Flames of the 2017 fire that destroyed part of Santa Rosa, California

13



APPLYING the 5 fundamental concepts Santa Rosa Fire of 2017

1

Science helps us predict hazards.

Wildfire is a very serious and costly natural hazard. Fortunately, fire science is a mature subject, and our ability to predict and forecast seasons with high potential for wildfires has greatly improved.

2

Knowing hazard risks can help people make decisions.

The 2017 wildfire demonstrates the risk of damage to land and property from future wildfires. Hazard reevaluation allows people to view future wildfires from a risk management perspective. In many forest and brush locations, wildfire is the greatest risk many communities face.

Wildfires

Wildfire (Tubbs Fire) near Santa Rosa, CA: October, 2017

One of the most catastrophic wildfire in Californian history occurred over a few days in early October 2017. The wildfire grew in size and intensity very fast, surprising homeowners who believed they lived beyond the fire hazard area that had been defined. People were left running or driving for their lives. About 40 people were killed. There were several fires that grew together into a much larger, more intense fire. Insured losses were about $3 billion and total damages will probably top $5 billion. The fires destroyed 5,000 homes, damaging 10,000 structures on farms and the regions wineries. At Santa Rosa entire blocks of homes burnt to the ground melting steel, aluminum, and glass. Entire automobiles melted (over 3,000 personal vehicles were lost). An important lesson learned from the fires was that the regulations to minimize the impact of fire are not adequate when urban areas burn. Santa Rosa neighborhoods well outside fire zones designated as having a mild risk burned. The density of homes was high, and each home can be considered a large bundle of fuel for fire. The fire in the urban area probably did not result from wildfire sweeping down hills into houses, but from embers blowing into the neighborhood from fire as far as 0.6 km (1 mi.) away. When wind-driven hot embers enter

< FIGURE 13.0
The Tubbs Fire (2017) burned several thousand homes including those shown here. *(Kent Porter/The Press Democrat/AP Images)*

As Earth's population grows, more people are moving into and near brushlands, forest, and other wildlands where wildfires naturally occur. This trend increases the risk of property damage and loss of life from wildfires.

After reading this chapter, you should be able to:

LEARNING Objectives

LO:1 Summarize the role of wildfire during the past 11,500 years.

LO:2 Explain why wildfire is a natural process that would occur with or without people.

LO:3 Explain why the wildfire hazard varies from region to region.

LO:4 Summarize how wildfires are linked to other natural hazards.

LO:5 Make the link between global change (warming) and the number and intensity of wildfires.

LO:6 List the potential benefits provided by wildfires.

LO:7 Evaluate the methods employed to minimize the fire hazard.

LO:8 Summarize the potential adjustments to the wildfire hazard and the role of human processes.

3

Linkages exist between natural hazards.

Wildfire is directly linked to soil erosion, flooding, and landslides, including debris flows.

4

Humans can turn disastrous events into catastrophes.

Factors such as population growth and land-use decisions result in more people living in areas with a high fire risk. For a variety of reasons, wildfires are becoming larger and more intense.

5

Consequences of hazards can be minimized.

Consequences of wildfire can be minimized but never eliminated through understanding of the fire cycle and better land-use decisions. The Santa Rosa Fire emphasized that management policies must be reevaluated if we are to minimize wildfire destruction.

homes with small openings such as unscreened roof vents or land on roofs that are old and flammable, a fire starting is very likely, especially if crawl space is used to store flammable materials. Once ignited, homes can burn extremely hot and fire is spread from home to home. Sometimes trees, swimming pools, and even trashcans were not damaged, suggesting a house-to-house pattern of fire. The Santa Rosa fire has opened many questions concerning the fire hazard of densely populated neighborhoods near wildlands where fire occurs periodically.

13.1 Introduction to Wildfire

Wildfires are one of nature's oldest phenomena, dating back more than 350 million years when trees evolved and spread across the land. Wildfire behavior changed markedly about 20 million years ago when grasses evolved. Grasses provided a new type of fuel that grew quickly and could sustain more frequent fires. Then, about 11,500 years ago (the beginning of the Holocene Epoch), when the climate warmed after the last major glacial advance, wildfire behavior intensified again. The geologic record shows a significant increase in the amount of charcoal found in sediment from this time, indicating an increase in fires. Part of this increase probably reflects activity by early humans, who used fire to clear land and assist in hunting.[1,2]

Before humans evolved, fires that were ignited by lightning strikes or volcanic eruptions would burn until they ran out of fuel or were extinguished naturally. After a fire, plant regrowth begins from roots, spores, and seeds, and the cycle starts again. This cycle is so ancient that some plants evolved to rely on and use fire to their advantage. For example, oak and redwood trees have bark that resists fire damage, and some species of pine trees have seed cones that open only after a fire. In the Mediterranean climate of Southern California, chaparral (brush) species have adapted to fire and regenerate new foliage after being burned.

Natural fires started by lightning strikes and volcanic eruptions allowed early humans to harness fire for heat, light, and cooking; these benefits of fire, in turn, helped human populations spread across continents.[1] The ability to use fire for cooking and for warmth allowed humans to expand their diet and settle in colder areas. Fires were also set to encourage new plant growth and attract game. Native Americans used fires as a tool in hunting, warfare, and agriculture. Early European settlers, including members of the famous Lewis and Clark expedition that explored North America from coast to coast, commented on the many fires set by native peoples for a variety of purposes. This practice continues today, sometimes with serious consequences.

13.1 CASE study Wildfires in the U.S. Southwest, Colorado, Arizona and California

Two destructive and deadly wildfires occurred during the summer of 2013 (see chapter-opener photograph). The first, known as the Black Forest fire, occurred outside of Colorado Springs, Colorado. The Black Forest fire burned about 6,000 ha and destroyed more than 500 homes (Figure 13.1), making it the most destructive fire in Colorado's history. Prior to the Black Forest fire, the most destructive fire had been the Waldo Canyon fire, which had burned through the Colorado Springs area just one year before, reflecting a disturbing trend in Colorado over the past few decades. Colorado wildfires in the 1970s and 1980s burned about 40,000 ha (100,000 acres) per decade, in the 1990s it was about 81,000 ha (200,000 acres), and in the 2000s the total burned area was more than 40,000 ha (100,000 acres). On a positive note, all the recent experience with wildfires enabled authorities to act quickly during the Black Forest fire, and thousands of people were safely evacuated and only two people were killed.

The second wildfire occurred near Yarnell, Arizona. Like the Colorado wildfire, this fire was a swift-moving event that burned at least 30,000 ha (8,000 acres) very quickly. Although the fire destroyed about 200 homes, the even greater tragedy was the death of 19 firefighters, part of a professional group of firefighters known as the "hotshots" often called in to fight the most serious wildfires. The fire overrode (burned through) the position of the firefighters, and their protective equipment and attempts to dig and cover in the ground were futile. Autopsies after the fire showed that the firefighters



FIGURE 13.1
Home destroyed by the 2013 wildfire near Colorado Springs, Colorado *(AP Photo/Ed Andrieski)*

died from a combination of burns, carbon monoxide poisoning (lack of oxygen), and smoke inhalation. Only one member of the 20-person crew escaped the fire, as he was moving the fire truck at the time.

Three large recent fires in California killed over one hundred people and destroyed more than 20,000 homes and other buildings. The first was the Thomas Fire in late December of 2017. The fire burned about 120,000 ha (300,000 acres) while destroying more than 1,000 homes and buildings in Southern California. Intense rain just weeks after the fire produced a catastrophic debris flow that killed 23 people in the town of Montecito. Damages from the fire and debris flow exceeded $2 billion.

Early November of 2018 brought the most damaging fire in California history. The wind-driven Camp Fire burned about 19,000 buildings (most in the first few hours of the fire). Nearly the entire town of Paradise in northern California was destroyed, killing more than 80 people. The fire burned about 62,000 ha (150,000 acres).

Estimated total losses are as high as $10 billion. The third fire, also in early November 2018, was in Southern California and burned about 39,000 ha (97,000 acres), including parts of Malibu. Named the Woosley Fire, flames destroyed about 1,600 homes and killed three people, while causing about $5 billion in damages. The three fires together caused about $15 billion in damages, prompting the evacuation of hundreds of thousand of people while taking an unprecedented number of lives. These fires are promoting fire scientists to rethink what we know about fires near urban areas and how best to limit future damages, and loss of life.

13.1 CHECK your understanding

1. How has the nature of wildfires and human interaction changed over geologic and historic time?
2. Why are recent wildfires in the United States so damaging?

13.2 Wildfire as a Process

Wildfire is a self-sustaining, rapid, high-temperature biochemical oxidation reaction that releases heat, light, and other products.[1,2] This reaction requires three things—fuel, oxygen, and heat—that are sometimes visualized as a fire triangle (Figure 13.2). For the chemical reaction to proceed, a fire must have appropriate fuel, adequate oxygen, and external heat that is high enough to start the reaction. If any one of the three requirements of this triangle is removed, the fire goes out.

Wildfires typically burn at the forest floor with temperatures of 200–1000°C (450–2000°F), but hot spots may exceed 1500°C (2700°F) which melts glass and aluminum and steel. Wood bursts into flames at about 300°C (570°F). At the temperatures of wildfire, plant tissue and other organic material (biomass) are rapidly oxidized and broken down by combustion, or burning. Grass, brush, and forestlands burn because, over long periods of time, these systems establish a balance between plant productivity and decomposition. Microbes alone do not decompose plants fast enough to balance plant growth, so wildfire helps in this decomposition. Therefore, in a sense, the primary cause of fire is vegetation, which has removed carbon dioxide from the atmosphere to produce organic matter by photosynthesis.[3,4]

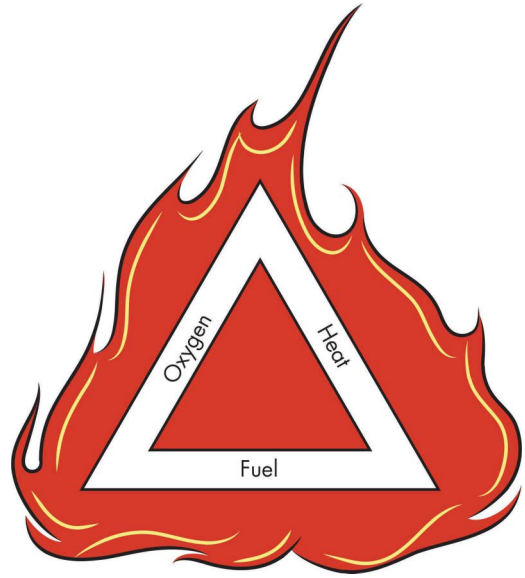


FIGURE 13.2 The Fire Triangle
If any part of this triangle is missing, a fire cannot start; likewise, if any part of the triangle is removed, the fire goes out. *(Based on Cottrell, W. H. Jr,* The Book of Fire, *2nd ed. Missoula, MT: Mountain Press, 2004.)*

Fire, like the rotting or decomposition of dead plants by bacteria, essentially reverses the process of photosynthesis. In this simplified view of wildfire, carbon dioxide, water vapor, and heat are released when plants burn. Actual combustion, however, is complex and releases numerous chemical compounds in solid, liquid, and gas form. Of the gases released, carbon dioxide and water vapor are the most abundant; other gases occur in trace quantities.[1] Common trace gases released are nitrogen oxides, carbonyl sulfide, carbon monoxide, methyl chloride, and hydrocarbons such as methane.[4] These gases, along with solid particles of ash and soot, comprise part of the smoke observed during a wildfire. Both ash and soot

are powdery residues that accumulate after burning. Ash consists primarily of mineral compounds, and soot is made of unburned carbon.

The image of flames and smoke is accurate as a mental picture of wildfire, but a closer look reveals three phases of a wildfire:

1. Preignition.
2. Combustion.
3. Extinction.

In the first phase, *preignition*, fuel is brought to both a temperature and a water content that favors ignition. Preignition involves two processes: preheating and pyrolysis.

In preheating, the fuel loses a great deal of water and other volatile chemical compounds. A *volatile compound* is one that is easily vaporized to a gas. For example, because gasoline contains many volatile chemical compounds, spilled gasoline evaporates quickly to a vapor that you can smell.

The other important process of preignition is **pyrolysis**, which literally means "heat divided." Pyrolysis is actually a group of processes that chemically degrade the fuel. Degradation takes place as heat divides, or splits, large fuel molecules into smaller ones. The products of pyrolysis include volatile gases, mineral ash, tars, and carbonaceous char.[1,2] You have probably caused pyrolysis unintentionally. Pyrolysis takes place when you scorch a piece of toast and turn it black. The burnt toast is covered with char, and smoke coming out of the toaster contains small black droplets of tar. A similar result occurs when you scorch cotton fabric with a hot iron. The processes of preignition—preheating and pyrolysis—operate continuously in a wildfire. Heat, radiating from flames, causes both preheating and pyrolysis in advance of the fire. These processes produce the first fuel gases, which can ignite in the next phase of a fire.

