Copyrighted Material

seasonality, extent, and weather. As a result, fire regimes can be defined and classified in a surprising variety of ways. In order to plan for and manage fire appropriately, it is important to be clear in our definitions. When scientists and land managers have classified fire regimes, they have typically focused almost exclusively on the frequency of fires in a given ecosystem. An ecosystem's fire regime is usually described in terms of fire-return interval, the estimated average period between fires. Defining fire regimes by their return interval alone can be problematic, because this reduces a dynamic trait to a single range of numbers. For example, a semiarid "desert" grassland of the southwestern United States might be described as having a fire return interval of seven to ten years, which would suggest to land managers that fires "naturally" occur at this interval. In fact, managers often see fire-return interval as a goal to be met and plan prescribed burns or fuel treatment projects in response to these figures.

The fire-return interval can be a misleading figure, however. Historical fire frequency is difficult to determine and, in some ecosystems, virtually impossible. Pinpointing it requires a great deal of site-specific information, which is most commonly gathered through dendrochronological (tree ring) analyses. When a given tree survives a fire, its rings show scars. In forests with many old trees that have survived multiple fires, scientists can reconstruct a hypothetical fire history based on these fire scars. However, the accuracy of this method is somewhat uncertain. A fire may burn through an area and not leave scars on all trees. Fires often burn in a spotty "mosaic" pattern, and even a tree that is charred may not necessarily scar.[18] In any case, many forests, and certainly most grass- and shrublands, lack the large, old trees needed for this kind of analysis. Notes from General Land Office

Copyrighted Material

Surveys or historical photographs are sometimes used to help build a historical record. On the whole, however, fire-return intervals should be viewed with a healthy dose of skepticism.

Fire-return intervals also change over time in response to climate and land-use patterns. The southwestern desert grasslands themselves may be an artifact, at least in part, of intentional or unintentional burning by Native Americans, in which case "natural regime" is a misnomer. A more accurate description of fire frequency might be one stating that fires occurring every seven to ten years will tend to maintain a grassland ecosystem, whereas areas characterized by less frequent fires will likely become dominated by woody plants.[19] Some systems also have mixed fire regimes in which frequent minor fires are interspersed with infrequent extreme fires. Classifying fire regimes according to frequency effectively obscures these important variations. Fire-return intervals can be misleading also because they make it easy to ignore other regime traits that may have even greater impacts on both humans and ecosystems.

Fires and fire regimes are also often described in terms of intensity. At its most basic level, *fire intensity* describes the heat released by a fire. The intensity of any given fire varies over both time and space.[20] *Intensity* also tends to be used as a shorthand descriptor for other traits closely associated with high- or low-intensity fires. For example, intense fires are often also very large fires, partly because hotter fires are more difficult to control. Similarly, fires may be described as intense because they display behaviors associated with large, hot fires, such as spotting, fire whirls, crowning, and long, fast runs.[21]

Ecosystems are further characterized by a climate conducive to fire during particular seasons. For example, the southwestern

Copyrighted Material

United States experiences a hot, dry period nearly every year between early April and late June, and this spring drought is broken by "monsoonal" thunderstorms. Thunderstorms usher in the summer when fuels are very dry; lightning from these storms historically ignited fires, and it still accounts for many wildfires. Storms that contain little precipitation are particularly likely to spark fires. As might be expected, native species in the region are adapted to fires that occur during this period. Land managers, however, often prefer to light prescribed fires during early spring or late autumn to reduce the likelihood that a fire will rage out of control. Native species are poorly adapted to fires that occur "out of season" relative to their evolutionary history, and such fires expose these organisms to conditions as unusual—and potentially as deadly—as a midsummer snowstorm. The season in which a fire occurs can affect plants' ability to produce seeds and take advantage of seasonal precipitation for growth and reproduction.[22] It can also dramatically influence fire behavior. Winter fires may be so low in intensity that they hardly reduce fuels in ecosystems where summer fires have historically predominated.[23] Therefore, fire use that does not take into account an ecosystem's historical fire season can result in a shift in dominant species, an increase in nonnative species, and even the extirpation of rare or particularly vulnerable organisms.[24]

Fire extent is another important trait to consider when measuring and describing fires: large and small fires tend to have very different effects on ecosystems. Large fires, especially intense ones, leave behind large "islands" of habitat that are structurally different from the surrounding area. Small or immobile species may be very slow to recolonize large burned patches, a circumstance often described as a major fault of large, intense fires, be-

