# Chapter 14
# Futuring: Trends in Fire Science and Management

**Learning Outcomes**
After reading and thinking about the material in this chapter, you will be able to:

1. Discuss and give examples of the implications of ongoing and future trends in fire science and management,
2. Synthesize the ideas of integrated fire science with those from the previous chapter on integrated fire management, and
3. Identify trends and challenges for fire science and management that apply in specific cases, and suggest some proactive solutions.

## 14.1 Introduction

Fires have shaped the evolution of plants and animals over millennia and humans have shaped fire regimes for a long time in the different regions of the world. Even if there is not a general appreciation of the many ecosystem services that fires influence, humans have relied and continue to rely upon many ecosystem services from fires. The social perspectives we have about fire have shaped ecological effects and will shape future fires greatly.

Fires can provision, regulate ecosystem processes, or otherwise provide culturally important ecosystem services. By creating open spaces, fires were an evolutionary force for many of the plants and animals upon which people depend (Pausas and Keeley 2019, Fig. 14.1). But fires can also decrease provisioning and regulation of ecosystem services such as wood production and erosion control, and produce ecosystem disservices, namely material and health disservices like infrastructure damage and air pollution (Sil et al. 2019).

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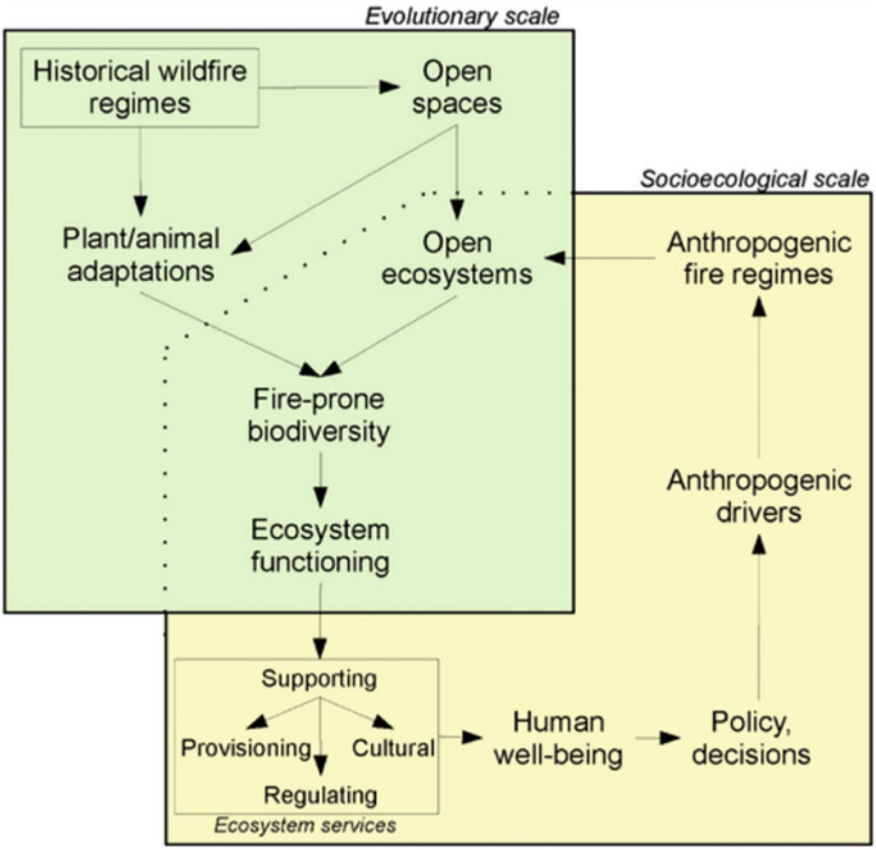

**Fig. 14.1** Fires have shaped the evolution of plants and animals over millennia, and humans have shaped fire regimes. (From Pausas and Keeley 2019)

Humans will likely continue to change the land uses and climate and both extreme and other fires will continue to bring smoke, policy issues, costs, and societal discussions. Fires will continue to be important to society with their social and economic impacts, for fires shape ecosystems, affect and respond to climate, and fires are essential to ecosystem health, ecosystem services, and water and carbon cycles. Globally, nearly 450 Mha have burned annually (Andela et al. 2017). Although the global area burned has declined by almost 25% in recent decades (Andela et al. 2017), many scientists predict that the area burned by extreme fires will increase. In this chapter, we highlight ongoing trends that will shape the future of fire science and management.