The second phase, **combustion**, begins with ignition. Combustion marks the start of a set of processes completely different from those related to preignition. Preignition processes absorb energy. In the combustion phase, external reactions involving flaming or glowing liberate energy in the form of heat and light.[2] Although there are many sources of ignition, such as lightning, volcanic activity, and human action, ignition does not automatically lead to a wildfire. In fact, many more ignitions occur than do full-blown wildfires because a wildfire will not become established unless sufficient fuel is present. Wildfires develop when vegetation is mature and has accumulated in sufficient quantities to carry fire across the land.[3] Ignitions are common at a time scale that is relevant for mature grass, brush, or forestlands; in a period of 50 to 100 years, nearly every acre of land is struck by lightning. On this time scale, wildfires set by humans are not nearly as relevant. If a person starts a large wildfire, he or she is simply preceding a lightning strike that would soon cause the fire anyway. Once wildfire has crossed an area and most of the vegetation has been destroyed, the low fuel supply reduces future wildfires, even with an ignition source such as lightning. Fire will not threaten again until there is sufficient new fuel. This argument is contrary to twentieth-century fire management concepts, which commonly held that only people could prevent forest fires. On an ecological time scale, we have seen that fires will occur whether or not people start them, and humans play a relatively minor role in affecting large wildfires.

During a wildfire, ignition is not a simple or single process but rather a continuum of processes marked by an acceleration of the pyrolysis that began in the preignition phase (Figure 13.3). Most people think of a wildfire as having a single ignition that starts the fire. Actually, ignition repeats time and time again as a fire moves, like sparks and embers popping out of a fireplace, campfire, or barbeque grill. The dominant types of combustion are flaming combustion and glowing or smoldering combustion (Figure 13.3). These two types of combustion are distinct from each other in that they proceed by different chemical reactions and have different appearances. Flaming combustion is the rapid, high-temperature conversion of fuel to thermal energy and is characterized by a large amount of residual unburned material. With wildfire, flaming combustion dominates during the early stages of a fire as fine fuel and volatile gases produce rapid oxidation reactions. These reactions sustain flames as the fire advances across the landscape. As volatile gases are removed from the fuel, woody materials continue to decompose through pyrolysis, and carbon and ash begin to blanket new fuel. This blanket of noncombustible material can hinder flaming combustion and lead to glowing or smoldering combustion instead. This glowing or smoldering combustion takes place at lower temperatures and does not require rapid pyrolysis for its growth. The ultimate product of glowing or smoldering combustion can be charcoal.

As wildfire moves across the landscape, three processes control the transfer of heat, and as topography and wind direction change, the zone of flaming combustion can take on several forms (Figure 13.4). The three primary ways by which heat is transferred are *conduction*, which is the transmission of heat through molecular contact; *radiation*, heat transfer though electromagnetic waves; and *convection*, heat transfer by the movement of heated gases driven by temperature differences in a fluid, such as air. In Chapter 9, you

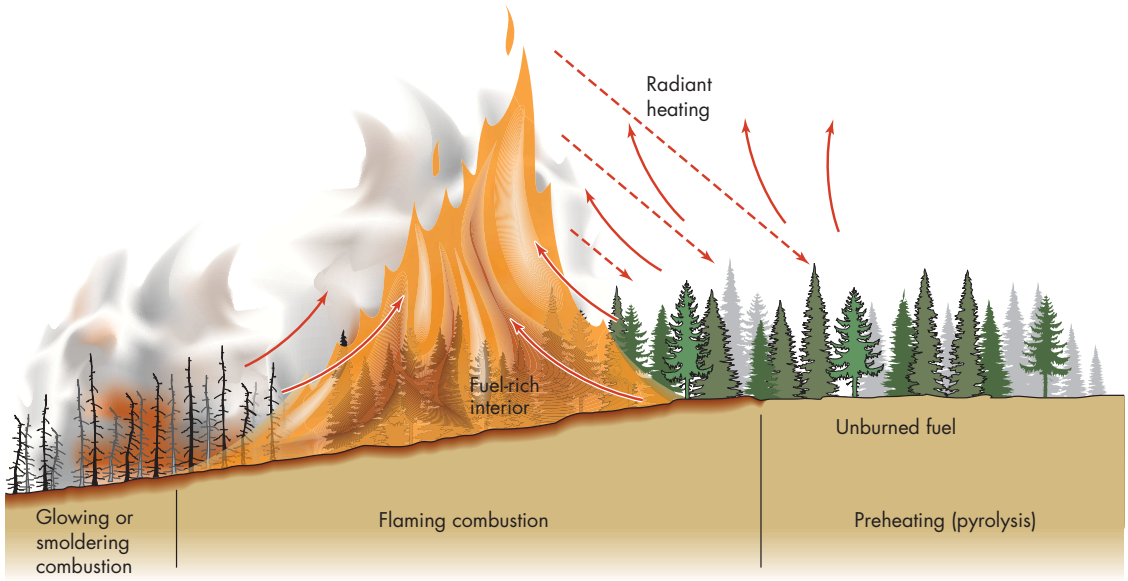


FIGURE 13.3 Parts of a Wildfire
Idealized diagram of an advancing wildfire showing phases of a wildfire: (1) an area of pyrolysis where unburned vegetation is preheating, (2) an area of flaming combustion with rising air currents, and (3) an area of glowing or smoldering combustion. Fire is advancing from left to right. Solid arrows indicate motion of air currents and dashed lines show radiant heating from the fire. *(Modified after Ward, D. 2001. Combustion chemistry and smoke. In* Forest fires: Behavior and ecological effects*, ed. E. A. Johnson and K. Miyanishi, pp. 55–77. San Diego, CA: Academic Press.)*

learned that convection is a dominant process in atmospheric transfer of heat. Wildfires also transfer heat primarily by convection, although radiation, which generates radiant heat, also plays a role (Figure 13.4). Transfer of both convective heat and radiant heat increases the surface temperature of the fuel. As heat is released, the air and other gases become less dense and rise. In wildfires, the oxidation chemical reaction in the fire releases heat, and this heat is transferred by convection of the air. The rising air and other hot gases remove both heat and combustion products from the zone of flaming. This process shapes the fire as it pulls in fresh air that is needed to sustain combustion.[2] Convection, thus, aids in continually providing the fire with oxygen.

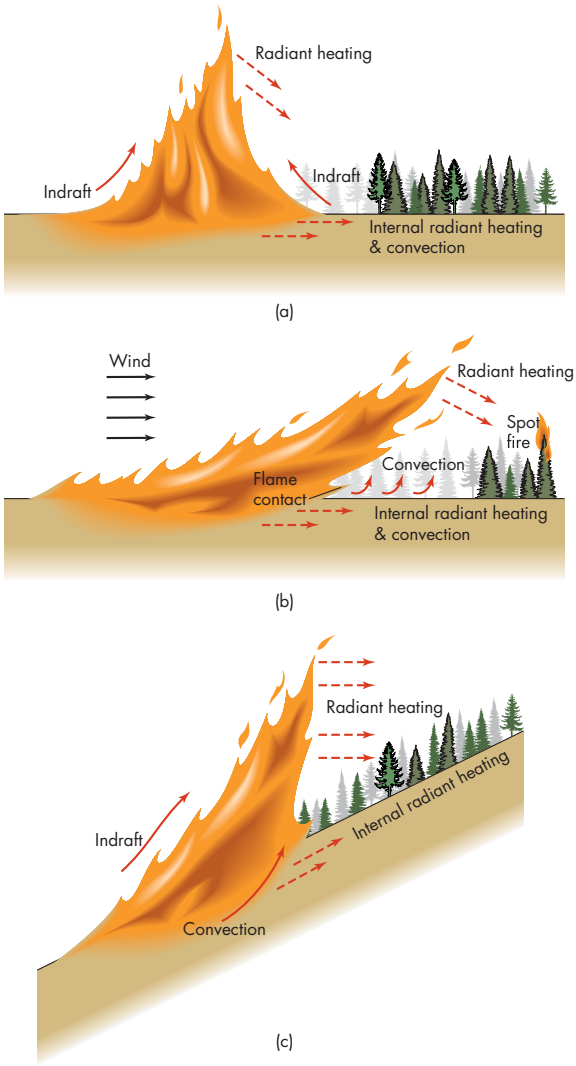
Finally, *extinction* is the point at which combustion, including smoldering, ceases. When there is no longer sufficient heat and fuel to sustain combustion, the fire is considered extinct.

FIRE ENVIRONMENT

The behavior of a large wildfire can be explained by three factors in its environment: fuel, topography, and weather (Figure 13.4). With sufficient information concerning these three factors, we can better understand and predict wildfire behavior.[3,5,6]

Fuel Wildfire fuels are complex and differ in type, size, quantity, arrangement, and moisture content. Types of fuel include leaves, twigs, and decaying material on the forest floor; grass and shrubs of various size; small trees; large woody debris; and large, living trees. Where forests, swamps, bogs, or marshes are underlain by soils with high organic content, the fuel for a wildfire can also include underground accumulations of *peat*, an unconsolidated deposit of partially decayed wood, leaves, or moss.

The size of the fuel can influence ignition, as well as how rapidly a fire moves. Finer fuels, such as grass and pine needles, burn more readily than large woody material. For example, if disease or a storm downs a large number of trees, after 15 to 30 years or so, the larger pieces of wood may dry out and become partly decayed, allowing them to sustain combustion during a wildfire. Fuel arrangement can also be important. Landslides, tornadoes, and hurricanes arrange downed woody debris in clumps or accumulations in various parts of the landscape.[6] Finally, during droughts, even organic-rich swamp and marsh soils, which are usually saturated with water, dry out and become fuel for wildfires. These fires, commonly referred to as *peat fires*, burn slowly and can last for many months.



▲ FIGURE 13.4 Influence of Wind and Topography on Wildfires

Idealized diagrams of flame shape and processes associated with a spreading fire under three conditions: (a) flat topography and no wind, (b) flat topography with wind, and (c) hillslope topography where slope drives fire uphill. Solid red arrows indicate motion of air currents, and dashed red lines show radiant heating from the fire. *(Based on Rothermel, R. C. 1972. "A Mathematical Model for Predicting Fire Spread in Wildland Fuels," U.S. Forest Service Research Paper INT-115)*

Topography Topography can have a profound effect on fire for several reasons. First, the moisture content of fuel is influenced by its location on the landscape. In the Northern Hemisphere, south-facing slopes are relatively warm and dry because they face the sun for a longer period of time. Thus, fuel on a south-facing slope is typically drier and burns more easily. Topography also influences air circulation. Slopes exposed to prevailing winds tend to have drier vegetation than do slopes sheltered from the wind and, thus, are more prone to combustion. Also, in mountainous areas, winds tend to circulate up canyons during the daytime, providing an easy path for wildfires. Finally, once a fire starts, topography can strongly influence its movement. Wildfires burning on steep slopes tend to preheat fuel upslope from the flames (Figure 13.4c). This makes it easier for a fire to move upslope and often causes it to spread more rapidly in that direction. Fires may also advance downslope, especially if they are driven by the wind.[6]

Weather Weather, especially temperature, precipitation, relative humidity, and wind, has a dominant influence on wildfire. Large wildfires are particularly common following droughts that reduce fuel moisture content. Hot, dry conditions associated with drought, as well as with summers in the southwestern United States, lead to the formation of "dry thunderstorms." During these storms, rain evaporates before it reaches the ground and is not available to extinguish fires started by lightning. Changes in relative humidity, even during a single day, influence the moisture content of fuel and how fast a fire burns. Wildfires burn more vigorously when relative humidity is at its lowest point, generally during the midafternoon.[2] Finally, winds greatly influence the spread, intensity, and form of a wildfire. Strong winds and changing wind conditions help a fire preheat unburned fuel in the surrounding area. Winds can also carry burning embers away from a wildfire to ignite *spot fires* well ahead of the flaming front (see Figure 13.4b).[6]

The influence of weather on fires was dramatically illustrated during the 1998–2002 drought in Florida, one of the worst in the state's history (Figure 13.5).[7] Hot, dry conditions during the drought reduced fuel moisture in swamps and wetlands. This resulted in wildfires in normally wet bald cypress swamps and grassy marshes, in addition to the more typical fires in upland pine/oak forests and scrublands. These wetland fires included the Mallory Swamp Fire in 2001, which burned more than 250 km^2 (~62,000 or 97 $mi.^2$) of swamp and commercial woodland west of Tallahassee, and the Deceiving Fire in 1999, which charred 700 km^2 (~173,000 acres or 270 $mi.^2$) of marsh in the Everglades and surrounding upland near Miami.[8] The name "Deceiving" was given to the fire because changing wind directions continually shifted its movement.[7] Smoke from the Deceiving Fire closed I-75 (Alligator Alley), the main east–west highway across southern Florida, for several weeks and drifted into Miami, where cars had to drive with headlights on in the middle of the day.[7] Windblown smoke was also a major problem in



FIGURE 13.5 Drought Contributes to Florida Wildfires
During the 1998–2002 drought, over 25,000 wildfires burned more than 6100 km^2 (~1.5 million acres or 2300 $mi.^2$) in Florida. Fires burned parts of the Everglades in south Florida and Mallory Swamp in north-central Florida. *(MIKE EWEN KRT/Newscom)*

2001, when it smothered central Florida theme parks, including Walt Disney World; closed I-4, the main east–west route across central Florida; and caused a 20-vehicle accident.[8,9]

TYPES OF FIRES

Wildfire scientists and firefighters classify fire behavior according to the layer of fuel that is allowing the fire to spread. Although there are three fire types—ground, surface, and crown—most fires are complex blends of all three. *Ground fires* creep along slowly just under the ground surface with little flaming and more smoldering combustion (Figure 13.6). In forests, these fires burn in *duff*, decaying organic matter in the soil, and in drained or temporarily dry swamps and marshes and in thicker peat deposits below the soil.