Copyrighted Material

cause the area is seen as "dead." But it is not dead at all. Birds, butterflies, and large ungulates may begin using even very large, intensely burned areas within a few hours after a fire has passed. Smaller and less intense fires create a mosaic of effects and may contribute greatly to the diversity of landscapes and thus to biological diversity.[25]

Of all the factors that influence wildland fire, weather is among the most profound and complex. Weather and fuels interact in important but often unpredictable ways, which helps explain why humans find it so difficult to influence wildfire behavior. Fire managers have long recognized the importance of weather variables in planning and conducting prescribed fires and in suppressing fire. Plans for prescribed fires include a strict range of suitable weather conditions outside of which the fire cannot be ignited. But weather doesn't follow human plans; a recent government study reported that weather concerns accounted for 40 percent of the delays on fuel-reduction projects at sites visited by researchers.[26] A basic understanding of how weather affects different kinds of fire regimes is crucial to the effective management of fire-prone and fire-dependent ecosystems.

Weather largely determines fuel moisture and thus the volatility of fuels. Hot, dry, windy weather over an extended period drives moisture from wildland fuels just as it would from an open pan of water. Small-diameter fuels lose moisture much more rapidly than larger fuels, because grasses and smaller leaves and branches have more exposed surface area from which moisture evaporates. As a result, grasslands and shrublands become tinderbox dry after only a few hours of desiccating winds. It takes considerably more energy and time to dehydrate large trees in shady forests.

Copyrighted Material

A close relationship exists also between a given ecosystem's response to weather and its fuel structure, in terms of the relative level of canopy cover. *Canopy cover* describes the amount and distribution of leaf area in an ecosystem and can range from very open—or even nonexistent, such as in a few of the world's deserts—to completely closed, such as in dense forests where there is no space between tree crowns. In grasslands and the least-dense shrublands and forests, fire is usually carried at ground level and through herbaceous fuels. As a result, fires tend to be less intense, although they may still spread very quickly. Where the forest or shrub canopy is more closed, undergrowth is less grassy and tends to consist of young shade-tolerant trees and shrubs of various sizes.[27] These "ladder" fuels often carry fire into the canopy, where it burns in very hot, intense, and rapidly spreading crown fires.[28]

Although all fires are driven by the same general forces of fuel, ignition, topography, and weather, the relative importance of these factors differs somewhat among ecosystems. In recent years, a useful new paradigm has emerged for describing fire regimes. While it cannot encompass the full variability of fire, this paradigm represents an important effort to move beyond the assumption that regimes are defined by the average frequency of fires. Today many fire ecologists describe three broad classes of fire regimes: low, mixed, and high severity.[29] Low- and high-severity fire regimes represent opposite ends of a continuum. Each designation corresponds to several ecosystem types and is generally defined by evidence of an ecosystem's fire history before suppression was widespread. In this case, the term *severity* indicates a number of interrelated traits, including fire intensity and behavior, fuel type, and the influence of weather. We will look at each of these regimes in turn.

Copyrighted Material

The dynamics of low-severity fire regimes are relatively well known because of exhaustive studies of low-severity-regime ponderosa pine forests in the southwestern United States. The Ecological Restoration Institute at Northern Arizona University has been especially active in unraveling the complex fire regimes of these systems. Low-severity fire regimes are characterized by open canopy structures, which produce and are maintained by relatively frequent, low-intensity fires. Low-severity regimes generally exist in ecosystems that experience annual seasonal droughts, where weather and fuel moisture conditions are favorable for fire nearly every year. Fires occur when fuel loads build to a critical threshold. Because fires in low-severity regimes tend to be driven more by the accumulation of fuels than by dry weather, it is possible to manage fire in them somewhat by manipulating fuels.[30]

This is not to say that low-severity regimes are immune to weather and climate influences. In low-severity-regime forests of the southern Rockies, for example, synchronous large fires tend to occur when fluctuations in the El Niño–Southern Oscillation (ENSO) produce a wetter-than-average winter and spring one year (known as an "El Niño year") and drier-than-average conditions the next (a "La Niña year").[31] Large amounts of vegetation accumulate during the wet year and are quickly desiccated during the dry summer that follows. As a result, La Niña years are often associated with busy fire seasons across the southern Rockies.[32]