Changing social-ecological systems and climate are two aspects of global change that are occurring widely but with uncertain consequences for fires, ecosystems, and people. Providing the range of ecosystem services people value while protecting people, property, and economies from the adverse effects of fire and smoke given global change has greatly increased the complexity of fire science and management (Fig. 14.1) as described in Chap. 13 on Integrated Fire Management. To address these challenges, fire science is increasingly interdisciplinary as scientists address ecological and social aspects of fires while recognizing the complexities of integrating across local to global spatial scales, and from immediate to long-term temporal scales (McLaughlan et al. 2020).

Access to new technology, big data, and data analytics are transforming fire science and management. In addition, there is increasing emphasis on collaborations among disciplines, and between scientists and managers. As a result, there is also an increasing trend of more education and training. Ideally, these trends will make our communities more fire-adapted, our ecosystems and landscapes more resilient to future fires, and help guide safe and effective fire response. These trends are already apparent in some national fire management strategies such as the USA's National Cohesive Wildland Fire Management Strategy (Fig. 14.2).

**Fig. 14.2** The National Cohesive Wildland Fire Management Strategy was developed for the USA through collaboration among many people from federal, state and local government agencies, multiple non-governmental organizations at these levels, and the public. The strategy integrates people and places for resilience to fires. It is centered on what we know and what we will continue to learn from science and experience

Fire is part of human history, present, and future. Comprehending why is fundamental to understanding the processes, changes, and consequences at local, regional, and national scales. The development of regional fire scenarios for Spain (Montiel et al. 2019) or the comparison of different areas in Spain and Portugal (Sequeira et al. 2019) based on historical fire research are examples of the importance of such studies. However, these analyses focus on particular areas or regions. For global analyses, we need to focus on global changes, including the drivers that operate globally that include climate change and social trends.

## 14.2 Global Changes Already Influence Fires and Fire Effects

Global changes, including climate change and human population change, are already influencing the occurrence, size, and ecological and social effects of fires. Climate change has already contributed to an increase in the occurrence of extreme and catastrophic fires, longer fire seasons (>18.5% longer worldwide, Jolly et al. 2015, Fig. 14.3) and an increase in the annual area burned in many areas (Williams and Abatzoglou 2016, and others) even as the area burned globally has decreased (Andela et al. 2017). Many large fires around the world have been costly to suppress and have resulted in considerable losses of human life and property (Bowman et al. 2011; Lannom et al. 2014; Doerr and Santín 2016). These trends, driven by global warming and a history of land management practices will be part of the Anthropocene, this epoch when people strongly influence Earth processes. See Chap. 8 for discussion of extreme fires.

As with climate change, demographic changes are occurring worldwide. Globally, human populations are changing their geographic distribution and their social, political, and economic relationships to natural resources and to fire. While many rural areas, especially in areas of low productivity, are depopulating, the global population is increasing with more people living in urban areas. In some regions, many wildland-urban areas are extensive and growing rapidly. As a result, more fires are damaging and judged as being extreme. All of these trends and others mean that people and the ecosystem services we value are increasingly vulnerable to fire and smoke in many places around the globe. Society must find ways to live with fire and to foster the good work fires can do in landscapes while reducing ecosystem vulnerability and negative consequences for people. See Chap. 10 for our discussion of vulnerability and resilience. See Chap. 12 for how climate, fuels, and prior fires are affecting how fires burn.