FIGURE 13.6 Ground Fire
A ground fire burns roots and some surface vegetation. Commonly, there is more smoldering combustion than flame. *(© Getty Images/Anadolu Agency/Contributor)*

Surface fires, which move along the ground, may vary greatly in their intensity, that is, the amount of heat energy released by the fire (Figure 13.7). Low-intensity surface fires burn grass, shrubs, dead and downed limbs, leaf litter, and other biomass. They burn relatively slowly with glowing or smoldering combustion and limited flaming combustion. Some surface fires, however, such as those in the Mediterranean (dry summer subtropical) climate of Southern California that burn chaparral brushlands, can be extremely intense and release large amounts of heat energy as they move swiftly across a landscape.

Finally, *crown fires* are those in which flaming combustion is carried through the canopies of trees (Figure 13.8). Crown fires may begin when a surface



FIGURE 13.7 Surface Fire
A surface fire, such as this one in a ponderosa pine forest, burns low vegetation rather than the upper part of tall trees. *(Kent Dannen/Science Source)*



FIGURE 13.8 Crown Fire
Crown fires burn the upper part of tall trees. They sometimes spread ahead of the fire on the surface. In 1995, high winds turned this crown fire, the Green Mountain Fire on Mount Lemmon outside of Tucson, Arizona, into a firestorm. *(A.T. Willett/Alamy)*

fire moves up trunks into limbs of trees through various layers of fuel, or it may spread independently of surface fires. Large crown fires are generally driven by strong winds and are often aided by steep slopes. Such fires will grow and expand as long as conditions for combustion are favorable. Large wind-driven crown fires are nearly impossible to stop; humans and other animals need to evacuate from their path.

13.2 CHECK your understanding

1. Define wildfire.
2. How are wildfires related to plant photosynthesis and decomposition?
3. What are the major gases and solid particles produced by a wildfire?
4. What are the three requirements for fire to start and for combustion to continue? What happens when one of these requirements is removed?
5. Describe the three phases of a wildfire.
6. Explain how processes in the preignition phase prepare plant material for combustion.
7. What are sources for the initial ignition of wildfires? How often does ignition occur?
8. Explain how the two types of combustion differ. How do the processes of combustion differ from those of ignition?
9. What are the three processes of heat transfer in a wildfire?
10. Link the types of fuel to wildfire behavior.
11. How does topography influence a wildfire?
12. Describe the weather conditions that are most favorable for wildfires.
13. Describe the three types of fire.

13.3 Geographic Regions at Risk from Wildfires

Wildfires in the United States burn 2 to 5 million acres (~8,000 to 20,000 km^2) per year, comparable to the area of New Jersey. The vast majority of wildfires are in the western USA where there are large forests and brushlands. Another hot spot for wildfire is southern Florida where there are abundant forests and grasslands.[10]

Most areas of the United States and Canada that are within or in close proximity to grasslands, shrublands, woodlands, or tundra are at risk for wildfires during dry weather or drought conditions. Even the sparsely vegetated Sonoran Desert in Arizona, rainforests in the Pacific Northwest, Hawaii, and Puerto Rico, and normally wet marsh and swamplands in the southeastern United States, Alaska, and Canada can experience wildfire. Large wildfires, however, are most common in Alaska and the western contiguous United States (Figure 13.9), in the Canadian Rockies, and in a belt that extends from Canada's Yukon Territory southeast to Lake Superior and then east to Labrador.[11,12] The geographic region at greatest risk for wildfires shifts from year to year due to factors such as weather conditions and fuel availability.

13.3 CHECK your understanding

1. Which North American regions are most vulnerable to wildfire?
2. Why does the wildfire risk shift from year to year?

13.4 Effects of Wildfires and Linkages with Other Natural Hazards

Wildfires affect many aspects of the local environment: They burn vegetation, release smoke into the atmosphere, char soil, create favorable conditions for landslides, increase erosion and runoff, and harm wildlife. Although we may primarily be concerned with the effects a fire has on the local biota of a region, it is important to consider the changes that may also occur in the geologic and atmospheric environments.

EFFECTS ON THE GEOLOGIC ENVIRONMENT

Wildfires have differing effects on soils, depending on the type and moisture content of the soil and the duration and intensity of the fire. The amount and intensity of precipitation after a fire also play a role in determining how a wildfire affects the soil.[13]

Extremely hot fires that scorch dry, coarse soil in semiarid brushlands, such as southern California, may leave a nonwettable, or water-repellent, layer—called a **hydrophobic layer**—in the soil. Water repellency is caused by an accumulation of water-repellent chemicals in the lower layers of debris on the forest or brushland floor. These chemicals are derived from the burning vegetation and penetrate the soil as a gas that, when cool, forms a "waxy" substance that coats soil particles (Figure 13.10).[2] This water-repellent layer in the soil increases surface runoff and, thus, erosion because

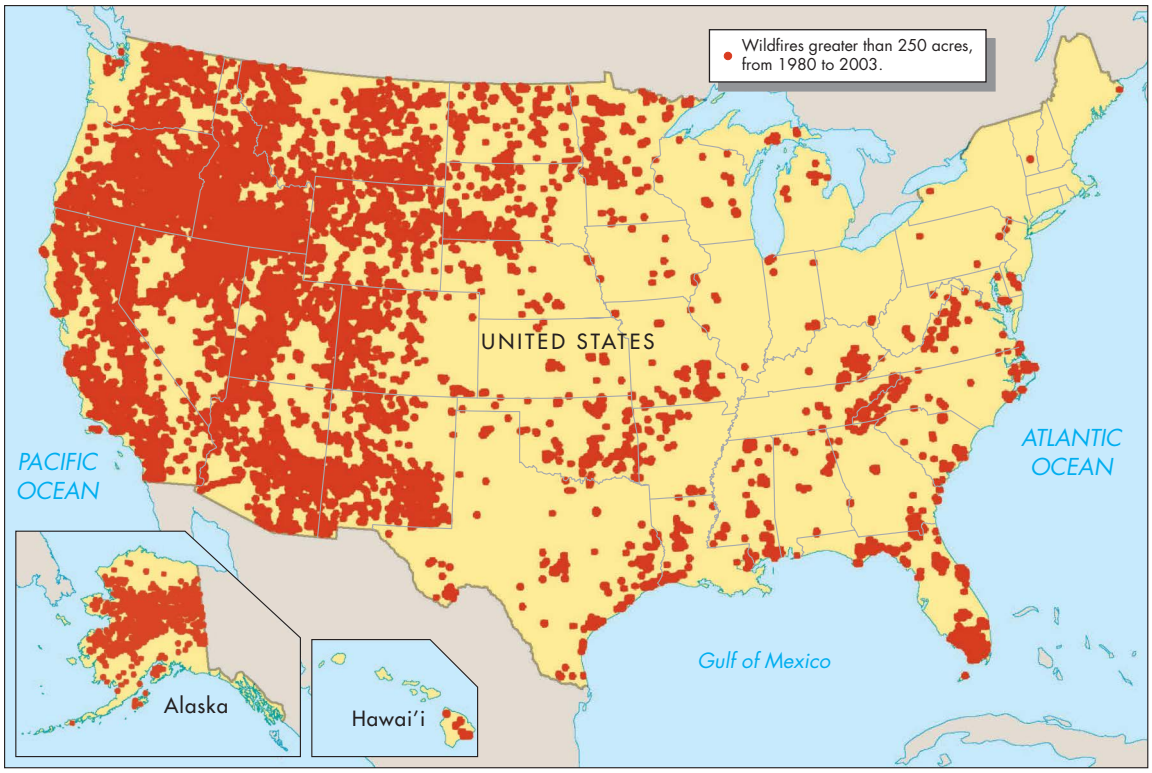


FIGURE 13.9 Alaska and Western Contiguous States with Greatest Wildfire Hazard
Map depicts areas of the United States that experienced wildfires greater than 1 km^2 (~250 acres or 0.4 $mi.^2$) from 1980 to 2003. There were no fires of this size in Puerto Rico during this time period. *(U.S. Geological Survey)*

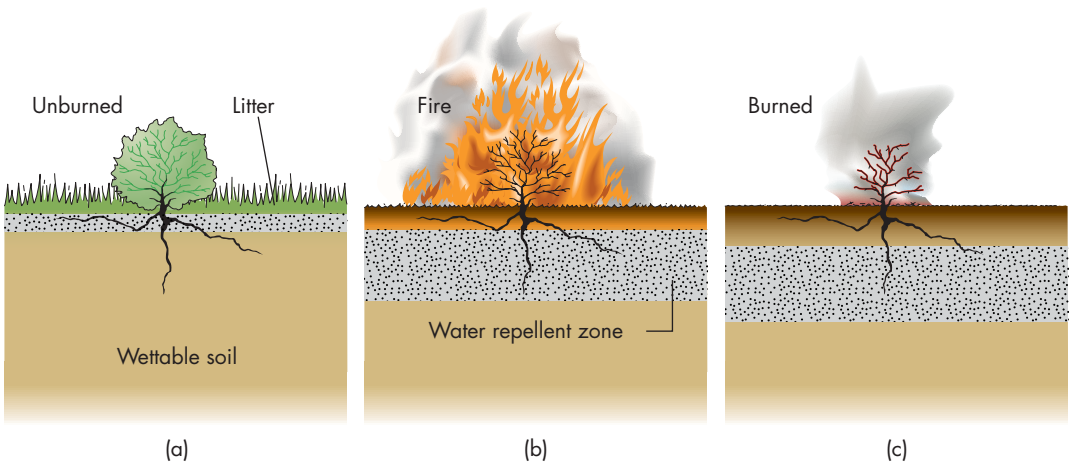


FIGURE 13.10 Effect of Fire on Water-Repellent Soil
Idealized diagram showing the response of a water-repellent soil layer to fire. A water-repellent layer normally resides under the litter layer, atop wettable soil. During a fire, the vegetation and leaf litter are burned, and the water-repellent layer moves downward. After the fire has passed, the water-repellent layer remains at depth, and wettable soil lies above and below it. *(Based on DeBano, L. F., "Water Repellent Soils: A State-of-the-Art Review," U.S. Forest General Technical Report PSW-46, 1981 in Pyne, S. J., Andrews, P. L., and Laven, R. D.,* Introduction to Wildland Fire, *2nd ed. New York: John Wiley & Sons, Inc., © 1996)*

the burned surface now lacks vegetation to anchor the loose soil above the hydrophobic layer. Water flows rapidly over a water-repellent layer, just like water down a raincoat. Loose soil at the surface is easily saturated and then moved by the water.[14] The presence of hydrophobic layers in soils may increase the flood hazard in burned areas for several years following a fire until the layer decays.

Soil erosion and landslides, including debris flows (a fast flow of water and sediment confined to a channel; see Chapter 7), are common following wildfires. Areas naturally subject to erosion commonly experience an increase in erosion rates for a few years after a fire, whereas areas that normally experience little erosion show less increase after a fire.[2] Erosion and landslide problems are significantly increased on steep slopes charred by a severe burn. Steeper slopes tend to have a greater erosion problem to begin with, and the removal of anchoring vegetation only adds to the erosion potential.