High-severity fire regimes, conversely, are often driven by short-term weather patterns more than by the accumulation of fuels. Fires can be frequent or infrequent (even centuries apart, as with the lodgepole pine forests of Yellowstone National Forest),[33]

Copyrighted Material

but they tend to be intense and to burn in the crowns of trees or shrubs. Fuels are nearly always abundant, and fires ignite and spread when weather patterns produce sufficiently dry conditions. In wetter ecosystems, such as the coastal forests of the Pacific Northwest, this requires a prolonged drought. In others, such as the highly flammable chaparral shrublands of Southern California, a hot, dry wind may be sufficient. In high-severity regimes, attempts to change fire behavior through fuels management are generally ineffective, because fuel regeneration can be extremely rapid and fire behavior is determined primarily by extreme weather conditions.[34]

Mixed-severity regimes combine the features of these two regimes and have both high- and low-severity fires at a variety of frequencies. They are common in midelevation forests, where topography creates a mosaic of tree species, densities, and moisture levels.[35] Fuel abundance and fuel moisture, fluctuating climate patterns, and short-term weather all play a role in the timing and behavior of fires (see figure 1).

It is far beyond the scope of this book to describe in suitable detail the multitude of fire regimes that make up the western United States. In any case, several authors have already done so. The seminal work is Henry Wright and Arthur Bailey's *Fire Ecology: United States and Southern Canada*.[36] An earlier volume edited by T. T. Kozlowski and C. E. Ahlgren, *Fire and Ecosystems*, is also highly informative.[37] More recently, James Agee has written an excellent treatment of the fire ecology of forests of the Pacific Northwest.[38] While they do not delve into specific fire regimes in any great depth, Stephen Pyne and colleagues offer an extremely thorough description of the principles and variables of fire behavior.[39]

Copyrighted Material

Figure 1. A prescribed fire moves across a landscape with a mixed-severity fire regime (juniper shrub and grassland on the 6666 Ranch in central Texas). Photo by Guy McPherson.

Before moving on to other topics, however, we do wish to provide a sense of the complicated situation facing anyone who would seek a national solution to wildland fire issues. In place of a more thorough treatment, we offer case studies of three western ecosystems with vastly different fuels, weather, fire regimes, and management consequences. Remember, however, that the variability among sites, seasons, or years in a given ecosystem can be even more striking than the differences among defined ecosystems. This spatial and temporal complexity is a theme to which we return several times in this book. We see the three case studies here as representing points along a multidimensional continuum of factors that affect fire behavior and fire ecology.

Copyrighted Material

CASE STUDY: FIRE IN PONDEROSA PINE FORESTS

Forests of ponderosa pine *(Pinus ponderosa)* cover vast swaths of the western United States.[40] The species dominates some 2.7 million acres of the West and forms virtually monotypic stands in many areas. The relatively continuous ponderosa pine forest that stretches along the Mogollon Rim between northern Arizona and central New Mexico is reportedly the largest ponderosa pine forest in the world and forms the only major commercial forest in the southwestern United States.[41] The ecology and fire history of the species are among the most studied in the world.

Ponderosa pine forest varies in density, from very open, parklike stands to dense thickets. This variation in stem density is partially attributed to human-induced changes in fire regimes; fires have been virtually absent in many ponderosa pine forests since the late 1880s.[42] Accounts by some early explorers and settlers describe more open canopies with understories of herbs and shrubs. Understory species vary widely across western North America.[43]

Ponderosa pines have an impressive set of adaptations that help them tolerate fire. Adults trees have thick, plated bark; the spaces between these plates dissipate heat and protect the cambium. The relatively open forest canopy, where it still exists, also allows heat to dissipate and minimizes crown scorching. Buds are encased in small bundles of needles that insulate and protect them from heat damage. Trees are deep-rooted, even at an early age, which also helps them survive fire.[44]

In addition to having considerable resistance to fire, ponderosa pine is well adapted to reproducing after a fire. Although its seeds are large and not particularly well dispersed by wind,

Copyrighted Material

fires in ponderosa pine forests tend to be relatively patchy, which helps ensure an adequate supply of seeds from healthy adult trees near recently burned areas. Patterns of reproduction appear to depend largely on soil moisture. Seedlings establish readily in more mesic (that is, less arid) forests but can also recruit in drier areas during periods of above-average precipitation.[45] Once seedlings become established, their growth in terms of both height and diameter is so rapid that trees became large and fire-resistant relatively quickly, although intense crown fires can kill adult trees.[46] Seedlings themselves are moderately susceptible to fire, but mortality depends strongly on fire intensity.[47] This combination of episodic recruitment patterns, rapid growth, and high resistance to fire makes ponderosa pine very well suited to surviving low-intensity surface fires and reestablishing populations in the wake of larger crown fires.