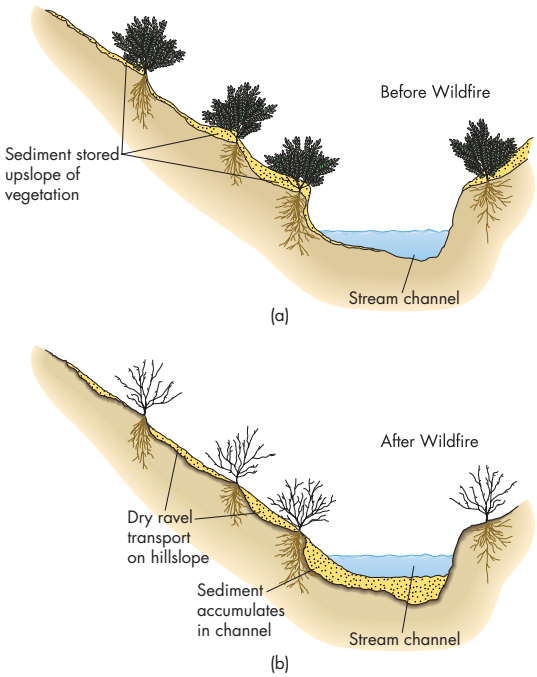
Precipitation helps trigger landslides, and this effect is exaggerated in a burned area. Heavy rains following a fire may significantly increase the number of landslides. Wildfires in California in 1997 denuded vegetation from many slopes before the winter rains intensified by the El Niño effect. Of 25 burned areas that were mapped by the U.S. Geological Survey, 10 produced debris flows during the first winter storm.[15] On other slopes, sediment was flushed through streams and rivers because the rate of sediment erosion on burned slopes was greatly increased. Wildfire in Southern California is different from forest fires insofar as the dominant vegetation is often a type of shrubland known as chaparral rather than tall trees. Southern California is also home to millions of people who live on the edge of or within areas that have a significant wildfire hazard.

How likely are catastrophic floods and debris flows following wildfire in Southern California? We can't answer this question precisely because the historical record is short, and the time between wildfires, their *return interval*, is about 40 years. However, if catastrophic flooding and debris flows generally are responses to intense rainfall after a very large wildfire, then the return period at a particular site is probably several hundred to several thousand years. This estimate assumes that the probability of intense precipitation in the first year following a fire is low.

Although catastrophic flooding and large debris flows certainly do not follow every fire, flushing (scouring and downstream transport) of sediment from stream channels is common. Following the 1985 Wheeler Fire and the 1990 Painted Cave Fire (both in southern California), scientific studies documented the flushing of sediment from small burned watersheds.[16,17]

In Southern California and, probably, in most similar settings, sediment moves downslope in dry weather following a wildfire. This gravity-driven process, known as **dry ravel**, moves a large volume of sand, gravel, and organic material that was stored upslope of brush vegetation before the fire (Figure 13.11a, b). Much of this material accumulates at the base of the slope or in adjacent stream channels. Other material that remains on the slope is often easily washed downslope in the first rainfall event after a fire because the water-repellent layer is now deeper below the surface (see Figure 13.10). The voluminous amount of material that moves downslope from dry ravel or surface runoff subsequently clogs stream channels with sediment (Figure 13.12a, b). In a second moderate rainstorm and stream-flow event, this sediment is flushed from the channel, leaving it much as it was before the fire (Figure 13.12c). This process is called **sediment flushing**. Less sediment was available on the hillslopes in the small watershed, and the stream flow was sufficient to transport the available sediment and also scour the channel. Less often, large catastrophic debris flows may be produced when intense precipitation of sufficient duration falls on burned slopes with abundant coarse debris. Figure 3.11c shows a part of the catastrophic 2018 Montecito debris flow that filled and destroyed homes. The large boulders were easily transported by the debris flow because the density of the boulders and mud matrix of the viscous, fast-moving flow are close to the same. Observers reported the boulders bobbed along near the top of the flow. The Montecito debris flows mostly came down three channels and spread out on the flatter land below the mountain where the flows originated. The flows closed the main highway along the coast for several weeks, killed 23 people and damaged or destroyed about 200 homes. The flows occurred within minutes following a 5-minute burst of 14 mm (0.54 in.) of intense rain that seemed to observers like a waterfall. The flow happened so fast that some people were trapped. There was an evacuation notice, earlier, but many people had just returned from a two-week or more evacuation order for the Thomas Fire. They probably had evacuation fatigue, and did not know what a debris flow was. As a result, not all people evacuated.

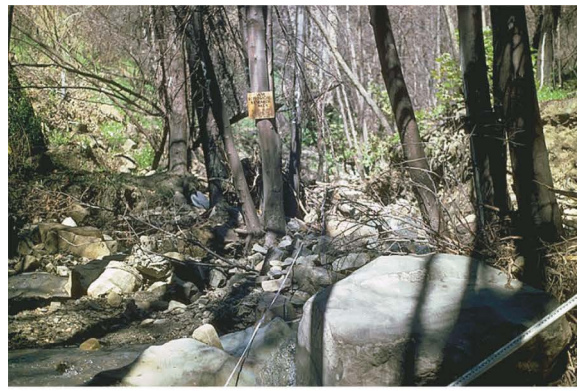
Studies of wildfire in Southern California brushland have shown that fire is only the first half of an event that alters the environment. There is often a one–two punch. Following a fire (first punch), runoff and erosion often increase (the second punch), even in response to rather modest rainfall. The result is often sediment flushing of gravel-sized particles. Engineering solutions are often used to mitigate the high rates of sedimentation that can occur following a wildfire.




(c)

▲ FIGURE 13.11 Debris Flows and Sedimentation after Wildfires

(a) Sediment stored on hillslopes between fires is trapped upslope behind chaparral vegetation stems. (b) After fire burns the stems, sediment moves downslope by the process of dry ravel and accumulates in irregularities on hillslopes or in channels. Moderate stream flows later flush the sediment from the channel. (c) Catastrophic debris flow in early January of 2018 in Montecito, CA. The flow killed 23 people and destroyed or damaged about 200 homes. Large boulders were easily carried near the top of the debris flow as the density of the boulders is only about 25 percent greater than that of the fast-moving, viscous mud-matrix that caries the flow. Thus, large boulders appear to float and bob in the flow, looking like corks on water. *(a and b: modified from Florsheim, J. L., Keller, E. A., and Best, D. W. 1991. Fluvial sediment transport in response to moderate storm flows following chaparral wildfire, Ventura County, southern California.* Geological Society of America Bulletin*, 103: 504–11; c: Edward A. Keller.)*


(a)


(b)

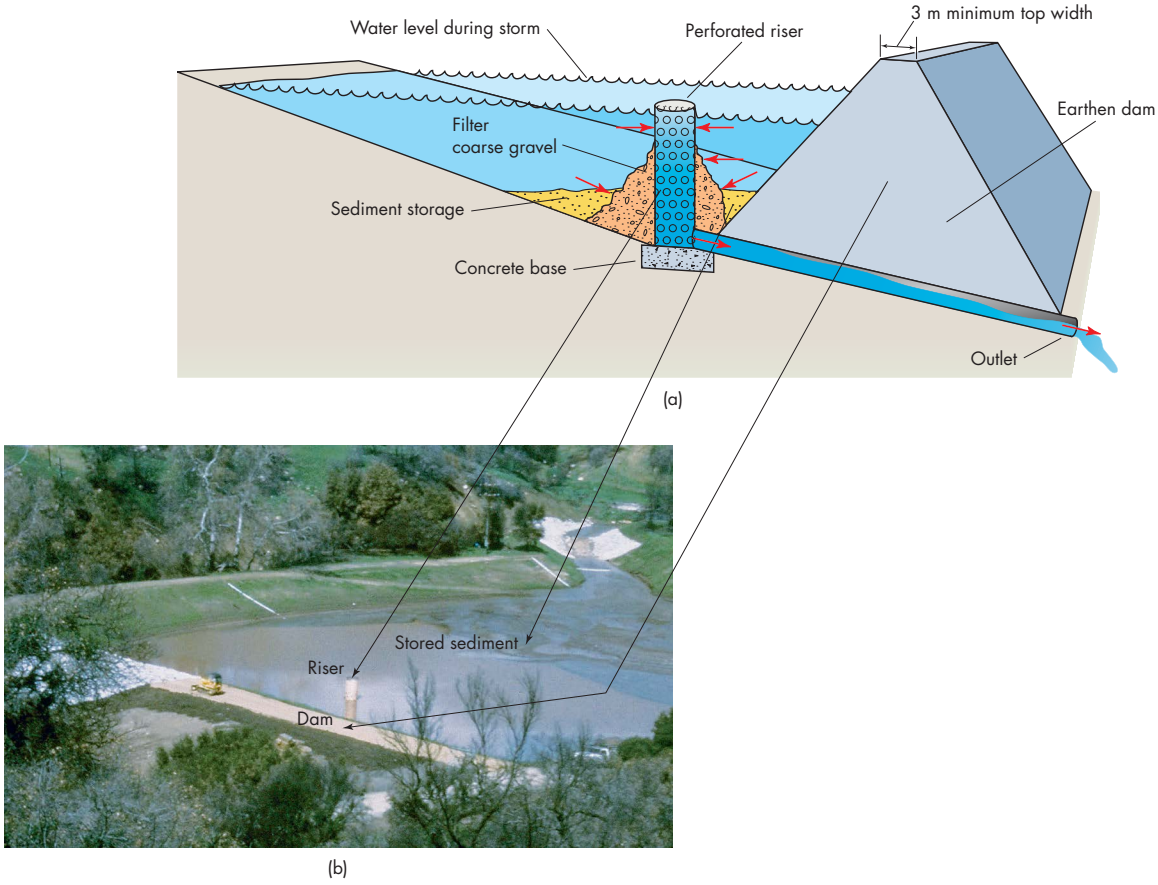

(c)

▲ FIGURE 13.12 Increased Sediment in Streams

(a) A small stream channel in Southern California shortly after a wildfire that burned vegetation in the drainage basin. Some trees near the channel survived the fire. *(Edward A. Keller)* (b) The scene after the first winter rainstorm. Note the voluminous amount of sediment deposited. *(Edward A. Keller)* (c) The same stream channel after a second winter rainstorm scoured the channel, removed much of the deposited sediment, and returned the channel to a shape that is similar to its shape before the fire. *(Edward A. Keller)*

Sediment control basins are constructed at the mouths of canyons to catch sediment flushed from stream channels, as well as debris flows. These basins, sometimes known as debris basins, have been constructed on many streams in Southern California (Figure 13.13a). For example, a debris basin was constructed following the Painted Cave Fire of 1990 near Santa Barbara, California (Figure 13.13b). Sediment was flushed from stream channels in the winter following the fire, and the debris basin trapped approximately 23,000 m^3 (~30,000 $yd.^3$) of sediment that otherwise would have been transported downstream, where it would have reduced the carrying capacity of the stream channel and increased the flood hazard.

Also, important to understanding wildfire in Southern California is reconstructing fire history for grassland, brush, and forest ecosystems. European settlers living in the Los Angeles area prior to the twentieth century were not, evidently, very concerned about wildfires that periodically burned for months in the mountains. This attitude changed as agriculture and urbanization transformed the land. As early as 1892, it was recognized that fire suppression was a potential management tool to preserve native vegetation in order to control erosion and flooding. This recognition led to the idea of setting small, controlled fires to reduce excessive accumulation of fuel and, thereby, reduce the risk of large, catastrophic wildfires.[18–20] However, large, catastrophic wildfires



▲ FIGURE 13.13 Sediment Control Basin

A sediment control basin can mitigate the effects of increased erosion and sedimentation after a wildfire. (a) Cross-section of a sediment control basin. Sediment carried by storm water settles out in the basin, while the water filters through loose gravel into a riser, where it then drains through a pipe to an outlet. Accumulated sediment is periodically removed mechanically. Red arrows indicate direction of water flow. *(Based on DeBano, L. F, "Water Repellent Soils: A State-of-the-Art Review," U.S. Forest General Technical Report PSW-46, 1981 in Pyne, S. J., Andrews, P. L., and Laven, R. D.,* Introduction to Wildland Fire, *2nd ed. New York: John Wiley & Sons, Inc., © 1996)* (b) A sediment basin constructed to trap sediment that eroded after a wildfire in Southern California. *(Edward A. Keller)*

occur during periods of warm weather and high winds when suppression of fire is nearly impossible. Therefore, prescribed burns to reduce the fuel load of Southern California brushlands are not likely to be successful in reducing or stopping a catastrophic wildfire and resulting debris flows.[18]

EFFECTS ON THE ATMOSPHERIC ENVIRONMENT

In the short term, large wildfires create their own clouds (Figure 13.14) and release smoke, soot, and invisible gases that contribute to air pollution. Smoke and soot significantly increase the concentration of very fine particles, referred to as *particulates*, in the atmosphere. This increase can be observed thousands of miles downwind of large, long-lasting fires. Several times during the past decade, fires burning in Mexico, Guatemala, and other countries in Central America have increased particulates in Texas and other parts of the southern United States, causing some cities to violate federal Clean Air Act standards. Smoke plumes from large wildfires can be easily seen from space and are now regularly monitored from satellite images. The information provides real time data on the type of fire—fast-moving surface or crown (flaming) or slow-moving ground (smoldering); the size; the intensity; and the amount and types of particles and gasses being emitted. The analysis can be used to help direct firefighting activities, as well as to decide if a fire may be too intense and fast moving to fight and control.[21]



FIGURE 13.14 Smoke from Forest Fire Creates Clouds
Helicopter water tanker takes off with 3800 liters (1000 gallons) to fight the Hayman Fire in Colorado. Large pyrocumulus clouds formed over the fire and grew to an estimated height of 6400 m (~21,000 ft.). *(FEMA)*

Wildfires can also contribute to the formation of smog through the release of large quantities of carbon monoxide, volatile organic compounds, and nitrogen oxides. In the presence of sunlight, these gases form harmful ground-level ozone. The significance of wildfires adding to global air pollution was demonstrated in an international study of gases released in central Alaska and the Yukon Territory of Canada during wildfires in 2004. Wildfires in these areas burned more than 45,000 km^2 (~11 million acres or 17,000 $mi.^2$) of coniferous forest and organic soil, a land surface equivalent to New Hampshire and Massachusetts combined.[22] Using satellites and computer models, atmospheric scientists estimated that these fires increased ozone levels in parts of Canada and the northern United States by 25 percent and up to 10 percent in Europe.[22,23]

On a much larger scale, wildfires and fires set by humans in Indonesia and Malaysia in 1997 and 1998 created smog conditions that affected millions of people in Southeast Asia. The favorable conditions for these fires in Southeast Asia were created by an El Niño climate event in the Pacific Ocean. Thus, wildfires have both short-term interactions with weather and long-term interactions with climate.

LINKAGES WITH CLIMATE CHANGE

One projected effect of climate change in this century is an increase in the intensity and frequency of wildfires. This increase may be brought about by changes in temperature, precipitation, and the frequency and intensity of severe storms. It may also be linked to biological changes that have taken place in the type and quantity of fuel available for wildfires. Some of these changes may already be underway in the western United States and Canada.[24,25] For example the wildfire, known as "The Beast" and formally called the Fort McMurray Fire, began on May Day 2016. The cause of the fire is believed to be due to someone who visited a remote trail system and probably started the blaze. Fort McMurray is a boomtown that grew to a pre-fire urban population of about 88,000 people in the rush to develop the vast petroleum resources of the Alberta oil sands. The area is basically an enormous industrial complex built in a forest ecosystem. The advent of increased population resulted in more people recreating in the fire-prone forests near Fort McMurray, and the number of fires in that area increased significantly in the past 50 years. The fire when first noticed was very small, but it exploded in area quickly and eventually burned about 5900 km^2 (2300 $mi.^2$). Over 80,000 people were evacuated between May 3 and June 1, 2016 in Fort McMurray and surrounding areas. About 2,500

buildings were destroyed, as were over 600 work camps that were mostly associated with the oil sand operations. Total losses were about $10 billion. Global temperature records were broken in several years prior to the fire, including 2015 and 2016. Increasing temperature and drought, with a predicted decrease in return period (time between fires) and increase in intensity of wildfires in the future, led some to suggest that the Fort McMurray Fire is an example of wildfire linked to climate change. Global warming is a symptom of climate change. Other symptoms include change in precipitation patterns, volume, and intensity that are also linked to wildfire, sometimes in complex ways. The climate change link to the Fort McMurray Fire is debatable because it is a region with a natural fire regime as a result of the boreal forest (a mixture of pine, spruce, and fir trees) in which wildfire is the dominant disturbance. Increasing human population and more forest recreation has become a factor in more fires.[26] The Fort McMurray Fire is consistent with climate change, but no one fire can be attributed to climate change.

More of the wildfires today are catastrophic fires known as "runaway" fires that escape initial firefighting efforts and then spread to damage large areas. The Santa Rosa Fire of 2017 that opened this chapter is an example. In Southern California, autumn and winter are particularly hazardous seasons for catastrophic wildfires. Wildfires often accompany hot, dry Santa Ana winds, a large-scale pattern of atmospheric circulation that produces dangerous conditions over the entire Southern California region.[27,28]

Although the number of large wildfires in Southern California has not changed significantly in the past few hundred years, the size and intensity of fires and their effect on people certainly have. Human population has doubled in Southern California in the past 50 years, and fire suppression has led to the increase in availability of natural fuels; as a result, the severity and intensity of burns and their ecological consequences are increasing.[27] The association of wildfire and Santa Ana winds is well known, but the exact timing of fires is related to complex patterns of rainfall during winter months and drought conditions prior to the fires. The relationship of these winds to global warming is not particularly well understood. However, if the trend toward drier, windier conditions continues, wildfires will likely become larger and more intense.[28,29]

Climate change is also likely to increase the number and intensity of wildfires in Northern California. Regional climatic conditions are projected to become warmer, drier, and windier—three factors that promote wildfires. Warmer, drier climatic conditions will result in changes to plant communities, with grasslands and chaparral (scrub forest) replacing the larger coniferous trees. These changes in plant types will increase fire frequency and intensity because grasslands and brush burn more frequently than do forests. As a result of these changes, more property will be destroyed, more lives lost, more floods and debris flows will follow fires, and ash and soot will reduce air and water quality. In addition, the cost of firefighting and insurance against fire will increase as damages increase.[28]

Increases in the size or intensity of severe storms may also promote wildfires by increasing the incidence of lightning, one method of igniting wildfires. In addition, warmer and drier conditions will make trees more susceptible to beetle infestations, weakening them and rendering them more vulnerable to fire.

As mentioned previously, changes in vegetation resulting from global warming may also affect wildfire frequencies and intensities. Precipitation changes in parts of the western United States are also likely to change some landscape dominated by sagebrush into widespread grasslands. As a whole, grasslands tend to burn more frequently than the sagebrush that grows there today.[27,28]

These trends in fire frequency and intensity are not limited to California and the Southwest. Similar changes are taking place in Alaska and Canada.[25,26] For example, temperatures on Alaska's Kenai Peninsula have risen several degrees in the past 30 years. Warmer temperatures have weakened the coniferous forest and led to a large infestation of beetles. An estimated 40 million trees have been killed throughout an area the size of Connecticut. This insect infestation may well be the largest ever recorded, and as the trees die and become fuel, catastrophic wildfire will be much more likely.[28]

Finally, the linkage between wildfires and climate change will also affect human health. As mentioned previously, increases in airborne particulates from wildfires can lower air quality and harm human health. For example, wildfires in Florida in 1998, which were related to La Niña conditions in the Pacific Ocean causing drought in the southeastern United States, resulted in a marked increase in the number of people seeking hospital emergency room treatment for asthma, bronchitis, and chest pain.[28] Recently, atmospheric scientists and geologists have become concerned with increases in peatland fires in both the boreal forests of Canada and Russia and the tropical forests of Malaysia and Indonesia. Burning peat releases smog-producing gases and higher levels of particulates than the combustion of wood or grass, as well as significant quantities of toxic mercury into the environment (Figure 13.15).[30,31]



FIGURE 13.15 Burning Peatlands Contribute to Smog and Global Warming
Fires in organic soils, such as this one in a bog in the Poca das Antas Biological Reserve northeast of Rio de Janeiro, Brazil, release gases into the atmosphere that cause smog and contribute to global warming. Carbon, originally stored for many hundreds or thousands of years in organic soil or underlying peat deposits, is released into the atmosphere as carbon dioxide, a greenhouse gas contributing to global warming. *(AP Photo/ Douglas Engle)*

EFFECTS ON THE BIOLOGICAL ENVIRONMENT

Fires have many direct and indirect effects on the biological environment, which includes plants, animals, and human beings. The effects may vary from moderate to severe, depending on the type, size, location, duration, and intensity of the fire.

Vegetation Fire's effects on vegetation are numerous, varied, and complex. Some plants, such as scrub oak, juniper, and mesquite, are susceptible to fire, whereas others are not. For example, Douglas fir and ponderosa pine are adapted to frequent fires with thick bark that insulates them from fire damage.[32] Even if a plant does not die in a wildfire, a fire can make it vulnerable to later destruction by disease or drought. On the other hand, some plants, such as a number of native prairie wildflowers, require fires for the continuation of their species. Fire also helps to propagate many woody plants. For example, seeds of sumac and bearberry remain dormant in the soil until opened by the heat from a fire.[2] Overall, fire is an important long-term control on the types of plants that grow in many areas of North America. The type, intensity, and frequency of fires selectively favor some plant species and eliminate others.[2]

It has been observed that, in some cases, dense large oak trees provided a partial barrier to a fire's advance. In some cases, fire burns some of the oaks only halfway through, stopping with a knife-edge line (a vertical line between burned and unburned tree). Oaks can release visible water vapor from heating as the fire approaches. Large oaks live several hundred years and usually survive a number of fires. Even oaks that appear dead after a fire will usually sprout quickly and recover. Of course, extremely hot, intense, and lingering fire may kill oak trees and set homes on fire, but the homes with oak trees around them have a better chance of surviving. It is much more difficult for fire to advance through oak trees than through chaparral. The possible natural service function of oak trees to retard fire moving across the land needs to be studied in more detail.

The eucalyptus, a tree native to Australia but imported to the United States and elsewhere, is also well adapted to wildfire but in an entirely different way from oak trees. Eucalyptus trees have loose bark that hangs down, inviting fire to move up into the canopy. Sometimes the trees literally explode, sending burning embers through the air for hundreds of meters. With the high winds that often accompany fire, the embers can travel even greater distances, spreading spot fires. However, fire is important in enabling eucalyptus seedpods to open, and wind and flames may disperse the pods. On hot days, a faint blue flammable gas from the rich oil the trees produce has been reported. Burning eucalyptus trees can significantly increase the temperature of the fire, greatly increasing the hazard in the immediate area. During the 2008 Tea Fire in Santa Barbara, California, the Mount Calvary Monastery burned (Figure 13.16a). Just downslope of the structure is a group of eucalyptus trees (Figure 13.16b) that the fire moved through just before encountering the monastery. The trees are still there, having sprouted following the fire. There is ongoing discussion about removing eucalyptus trees from areas with a wildfire hazard. Some investigators have stated that eucalyptus trees are the most dangerous trees in a wildfire. Certainly, that is the experience in Australia.

Animals Although extremely large, intense wildfires may kill even the fastest-running animals, in general, fire has few direct effects on wildlife. Most animals are able to escape or hide from the danger posed by a fire. Mobile species, such as birds, deer, cougars, and bears, are generally able to move away from a fire as it advances. Rodents that nest beneath the ground also have a good chance of survival because soil is a good insulator. However, wildfires may have indirect effects on wildlife. In fire-denuded areas, loss of plant cover exposes the soil to solar heating, thereby increasing ground temperatures and altering habitats. In intensely burned areas, the pioneering plant species that initially colonize the land will determine both the type and the



(a)



(b)

FIGURE 13.16 Mount Calvary Monastery
(a) Located above the city of Santa Barbara, California, this monastery burned during a wildfire in 2008. *(Edward A. Keller)* (b) A grove of eucalyptus trees just downslope contributed to the intense fire that claimed the structure. *(Edward A. Keller)*

number of vertebrates that can thrive in the area. In streams, fish and other aquatic species may suffer from increased sedimentation resulting from wildfires, and water temperatures may increase because plants along the stream banks have been destroyed.[13]

Human Beings When a fire removes much or all of the vegetation in a watershed, subsequent rains will have much greater erosive potential. Erosion produces large quantities of sediment and plant debris that affect the water quality of streams and lakes. For example, in May 1996, a fire burned two watersheds that contribute runoff into the drinking water reservoir for Denver and Aurora, Colorado. Two months after the fire, a storm produced floods in the watersheds and sent large amounts of floating debris and high dissolved concentrations of manganese into the reservoir. Even two years after the fire, the water quality was still not as good as it had been before the fire.[15]

Smoke and haze produced by fires can harm human health. Exposure to smoke and haze commonly produces eye, respiratory, and skin problems. After prolonged exposure to smoke, people, especially firefighters, may experience respiratory problems that become permanent or even fatal.

Wildfire, of course, has the potential to destroy personal property. As human population continues to increase, more and more people are living on the fringes of wildlands, in an area called the **wildland–urban interface**. Homes are built in undeveloped canyons and on wooded slopes susceptible to fire, and naturally occurring fires are suppressed to protect homes and businesses, resulting in longer return intervals and accumulations of fuel. When a wildfire occurs in brushland or forest areas near a city, such as in the Santa Monica Mountains of Los Angeles or the Front Range near Denver, Colorado, hundreds to thousands of homes are at risk.

13.4 CHECK your understanding

1. How does burned vegetation and soil interact to repel water?
2. What is dry ravel?
3. Describe the process of sediment flushing following wildfire. How common is the flushing?
4. Why might high-magnitude debris flows occur following wildfire?
5. Describe how wildfire affects air and water quality.
6. How is wildfire linked to climate change?

13.5 Natural Service Functions of Wildfires

Although fires threaten human lives and property, they are also beneficial to ecosystems. Fire is a part of the natural cycle of the landscape and, as mentioned earlier, has been so since terrestrial plants evolved.