Other species in ponderosa pine forests also have a close relationship with fire. Gambel oak *(Quercus gambelii)* is a dense shrub commonly found beneath stands of ponderosa pine in the central and southern Rocky Mountains. These oaks are relatively resistant to low-intensity surface fires, and, because the species is clonal, individuals damaged by fire often resprout vigorously.[48] As a result, Gambel oak may dominate stands in more arid areas within the first several years after a fire. New Mexico locust responds somewhat similarly. Stems are easily killed by fires, but rapid resprouting and recruitment (which is more successful after seeds have been scarified by fire) allows the species to become locally dominant. These patches of locust usually give way to conifers within fifteen to twenty years. On wetter sites, species such as Douglas-fir *(Pseudotsuga menziesii)*, southwestern white pine *(Pinus strobiformis)*, and quaking aspen (*Populus tremuloides*)

Copyrighted Material

coexist more commonly with ponderosa pine. Douglas-fir is thick barked and therefore resistant to all but intense, stand-replacing fires. It reestablishes through wind-borne seeds and grows rapidly, and individuals may persist for several centuries.[49] Southwestern white pine is moderately resistant to fire as a mature tree, but seedlings are highly susceptible to even low-intensity fires.[50] Quaking aspen rarely burns at all when it occurs in pure stands, because aspen leaves and standing trees have a high moisture content.[51] Where aspens are scattered among ponderosa pine forests, however, they may be subjected to more frequent fires. In even relatively low-intensity fires, the aboveground portions of the trees are usually killed.[52] But quaking aspen is the archetypical fire-adapted species in these systems: it resprouts vigorously and grows quickly after a fire, so that it appears on first inspection to be the only tree present. It is also highly shade-intolerant, however, and postfire stands of quaking aspen generally give way to conifers within thirty to sixty years.[53]

These adaptations to fire tell us a great deal about the fire regimes of a given system. Indeed, fire and plant species coexist in a synergistic relationship. The unique characteristics of plants (especially the kinds of fuels they create) shape fire regimes, which in turn favor certain plant adaptations for tolerating fire. Fire and plants are thus inseparable in ponderosa pine and many other ecosystems, and changes in one can have a great impact on the other. Despite a long history of study (or perhaps because of it), considerable debate still surrounds the fire history and ecology of ponderosa pine forests. For many years, scientific consensus has held that, before European settlement, ponderosa pine forests were characterized by frequent low-severity surface

Copyrighted Material

Figure 2. A low-intensity prescribed fire burns in a ponderosa pine forest on the Mogollon Rim in northern Arizona. Photo by Guy McPherson.

fires (see figure 2). Nearly all fires were ignited by lightning; Native Americans may have started a few fires.[54] Fire-return intervals varied in different geographic regions, from about four to thirty-five years.[55] Newer evidence suggests that this long-held understanding of fire in ponderosa pine forests is not entirely accurate. It remains likely that this fire regime predominated on most sites, but some important exceptions are worth noting.

Since at least 2001, considerable new evidence has pointed to the historical occurrence of infrequent, high-intensity crown fires in some ponderosa pine forests.[56] It may be that a cycle of frequent surface fires influenced most stands but that infrequent stand-replacing fires occasionally interrupted that dominant cycle.

Copyrighted Material

A combination of variables related to weather, climate, and stand structure help explain these overlapping cycles.

Fire frequency and intensity are strongly controlled by fuel density and cover in most ponderosa pine forests. These forests are generally found in regions with annual summer droughts followed by dry thunderstorms, so that weather and fuel moisture conditions are favorable for fire nearly every year. Fires occur every few years, or as soon as fuel loads build up to the necessary threshold. Historically, a positive feedback cycle was probably maintained on many sites, in which frequent low-intensity fires maintained relatively open, parklike stands of widely scattered pine trees. However, denser stands probably became established during periods of above-average precipitation and on relatively mesic sites.[57] As a result, in a regime more commonly dominated by frequent, low-intensity fires, occasional high-intensity fires could result from even modest variations in precipitation over relatively short periods of time. For example, a decadelong period of above-average precipitation would cause rapid recruitment and growth, as noted earlier, while also acting to reduce fire occurrence and spread. Fuel loads build rapidly in such situations. A subsequent decadelong period of below-average precipitation would lower fuel moisture and could easily trigger widespread severe, stand-replacing fires. In general, however, large stand-replacing fires were probably rare until the last century or so, when humans largely eliminated low-intensity fires. As we discuss in later chapters, ponderosa pine fire ecology has played a disproportionately large role in recent fire policy and management decisions, and a desire to return these forests to a low-intensity regime has played a major role in reshaping western forests.