BENEFITS TO SOIL

Fires tend to leave an accumulation of carbon on the surface in the form of ash and increase the nutrient content of a soil. Under the right conditions, when erosion does not remove the ash from the environment, a nutrient reservoir may form that is beneficial to local plants. For plants that are well adapted to fire, such as those that release seeds only after a fire, these nutrients provide a valuable resource for new seedlings. Fires also tend to

reduce populations of soil microorganisms. Decline in microorganisms may benefit those plants with which they compete for nutrients. In some cases, the destruction of microorganisms may also be beneficial since some microorganisms are parasites or carry diseases.[2]

BENEFITS TO PLANTS AND ANIMALS

When a wildfire reduces the number of individuals of a species of plant in a given area, the result may be beneficial to the plant community as a whole. The removal of some species temporarily reduces competition for moisture, nutrients, and light, allowing the surviving species as well as new species to thrive.

In species that depend on fire for reproduction, a wildfire may trigger the release of seeds or stimulate flowering. Two species of trees, lodge pole pine and aspen, are strongly dependent on fire for reproduction and growth. In aspens, fire stimulates the release of a growth enzyme that can cause an aspen tree to produce as many as a million sprouts per acre.[33] These sprouts are important food for elk and moose. In lodgepole pines, seeds remain sealed in pine-cones for decades until fire melts a resin surface coating on the cones to release the seeds.[2] The seeds then fall to a nutrient-rich, ash-covered forest floor that is devoid of competition for the growth of pine seedlings. Species with these reproductive adaptations tend to exist mainly in environments where fire is common and frequent. If wildfires were eliminated from their environment, some species would eventually become extinct.

Fire is also important to ecosystems as a whole. The North American prairie is an example of an ecosystem that is well adapted to wildfires. Grasses, the dominant class of prairie plant, are especially suited for growth after a fire because they grow from their base rather than leaf tips, and 90 percent of their biomass is underground and generally undamaged by fire. Fire also removes surface litter and allows nutrients and moisture to reach the roots of grasses, allowing them to flourish. Native Americans long ago understood the importance of fire, wind, drought, and grazing animals for the prairie ecosystem.[34] Following a fire, colonization and replacement of plant species follow a regular pattern known as *secondary succession*.

Burning of plant material recycles nutrients in the system by quickly decomposing organic matter and allowing new plants to grow. Fire also reduces competition among species for sunlight, water, and nutrients, and crown fires allow more sunlight to reach the understory.

Many species of birds, insects, reptiles, and mammals may benefit from wildfire. For example, new grassland and forage for deer and bison emerge following removal of trees by fire. Also burned, decaying logs provide homes for insects and supply food for mice, coyotes, birds, and bears.

Because wildfires potentially benefit ecosystems, many scientists believe that natural fires in woodland areas should not be suppressed. In 1976, Yellowstone National Park, which covers 9000 km^2 (~2.2 million acres or 3500 $mi.^2$) of Wyoming and Montana, began a policy of allowing natural burns in all areas of the park managed as wilderness. This meant that any fire that started naturally was allowed to burn, provided it did not endanger human life, threaten visitor areas such as Old Faithful, or risk spreading to areas around the park. Any human-caused fire would be extinguished immediately. Before the summer of 1988, the worst fire in Yellowstone's history had burned about 100 km^2 (~25,000 acres or 29 $mi.^2$). By the end of the 1988 fire season, more than 3200 km^2 (~800,000 acres or 1250 $mi.^2$) had burned, causing a major controversy over the natural burn policy.

Lightning strikes during the summer of 1988 ignited 50 fires in the park. Of those, 28 were allowed to burn, according to the natural burn policy. Initially small, the fires quickly expanded in the hot, dry conditions, fueled further by high winds in mid-July. On July 17, bowing to political pressure, Yellowstone officials sent fire crews in to fight a natural fire. By July 21, multiple natural fires in and around Yellowstone were being fought; by July 22, however, it was clear that the fires were beyond the control of the crews. The fires did not slow until September 11, when rains fell throughout the area. The snows of November finally extinguished the fires.

The large area burned at Yellowstone National Park in 1988 generated much criticism of the national park's natural burn policy. Although most scientists agree that fire is good for the natural environment, it was difficult for some people to sit by and watch the park burn. Eventually, 9,500 firefighters were deployed at a cost of $120 million to taxpayers. Nonetheless, the fires continued until they were naturally extinguished. Critics stated that the fires would not have been so big if park officials had fought them from the beginning. Others argued that the fires would not have been so severe if years of fire suppression prior to the mid-1970s had not allowed fuel to accumulate in the area. Postfire studies have shown that the effects of the 1988 Yellowstone wildfires were beneficial to the environment, and the park still adheres to a natural burn policy. This policy is correct because Yellowstone's ecosystems have, through geologic time, adapted to and become dependent on wildfire. The fires of 1988 did not destroy the park; rather, they revitalized ecosystems through natural transformations that cycle energy and nutrients through soils, plants, and animals.

13.5 CHECK your understanding

1. Why is wildfire necessary for some plants and animals?
2. Was the impact from the 1988 wildfires in Yellowstone harmful or beneficial? Why?

13.6 Minimizing the Wildfire Hazard

Clearly, it is desirable to minimize the potential of wildfires to destroy human life and property. There are several components of fire management.

FIRE MANAGEMENT

The task of *fire management* is a difficult one because large wildfires cannot be prevented. Furthermore, not all fires should be suppressed; remember the benefits of fire to the natural environment. However, suppressing fires when they threaten human lives and property is desirable. The primary approaches to fire management include science, education, data collection, and use of prescribed burns.

Science Scientific understanding of wildfire and its role in the structure and function of ecosystems is critical to fire management; we cannot manage what we do not understand. Of particular importance in fire ecology is an understanding of the **fire regime** of an ecosystem. The fire regime is broadly defined to include (1) the types of fuel that are found in plant communities; (2) typical fire behavior as described by fire size, intensity, and amount of biomass removed; and (3) the overall fire history of the area, including fire frequency and recurrence interval. Reconstruction of fire histories is difficult in many areas where fires have been suppressed for nearly a century.[17,18] Nevertheless, fire management is more likely to be successful if fire regimes for specific ecosystems can be defined.

Education Public education is an integral part of fire management. People can be made aware of wildfire as a hazard and what they can do to minimize their personal risk.

Data Collection Remote sensing has become an important tool for fire management, especially the use of satellite imagery to map vegetation and determine fire potential. Since the early 1990s, the U.S. Geological Survey (USGS), in cooperation with the National Oceanographic and Atmospheric Administration (NOAA), has prepared weekly and biweekly maps for the contiguous United States and Alaska, illustrating plant growth and vigor, vegetation cover, and biomass production. These maps, combined with determinations of the moisture content of vegetation in a given area, are invaluable resources for fire managers. A management tool called the Fire Potential Index (FPI) was developed by the USGS and the U.S. Forest Service to characterize the relative fire potential of forests, rangelands, and grasslands. The FPI takes into account the total amount of burnable plant material or fuel load, the water content of dead vegetation, and the percentage of the fuel load that is living vegetation. Regional and local FPI maps are prepared daily in a geographic information system (GIS) to help land managers develop plans for minimizing the threat from fires. Satellite images are also used to monitor the intensity of wildfire growth in real time. This information can help direct fire control measures.

Prescribed Burns For the past century, fire management in the United States has been guided by a policy of wildfire suppression, mainly to protect human interests. In forests, this policy has led to a buildup of fuel and the potential for larger, high-intensity fires. One way to counter this dangerous buildup of fuel is to ignite **prescribed burns**. The use of prescribed or controlled burns for forest management is not new; such fires have been used for years as an alternative to absolute fire suppression (Figure 13.17).[18]

The main goal of prescribed burns is to reduce the amount of fuel and, thus, the likelihood of a catastrophic wildfire.[15] Fire ecologists have found that more frequent, smaller fires will lead to fewer large fires.

Each prescribed burn has a written plan that outlines the objectives, where and how it is to be carried out, under whose authority it will be carried out, and how the burn will be evaluated. Those in charge of a prescribed burn take on a great deal of responsibility—they have to predict the natural behavior of the fire and successfully keep it under control. Planners face the difficult task of predicting the acceptable fuel and weather conditions under which they can safely control the fire. Factors such as temperature, humidity, and wind must be taken into account.

Unexpected changes in wind direction during a prescribed burn can have catastrophic results. The unexpected happened in spring 2000 when fire managers lost control of a prescribed burn at Bandelier National Monument in New Mexico. A prescribed burn ignited on May 4 quickly raged out of control and sliced through 80 km^2 (~20,000 acres or 31 $mi.^2$). Within 24 hours, the burn was declared a wildfire as a result of sporadic, unexpected changes in wind direction. After two weeks, the fire had engulfed 190 km^2 (~46,000 acres or 73 $mi.^2$) and was still on the move. Nearby drought-parched pine forest and grassland supplied ample fuel



< FIGURE 13.17 Forest Management with Prescribed Burns

This old-growth longleaf pine forest near Thomasville, Georgia, has been managed with annual prescribed burns during lightning season by the Tall Timbers Research Station for more than 25 years. The result is a healthy, diverse ecosystem similar to what existed when Europeans first explored the region in the sixteenth century. *(©Getty Images/ Andrew Kornylak)*

for the fire that destroyed 280 homes and forced 25,000 people to evacuate the town of Los Alamos, just 110 km (~70 mi.) north of Albuquerque.

After the flames were extinguished and the damage assessed, the town and the nation were left only with questions. How could a controlled burn, ordered by the National Park Service itself, end up nearly destroying a town? A formal review following the fire called for changes in policy. The changes included a more careful analysis and review of burn plans, better coordination and cooperation among federal agencies in developing burn plans, and use of a standard checklist before setting a prescribed fire. These and other changes have been instituted. Furthermore, because of the near-disaster at Los Alamos, the existing 1995 Federal Fire Management Policy was reviewed and then updated in 2001. Specific changes include emphasizing the role of science in developing and implementing fire management programs.

In 2003, the U.S. Congress passed the Healthy Forests Restoration Act, a forest management plan to reduce large damaging wildfires by thinning (logging) trees on federal lands. The act reduces or limits the environmental analysis that is normally required to initiate logging projects. Those in support of the act state that the new management procedures will reduce the risk of catastrophic fires to towns in and around national forests, will save lives of forest residents and firefighters, and will protect wildlife, including threatened and endangered species. Those opposing the act argue that large-scale logging will be promoted far from communities at risk from wildfire and, overall, will damage our forests. They further argue that the best approach to minimizing risk from wildfire is through the selective removal of vegetation around communities and homes and through education and planning.

13.6 CHECK your understanding

1. Define fire regime.
2. What is the role of science in helping control wildfire once it has started?
3. Define prescribed burns and explain why they are part of fire management.

13.7 Perception of and Adjustment to the Wildfire Hazard

PERCEPTION OF THE WILDFIRE HAZARD

In general, people who live or work in the wildland–urban interface do not adequately perceive a risk from wildfires. California provides a good example of this apparent lack of concern. Residents of California, where fires burn almost every year, should be familiar with the risks associated with wildfires, yet development continues on brush-covered hillslopes. The demand for hillside property has increased property prices in these areas, which means that the people whose property is most at risk from fire have paid a premium for that "privilege." Fire insurance and disaster assistance may actually worsen the situation; if people believe that the government will reimburse their fire losses, they may not see any reason not to live where they choose, regardless of the risk. In the past hundred years, dozens of fires have struck brushlands of California, while

population and property values continue to increase. The results of not perceiving a real risk from fires was tragically illustrated in October 1991, when a wildfire destroyed almost 6.5 km^2 (~1600 acres or 2.5 $mi.^2$) and about 3,800 houses and apartments in the cities of Oakland and Berkeley (Figure 13.18). The fire killed 25 people and caused more than $1.68 billion in damages. When it was over, it was labeled one of the worst urban disasters in U.S. history.

The fire started on October 19 from cooking fires in a camp of homeless people who thought their fires were extinguished and left the site around midnight. The next day was hot with high winds, and embers left from the night before reignited the fire. Urbanization had added additional fuel to the area, which was previously composed of grass-covered slopes with a small number of oak and redwood trees. The additional fuel included numerous wood structures and imported trees, such as eucalyptus. For decades prior to the fire, the density of trees and structures had increased. Open land was reduced from 47 percent of the area in 1939 to 20 percent in 1988, and the number of plant species increased from a few to a few hundred. When the fire reignited, it quickly became uncontrollable. All that firefighters could do was evacuate residents. The fire moved through the urban landscape very quickly; during the first hour, it consumed a home every five seconds! Although the fire was started by people, other factors contributed: an ample fuel supply of buildings, brush, and trees and hot, windy weather. Furthermore, from a fire hazard perspective, land-use planning in the area was inadequate. Structures were not required to be fire resistant, the density of buildings and placement of utilities with regard to fire hazard were not restricted, and there were no legal requirements for removal of excess vegetation around buildings.[2]



▲ FIGURE 13.18 Killer Wildfire
A wildfire in the hills of Oakland, California, in 1991 devastated an entire neighborhood, killing 25 people and destroying about 3,800 homes. Damages were more than $1.68 billion. *(AP Photo/ Olga Shalygin)*

ADJUSTMENTS TO THE WILDFIRE HAZARD

Adjustment to the fire hazard may be accomplished through hazard mapping, fire danger alerts and warnings, education, codes and regulation, insurance, and evacuation. When wildfire breaks out, the mode shifts to firefighting, which is a coordinated, cooperative effort that, with large fires, involves firefighter units from across the region converging on the fire. Fire trucks may come from hundreds of miles away to assist in controlling a fire and protecting property. Firefighting is a dangerous profession.

Wildfire Hazard Maps Maps in California and other areas routinely indicate areas (zones) with moderate to very high wildfire hazard. These are often at the wildland–urban interface. Zones with very high hazard are subject to rules, regulations, and building standards. The Santa Rosa Fire suggests these zones may be too narrow. Hazard maps should also have to reflect dense urban development in areas adjacent to areas previously thought to have a mild to low hazard.

Fire Danger Alerts and Warnings Both U.S. and Canadian federal agencies have developed fire danger rating systems to alert land managers, residents, and visitors to daily changes in conditions affecting the development of wildfires. Fire danger ratings combine information about fuel conditions, topography, weather, and risk of ignition to assess the wildfire hazard. National Weather Service forecast offices also issue fire weather watches 12 to 72 hours in advance of extreme fire conditions and **red flag warnings** when extreme fire conditions either are occurring or will take place in less than 24 hours. These watches and warnings put citizens, public officials, and firefighters on alert.

Fire Education Community awareness programs and presentations in schools about fire safety may help reduce the fire hazard. Unfortunately, for many people who have never experienced a fire, the risk may not seem "real," even with the help of fire education programs.

Codes and Regulations One way to reduce risk in fire-prone areas is to enforce building codes that require structures be built with fire-resistant materials. For example, using stone or brick for building and roofing materials, rather than wooden shingles, helps to fireproof homes. Unfortunately, in California, stone roofing tiles are not always safe during earthquakes. Making appropriate fire-resistant materials mandatory in new structures could significantly reduce the

amount of damage caused by fires. Many local governments and state/province and federal land management agencies also exercise their regulatory authority by issuing bans on outdoor burning and fireworks when conditions are favorable for grass, brush, and forest fires. These bans help reduce the number of fires ignited by people.

Fire Insurance Fire insurance is another adjustment to the threat of fires. Such insurance ensures that people whose property has been destroyed by a fire will be reimbursed. However, insurance may provide a false sense of security and prompt more people to live in fire-prone areas.

Evacuation Evacuation of people from danger zones is probably the most common adjustment to the fire hazard. Evacuation of people from homes helps ensure their safety, but it does not protect their homes or personal belongings. In some areas, reverse 911 calls warn people that a fire has started and update them with advised or required evacuations. The role of social media is becoming more important in people getting real-time fire conditions and warnings and evacuation options that are open. Evacuation of a large number of people is often a difficult process, and community-planning groups work on this issue, so that when evacuation is necessary, it can possibly be done in a more orderly manner. Many people may wait until the last moment, and that can be dangerous to property owners and firefighters entering a fire zone.

News reporters on the ground who are filming the fire and burning homes and those in the air who are covering the story may also be in personal danger and may impede firefighters. Risking the lives of reporters should not be a part of covering the news!

PERSONAL ADJUSTMENT TO THE FIRE HAZARD

There are many things you can do to protect yourself from fire (Table 13.1). If you live or work in the wildland–urban interface, you may want to obtain literature that describes how to prepare for the inevitable wildfire.[35]

13.7 CHECK your understanding

1. List ways in which communities can make adjustments to the wildfire hazard.
2. Suggest several ways that individuals can prepare for the wildfire hazard.

TABLE 13.1 Reducing Your Fire Hazard at Home

Maintain Home Heating Systems
• Have your chimney regularly inspected and cleaned.
• Remove branches hanging above and around the chimney.
Have a Fire Safety and Evacuation Plan
• Install smoke alarms on every level of your home.
• Test smoke alarms monthly and change the batteries at least once a year.
• Practice fire escape and evacuation plans.
• Mark the entrance to your property with signs that are clearly visible.
• Know which local emergency services are available and have those numbers posted.
• Provide emergency vehicle access through roads and driveways at least 3.7 m (~12 ft.) wide with adequate turnaround space.
Make Your Home Fire Resistant
• Use fire-resistant and protective roofing and materials such as stone, brick, and metal to protect your home. Avoid using wood materials, which offer the least fire protection.
• Keep roofs and eaves clear of debris.
• Keep windows and damper to the chimney tightly closed to keep smoke out.
• Cover all exterior vents, attics, and eaves with metal mesh screens having openings no larger than 6 mm (~0.2 in.)
• Install multiplane windows, tempered safety glass, or fireproof shutters to protect large windows from radiant heat.
• Use fire-resistant draperies for added window protection.
• Keep tools for fire protection nearby: 30 m (~100 ft.) of garden hose, shovel, rake, ladder, and buckets.
• Make sure that water sources, such as hydrants and ponds, are accessible to the fire department.
Let Your Landscape Defend Your Property
• Trim grass on a regular basis up to 30 m (~100 ft.) surrounding your home.
• Create defensible space by thinning trees and brush within 10 m (~30 ft.) around your home.
• Beyond 10 m (~30 ft.), remove dead wood, debris, and low tree branches.
• Landscape your property with fire-resistant grasses and shrubs to prevent fire from spreading quickly.
• Stack firewood at least 10 m (~30 ft.) away from your home and other structures.
• Store flammable materials, liquids, and solvents in metal containers outside the home, at least 10 m (~30 ft.) away from structures and wooden fences.

Source: Based on Federal Emergency Management Agency, "Wildfire: Are you Prepared?" FEMA Publication L-203, 1993. www.usfa.fema.gov/downloads/pdf/publications/wildfire.pdf.

CASE study

13.2 Survivor Story

Elderly Couple Survives Wildfire by Jumping into a Neighbor's Swimming Pool

The evening sky at 10:00 P.M. on Sunday October 8, 2017 was clear on the hills above Santa Rosa, California, and an elderly woman was on her deck, enjoying the view in a home she and her husband had built. After checking her tomatoes and enjoying the moonlit night, she took a shower, and when she got out, she could smell smoke. Her husband went outside, and the sky was red, but he thought it was probably just the sunset, and the couple got into bed. A phone call came from their daughter who advised them to evacuate because there was a wildfire in the area, but they didn't make a move at that time. The daughter called again at midnight, advising them that they had to get out. They looked outside, and the wind had kicked up and flames were approaching. They loaded their car and tried driving from the home, but there was a wall of flames and they had to return. They then had to make a decision of what would be a likely plan to survive. No one plans for such emergencies, but sometimes they happen. They called 911, but help was not available and likely not to come until the flames had swept through the area. They were trapped, but they remembered that their neighbor had a swimming pool, and they wondered if they could possibly survive in the pool, still thinking that someone would come to get them soon. The 911 operator told them to get to a safe place—the pool was the only choice as flames raged through the area. At first, they hesitated getting in the pool because the water was cold and the fire wasn't quite there. But then the fire began licking on some wood near the pool. The heat was intense, so they jumped in. They were lucky that the pool was only 4 feet deep, so they didn't have to tread water, but it was cold as they clung to each other for warmth. Cold water that lowers body temperature can result in hypothermia which is a medical emergency that can kill people, especially the elderly. They wondered how long it was going to take for the house to burn and when they could get out of the water. The entire neighborhood (homes, cars, and trees) was on fire. They had to keep going under the surface to avoid all the soot and ash and burning embers in the air and falling in the pool. They'd go underwater for a bit, then come up, take a breath, and go back down. Hours later, when the neighbor's home had burned but was still warm, they decided to get out and warm up because the flames had moved on. They looked for the phone that the wife had left in her shoe along the edge of the pool. It had melted! The couple then walked back to their own home, which was just a short distance away, and it was completely burned, along with their vehicles. In the meantime, their daughter was still trying to call but couldn't get through and prepared for the worst as she had heard that there had been numerous deaths from the wildfire. About 8:00 A.M. the next morning, officials were able to tell their daughter that they had survived the fire. They were extremely lucky.

(ABCARIAN, *R. THEY SURVIVED SIX HOURS IN A POOL AS A WILDFIRE BURNED THEIR NEIGHBORHOOD TO THE GROUND.* LOS ANGELES TIMES, *OCTOBER 12, 2017.*)

APPLYING the 5 Fundamental Concepts

Santa Rosa Fire of 2017

1. **Science helps us predict hazards.**
2. **Knowing hazard risks can help people make decisions.**
3. **Linkages exist between natural hazards.**
4. **Humans can turn disastrous events into catastrophes.**
5. **Consequences of hazards can be minimized.**

Wildfires in North America are apparently getting larger and more intense and are causing more damage to forest resources and homes inhabited by people living in the nation's wildlands. Wildfires that were considered to be unusually large in size and intensity 40 years ago are no longer thought to be surprising events. In addition, droughts are expected to be longer and more severe in coming decades. If vegetative cover is reduced by more frequent fires, and less frequent but more intense precipitation occurs, there may be an increase in flash flooding and increased erosion and movement of sediment to rivers and streams. Debris flows may become more common as sediment deposited in channels is mobilized by less frequent but more intense precipitation following wildfire.

Although the wildlands in the western United States are public lands and generally undeveloped, a larger percentage of the private land that is available for development is being turned into suburban housing estates. If the trend toward increased development continues, then changes in fire policy and management to further reduce the fire risk will be necessary.

Since 1960, the six most serious fire seasons have occurred since 2000, and the total amount of land burned, is about 1.5 times the size of the entire state of Oregon. During the next century, the total U.S. land area burned per year may double.[36]

Larger, more intense wildfires result from several factors:[36,37]

- Biomass fuels (trees and brush) have increased in the past few decades as a result of land management practices that include overgrazing, which reduces ground cover (grass) while encouraging the growth of young trees.
- Timber harvesting (logging) of the largest pine trees has resulted in less fire-tolerant understory (smaller trees).
- Fire suppression has eliminated the smaller, less intense fires that previously reduced the amount of biomass (fire fuel) available.
- Higher temperatures and drought are widespread in recent years, perhaps related to global climate changes.
- Warmer summer and winters have occurred in North America. As a result, runoff is quicker and soil dries out earlier. When the heat of spring and summer arrives, vegetation is drier, which increases the fire hazard.
- While climate change can't be blamed for any one fire, the trend for larger, more intense fires is clearly expected with warming.
- In recent years as spring growth is extended, there has been a noted increase in insect and disease occurrences that can weaken trees.
- The fire season has grown in length by at least two months in recent decades.
- Continued human use and interest in the natural, rural forest environment of the North America has resulted in more homes and other structures being built at



▲ FIGURE 13.19 The 2017 Santa Rosa Fire
The fire rapidly moved from home to home. This urban development with high density of homes was well out of the identified high fire hazard zone and, therefore, not subject to rules and regulations. That fire hazard zones should be expanded based on new criteria is being explored. *(California National Guard)*

the wildland–urban interface (previously undeveloped land close to towns and cities). Depending on the density of homes, these homes do not necessarily change the fire hazard (although some fires are started by carelessness or arson); they do increase the risk as defined in part by the product of the probability of a fire occurring and the consequences should a fire actually occur. Building additional homes in areas with fire hazards obviously also increases the risk through greater exposure and vulnerability that leads to greater financial losses from wildfire. The Santa Rosa Fire in 2017 is particularly worrisome because thousands of homes (Figure 13.19) were burned in areas previously thought to be outside the fire danger area. The fire will require rethinking how we define the wildland–urban interface.

As people responsible for fire safety and risk reduction become more familiar with large, damaging wildfires, better evacuation and warning systems are being developed. When wildfire breaks out, authorities are quicker to call in emergency firefighting assistance, including aircraft support that drops fire suppressants.

During recent large wildfires, authorities generally moved quickly, sending out telephone messages and sending deputies door-to-door to make sure that everyone had evacuated the area. In Santa Rosa the fire moved so quickly that little warning was possible. People in their homes were completely surprised as they believed they lived in a much more fire-safe area. Social media will take on a larger roll in real-time warning in future fires. A quick response is absolutely necessary, as large forest fires can double in size in just a few hours. However, with fast-moving fires in hot and windy conditions, there is always the potential for loss of life. There is growing concern that the largest and most intense wildfires are so dangerous that we will just have to let them burn rather than send firefighters into dangerous, unpredictable situations.

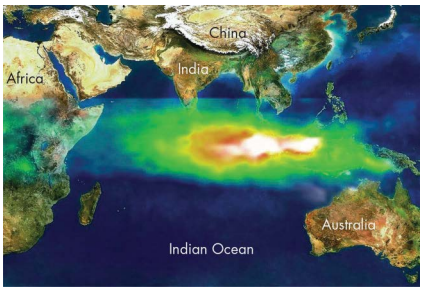
APPLYING THE 5 FUNDAMENTAL CONCEPTS

1. Based on what you have learned in this chapter about wildfires, can the wildfire hazard be predicted?
2. How does the assumption that future wildfires will be larger and more intense in the future affect state fire management agencies and the decisions that developers make?
3. How are wildfires semiarid and other regions linked to soil erosion and landslides?
4. Explain how human processes and decisions are changing the risk and economic impact of wildfires in North America
5. List ways that loss of lives and property from the recent wildfires (United States and Canada) might have been further minimized.