Copyrighted Material

CASE STUDY: FIRE IN MIXED-CONIFER FORESTS

The mixed-conifer forest type of the western United States is found throughout the Pacific states, particularly at the middle elevations of the Cascade and Sierra Nevada ranges. It also occurs in the northern and central Rocky Mountains and the southwestern mountain ranges.[58] Common species include Douglas-fir, sugar pine *(Pinus lambertiana)*, ponderosa pine, Jeffrey pine *(Pinus jeffreyi)*, incense cedar *(Libocedrus decurrens)*, grand fir *(Abies grandis)*, and white fir *(Abies concolor)*.[59] In the southwestern forests, southwestern white pine and quaking aspen also are common.[60] Canopy density varies among mixed-conifer forests, depending on moisture, elevation, and aspect.[61] Canopy cover and species composition are influenced by other site conditions as well, including soils, temperature, and fire and other natural disturbances.[62] On moist sites (generally, at higher elevations and on north- and east-facing slopes), fir is more common than pine, and forests are normally mature and dense, with a tightly closed canopy and shrubby undergrowth. Drier forests have more pine, a more open canopy, and less undergrowth.[63]

Mixed-conifer forests are characterized by mixed-severity fire regimes, and the relatively complex regimes that create and maintain these forests produce a rich mosaic of trees across the landscape. Before European settlement, fire intensity probably varied considerably even within a single burn, so that some areas did not burn at all, other areas burned as low-intensity surface fires, and some patches burned as high-intensity crown fires. This variety of intensities is undoubtedly responsible for the presence of tree species with very different tolerances to fire. There is little question

Copyrighted Material

that fire was a recurrent phenomenon and an integral component of these forests before suppression became common.

Fires are more frequent and less intense in the drier mixed-conifer forests, where pine needles provide abundant fine fuels and all fuels are drier. The wetter mixed-conifer forests, conversely, experience something closer to a high-severity regime—fires are infrequent but intense, and both surface and crown fires occur.[64] In earlier literature the distinction between these two regimes was unclear, leading different scientists to make wildly varying estimates of fire-return intervals. Regimes of more frequent fires tend to create stands of more fire-tolerant species, particularly ponderosa pine, while regimes of less frequent fires favor more shade-tolerant species such as firs and incense cedar.[65] Tree-ring analyses from southwestern mixed-conifer stands suggest that fires historically occurred at three- to twenty-year intervals.[66] However, in the moister forests of the Pacific Coast, fire scientists Wright and Bailey suggest, intervals ranged from forty to five hundred years, depending on the site and associated species. Fires in both areas tend to occur primarily during major regional droughts and during the dormant season when fuels are driest, and intervals in both have been lengthened considerably by fire suppression.[67]

CASE STUDY: FIRE IN COASTAL DOUGLAS-FIR FORESTS

Douglas-fir is very common in western North America, with a range extending from northern British Columbia to near Mexico City and from the Pacific Coast to the eastern Rocky Mountains. In terms of timber, no North American tree is more significant and

Copyrighted Material

productive. Remaining old-growth forests on the northwest coast are legendary for their biological diversity, as well as for the size and growth rate of Douglas-fir trees. These forests harbor some of the nation's most celebrated and contentious rare species, including many species of migratory fish and the northern spotted owl *(Strix occidentalis).* The ecological communities associated with Douglas-fir vary greatly, as do their fire regimes. These communities are classified according to geography (interior or coastal) and associated species: for example, cedar-hemlock communities in the most mesic, northern climates, quaking aspen and lodgepole pine in interior continental climates, and ponderosa pine in the drier ranges of the southwestern United States.[68] They overlap somewhat with the mixed-conifer forests just discussed, in that these are often dominated by Douglas-fir in the northwestern states. In this example, we focus on the coastal Douglas-fir ecosystems that predominate in the Pacific Northwest of the United States on the western flanks of the Cascade and Sierra Nevada mountains.