CONCEPTS in review

13.1 Introduction to Wildfire

LO:1 Summarize the role of wildfire during the past 11,500 years.



- Wildfire, one of nature's oldest natural processes, is a self-sustaining, rapid, high-temperature, biochemical oxidation reaction that releases heat and light. Most wildfires in natural ecosystems maintain a rough balance between plant productivity and decomposition.

13.2 Wildfire as a Process

LO:2 Explain why wildfire is a natural process that would occur with or without people.



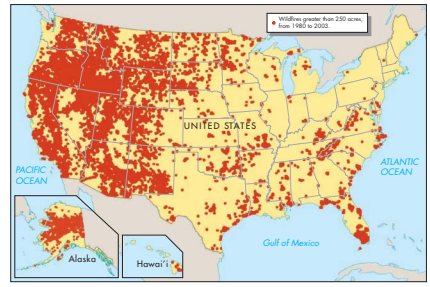
KEY WORDS

combustion (p. 532), **pyrolysis** (p. 532), **wildfire** (p. 531)

- Wildfire is a natural process that can be defined as a rapid, self-sustaining, high-temperature biochemical reaction that releases heat, light, gases, and other products. Wildfire, by burning organic matter, is part of the carbon cycle that returns carbon dioxide to the atmosphere.
- For a fire to burn, it must have fuel, oxygen, and heat. The two main processes that generate wildfires are preignition and combustion. Preignition involves heating and the pyrolysis of fuel to drive off moisture and break down large carbon molecules into smaller ones. The smaller molecules create a cloud of flammable gas directly above the fuel, which then ignites. Ignition often starts with a lightning strike and then continues with windblown embers from the existing fire. Combustion typically occurs first by flaming, followed later by glowing and smoldering.
- Wildfires can be classified based on what part of the landscape burns. Surface fires burn along the forest floor or across the surface of brush and grasslands. Ground fires burn beneath the forest floor by smoldering. In forests, swamps, and marshes with organic soils, ground fires can smolder in peat deposits for many months. Fast-moving crown fires begin when surface fires ignite treetops. Spot fires are ignited ahead of the main fire by embers carried on the winds.
- Wildfire behavior is influenced by fuel, weather, topography, and the fire itself. Fuel varies in size, shape, arrangement, and moisture content, ranging from fast-burning grasses and conifer needles to slow-burning logs and organic soil matter. Weather conditions favoring wildfires include high winds and high temperatures, low humidity, and dry thunderstorms. Longer-term drought conditions are especially favorable for wildfires. Fires spread rapidly up steep slopes and are driven by winds up canyons.

13.3 Geographic Regions at Risk from Wildfires

LO:3 Explain why the wildfire hazard varies from region to region.



- Most areas of the United States and Canada that are within or in close proximity to grasslands, shrublands, woodlands, or tundra are at risk for wildfires during dry weather or drought conditions. Even the sparsely vegetated deserts, rainforests, and normally wet marsh and swamplands can experience wildfire.

13.4 Effects of Wildfires and Linkages with Other Natural Hazards

LO:4 Summarize how wildfires are linked to other natural hazards.

LO:5 Make the link between global change (warming) and the number and intensity of wildfires.

- Fire can increase runoff, erosion, flooding, and landslides.
- Wildfire is linked to air pollution, reduction of water quality, and vegetation changes through damage and fire adaption.
- Wildfire occurrence and intensity are linked to global warming through drought, increasing surface temperature, and extended fire seasons.



KEY WORDS

dry ravel (p. 538), **hydrophobic layer** (p. 536), **sediment flushing** (p. 538), **wildland–urban interface** (p. 544)

13.5 Natural Service Functions of Wildfires

LO:6 List the potential benefits provided by wildfires.

- Natural service functions of fires include increasing the nutrient content of soils, initiating regeneration of plant communities, creating new habitat for animals by altering landscapes, and potentially reducing the risk of large fires in the near future.



13.6 Minimizing the Wildfire Hazard

LO:7 Evaluate the methods employed to minimize the fire hazard.

- Wildfire management is difficult because large wildfires cannot be prevented or, in some instances, even controlled.
- In recent decades, there has been a move to suppress wildfire. As a result, natural fires that occur may become larger and more intense. From that perspective, events that were previously disasters may now be catastrophes. The same change from disaster to catastrophe can occur because more and more people are living in the wildland–urban interface in areas with a high fire hazard and increasing the impacts of wildfire in the coming decades.



KEY WORDS

fire regime (p. 546), **prescribed burns** (p. 546)

13.7 Perception of and Adjustment to the Wildfire Hazard

LO:8 Summarize the potential adjustments to the wildfire hazard and the role of human processes.

- Adjustments to wildfire at the institutional level include establishing alerts and warnings, firefighting by fire crews, quick evacuation, and education.
- Most important in fire management is for homeowners to utilize fire-resistant construction, develop a defendable space around their homes, and be prepared to evacuate. Emergency planning at the community level is also important.



KEY WORD

red flag warnings (p. 548)

CRITICAL thinking questions

1. You live in an area with a significant wildfire hazard. What can you to do protect your home and belongings from fires? Make a list of actions you can take to protect yourself.
2. A large national park is reviewing its fire policy. As a wildfire expert, you have been asked for advice. The park's current policy is to suppress all fires as soon as they begin. It does not use prescribed burns and is considering switching to a policy of allowing natural burns. What would you suggest? List the pros and cons of each policy before making your decision.
3. Most discussion of the wildfire hazard focuses on the potential destruction, injury, or death that can take place from the flames. Discuss the hazards to humans and the environment that come from the smoke produced by wildfires.

References

1. **Rossotti, H.** 1993. *Fire*. Oxford, UK: Oxford University Press.
2. **Pyne, S. J., Andrews, P. L.,** and **Laven, R. D.** 1996. *Introduction to wildland fire*, 2nd ed. New York: John Wiley & Sons, Inc.
3. **Minnich, R. A.** 2002. Personal written correspondence.
4. **Ward, D.** 2001. Combustion chemistry and smoke. In *Forest fires: Behavior and ecological effects*, eds. E. A. Johnson and K. Miyanishi, pp. 57–77. San Diego, CA: Academic Press.
5. **Mennich, R. A.** and **Chou, Y. H.** 1997. Wildland fire patch dynamics in the chaparral of southern California and nothern Baja California. *Int J. of Wildland Fire* 7(3): 221–248.
6. **Arno, S. F.,** and **Allison-Bunnell, S.** 2002. *Flames in our forests*. Washington, DC: Island Press.
7. **Verdi, R. J., Tomlinson, S. A.,** and **Marella, R. L.** 2006. *The drought of 1998–2002: Impacts on Florida hydrology and landscapes*. U.S. Geological Survey Circular 1295.
8. **Florida Division of Forestry.** 2006. Wildland fire; Fire data reports. http://tlhforweb1.doacs.state.fl.us/PublicReports/. Accessed 1/28/07.
9. **New York Times.** 2001, May 31. Rain clears some smoke, but fires persist in Florida. Sec. A, p. 14.
10. **Kaufman, Yoram J.,** and **seven others**. 1998: Potential global fire monitoring from EOS-MODIS. *Journal of Geophysical Research*, *103*, pp. 32, 215–38.
11. **U.S. Geological Survey.** 2006. *Wildfire hazards—A national threat*. U.S. Geological Survey Fact Sheet 2006–3015.
12. **Canadian Forest Service.** 2006. Canadian Wildland Fire Information System: Historical analysis—Large fire database. http://cwfis.cfs.nrcan.gc.ca/en/historical/ha_lfdb_maps_e.php. Accessed 1/29/07.
13. **Chandler, C., Cheney, P., Thomas, P., Trabaud, L.,** and **Williams, D.** 1983. *Fire in forestry*, *Volume I: Forest fire behavior and effects*. New York: John Wiley & Sons.
14. **DeBano, L. F.** 1981. *Water repellent soils: A state-of-the-art*. U.S. Forest Service General Technical Report INT-79.
15. **U.S. Geological Survey.** 1998. *USGS wildland fire research*. U.S. Geological Survey Fact Sheet 125–98.
16. **Florsheim, J. L., Keller, E. A.,** and **Best, D. W.** 1991. Fluvial sediment transport in response to moderate storm flows following chaparral wild fire, Ventura County, southern California. *Geological Society of America Bulletin* 103: 504–11.
17. **Keller, E. A., Valentine, D. W.,** and **Gibbs, D. R.** 1997. Hydrologic response of small watersheds following the southern California Painted Cave Fire of June 1990. *Hydrological Processes* 11: 401–04.
18. **Keeley, J. E., Fotheringham, C. J.,** and **Morais, M.** 1999. Reexamining fire suppression impacts on brushland fire regimes. *Science* 284: 1829–32.
19. **Minnich, R. A.** 1983. Fire mosaics in southern California and northern Baja California. *Science* 219: 1287–94.
20. **Minnich, R. A., Garbour, M. G., Burk, J. H.,** and **Sosa-Ramiriz, J.** 2000. California mixed-conifer forests under unchanged fire regimes in Sierra San Pedro Martir, Baja California, Mexico. *Journal of Biogeography* 27: 105–29.
21. **Huff, A. K.,** and **Kondragunta, S.** 2017. Meteorologists track wildfires using satellitesmoke images. *Eos 98*. April.
22. **Beitler, J.** 2006. Tracking nature's contribution to pollution. NASA Earth Observatory. http://earthobservatory.nasa.gov/Study/ContributionPollution/. Accessed 1/29/07.
23. **Pfister, G., Hess, P. G., Emmons, L. K., Lamarque, J.-F., Wiedinmyer, C., Edwards, D. P., Pétron, G., Gille, J. C.,** and **Sachse, G. W.** 2005. Quantifying CO emissions from the 2004 Alaskan wildfires using MOPITT CO data. *Geophysical Research Letters* 32: L11809.
24. **Westerling, A. L., Hidalgo, H. G., Cayan, D. R.,** and **Swetnam, T. W.** 2006. Warming and earlier spring increase western U.S. forest wildfire activity. *Science* 313: 940–43.
25. **Kasischke, E. S.,** and **Turetsky, M. R.** 2006. Recent changes in the fire regime across the North American boreal region—Spatial and temporal patterns of burning across Canada and Alaska. *Geophysical Research Letters* 33: L09703.
26. **Stocks, B. J. and five others.** 2001. Boreal forest regimes and climate change. In *Remote sensing and climate modeling: synergies and limitations*, ed. M. Beniston, and M. M. Verstraete, pp. 233–46. Dordrecht, Netherlands: Kluwer Academic.
27. **Westerling, A. L., Cayan, D. R., Brown, T. J., Hall, B. L.,** and **Riddle, L. G.** 2004. Climate, Santa Ana winds and autumn wildfires in southern California. *EOS*, *Transactions*, *American Geophysical Union* 85(31): 294, 296.
28. **Tolmé, P.** 2004. Will global warming cause more wildfires? *National Wildlife* 42(5): 14–16.
29. **Fried, J. S., Torn, M. S.,** and **Mills, E.** 2004. The impact of climate change on wildfire severity: A regional forecast for northern California. *Climatic Change* 64: 169–91.
30. **Barber, C. V.,** and **Schweithelm, J.** 2000. *Trial by fire: Forest fires and forestry policy in Indonesia's era of crisis and reform*. Washington, DC: World Resources Institute.

31. Turetsky, M. R., Harden, J. W., Friedli, H. R., Flannigan, M., Payne, N., Crock, J., and **Radke, L.** 2006. Wildfires threaten mercury stocks in northern soils. *Geophysical Research Letters* 33: L16403.

32 Miller, M. 2000. Fire autecology. In *Wildland fire in ecosystems: Effects of fire on flora*, ed. J. K. Brown, J. Smith, and J. Kapler. U.S. Forest Service General Technical Report RMRS-GTR-42-vol. 2.

33. Fuller, M. 1991. *Forest fires: An introduction to wildland fire behavior, management, firefighting and prevention*. New York: John Wiley.

34. Jones, S. R., and **Cushman, R. C.** 2004. *A field guide to the North American prairie*. Boston: Houghton Mifflin.

35. Arrowood, J. C. 2003. *Living with wildfires: Prevention, preparation, and recovery*. Denver, CO: Bradford Publishing Company.

36. U.S. Department of Agriculture, Forest Service. 2012. Effects of climatic variability and change on forest ecosystems: A comprehensive science synthesis for the U.S. Forest Sector. General Technical Report PNW-GTR-870.

37. Gorte, R. 2013. The rising cost of wildfire protection. http://headwaterseconomics.org/wildfire/fire-costs-background/