In general it is high-intensity, stand-replacing fires, with return intervals of 250 to 700 years, that produce these coastal Douglas-fir forests.[69] Exceptionally deep or long droughts are required for fires in coastal areas, whereas somewhat more frequent but smaller fires, or periodic surface fires, characterize the Cascade Range farther inland.[70] While Douglas-fir is common throughout much of this area, it is generally found in forests dominated by other species. Western hemlock *(Tsuga heterophylla)* and Pacific silver fir *(Abies amabilis)* forests often include Douglas-fir stands. As noted earlier, adult Douglas-fir trees are highly resistant to surface fire, in part because of their very thick bark and fire-resistant seeds. Interestingly, not all associated species are equally resistant to fire.[71]

Copyrighted Material

In the humid, high-elevation silver fir forests, Douglas-fir and silver fir are often joined by noble fir *(Abies procera)*, western red-cedar *(Thuja plicata)*, and western white pine *(Pinus monticola)*. None of these species are as resistant to fire as Douglas-fir, and Pacific silver fir is killed very easily by fire. It has thin bark and shallow roots, and Wright and Bailey suggest that it may require seven hundred to eight hundred years to become reestablished in a burned area, As a result, more frequent large fires limit its distribution.[72] Fire scientist James Agee, however, estimates that its fire-return intervals are between three hundred and six hundred years at higher elevations and between one hundred and three hundred years in lower, drier forests. In Pacific silver fir forests, it is likely that nearly all fires were historically large, intense, and fueled by extreme drought.[73]

The lower, drier western hemlock forests likely experienced a mixed-severity fire regime before Anglo settlement. Low-intensity surface fires were frequent but burned over small areas, and very large, intense crown fires were infrequent but played a major role in shaping landscapes and determining species composition.[74] These large fires, like those in silver fir forests, were typically caused by lightning during significant summer droughts, and they were probably regulated more by weather patterns than by fuel accumulation. In western hemlock forests today, Douglas-fir trees typically dominate after logging or large fires, and they will be taken over by more shade-tolerant conifers after a few centuries.

In coastal forests containing Douglas-fir trees, as in other systems, we see the synergistic relationship between fire and fire-adapted plants. In this case, it is the native Douglas-fir that competes by carrying fire; in nearly all northwestern forests, increased

Copyrighted Material

dominance of Douglas-fir is associated with an increase in fire activity, which in turn favors it over less fire-resistant species.[75] This has interesting implications for forest management, as Douglas-fir is highly valued commercially and forms the basis of the northwestern logging industry.

The preceding examples illustrate an intriguing contradiction. We do know, within very broad parameters, where fire "belongs" and about how frequently it should occur to maintain biological diversity in many western ecosystems. We also know, again in very broad terms, the conditions under which fires are likely to occur. But the beauty, mystery, and difficulty of fire occurrence, spread, and behavior are in the details of specific sites and environmental conditions. Of course, even if we fully understood all these details, we still would not have the ability to stop large fires, just as we are unable to stop earthquakes, volcanoes, hurricanes, tornadoes, and other natural cataclysms. Nor should we want to. The environmental consequences of disrupting these large-scale processes would be catastrophic, not least for humans themselves.

Because we now recognize that most species native to the western United States evolved in cycles of periodic fire, we can draw at least two important conclusions. First, these native species have developed adaptations to fires that occur at a particular frequency and season and to a particular extent. Second, because fire is a major disruptive force in the ecosystems it affects, the maintenance or reintroduction of past fire regimes—the fire regimes with which species evolved—is likely a key to maintaining high levels of native biodiversity. Indeed, fire cycles are part and parcel of these ecosystems, just as the cycling of water and nutrients is.

Copyrighted Material

Seen from this perspective, fire is an integral component of nearly every western ecosystem.

But as the our examples illustrate, contemporary fires are often unlike the fires with which species evolved. Despite the close synergistic relationships between ecosystems and fire regimes, a century of fire suppression, timber management, the introduction of nonnative species, and countless other habitat alterations have changed the mix of species and wildland fuels in many of these systems. Before we move on to a discussion of management solutions—both successful and unsuccessful—for living with fire, we want to discuss a few of the more pervasive human influences on western fire regimes.

Copyrighted Material