Landscapes reflect and influence changes. Social changes have altered the fuels that burn when fires ignite, and therefore the size and intensity and severity of fires. We might expect more extreme fires in the future, particularly if most of the smaller fires that are burning under relatively mild wind and fuel dryness continue to be suppressed in the future. Landscapes have changed greatly through land use, so

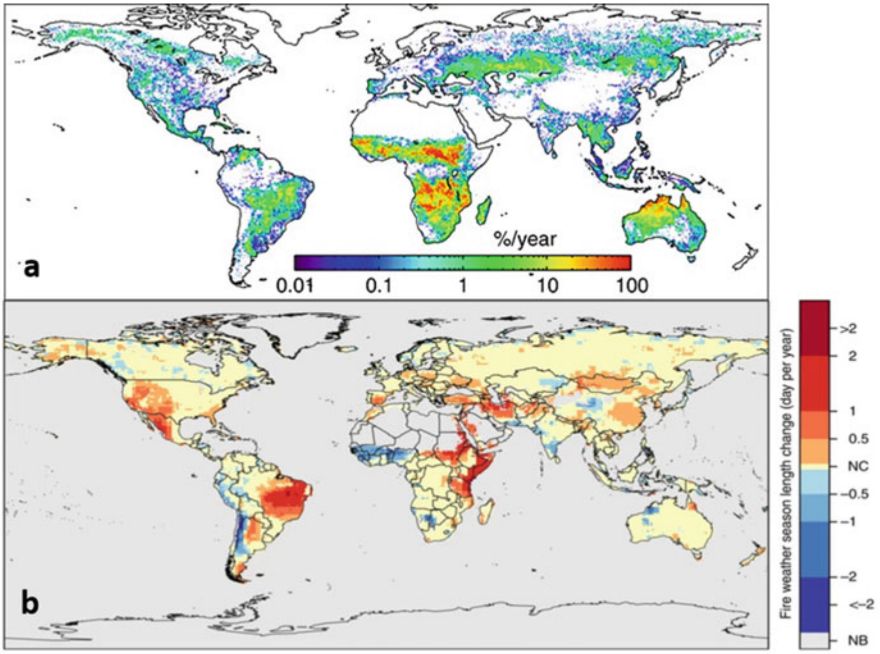

**Fig. 14.3** (**a**) Extensive area burned in recent decades (1997–2013) and more is expected in the future (Giglio et al. 2013). (**b**) Globally, long fire weather seasons were more frequent in most places but not everywhere. On average, global fire seasons are 18.5% longer globally in the time period considered (1979–2013), and this trend is likely to continue into the future (Jolly et al. 2015)

much so that the vegetation trajectories are often novel, especially under the influence of changing climate. For some ecosystems, future trajectories may be quite different from the historical range of variability (HRV, See Chap. 12), especially with invasive species.

Future conditions will be increasingly novel. Uncertainty is certain. Current trends for the relationship between fires and people can be determined, and their legacy will shape future ecosystem responses to fires. We know that fire regimes and vegetation response to fires will change with climate and social trends. In the future, fires will likely occur in places and burn in ways that are unknown to the plants and animals that often depend on fires to maintain their habitat and unfamiliar to those who study and manage them. This uncertainty also arises from many other unexpected sources. Fire management organizations have been involved in the responses to floods, earthquakes, and other hazards. Fire managers are effective leaders, but these assignments compound the stress of longer fire seasons, financial oversight on decisions in managing large fires, and the complexities for managing fires burning across boundaries with multiple different objectives. Currently, the viral COVID-19 disease poses great challenges for society. The leaders in fire organizations wrestle with the novel requirements of maintaining physical distance when fighting fires as they worry about how smoke exposure will interact with COVID-19 exposure for fire personnel and the public (Rover 2020). Increasingly, fire scientists and managers are learning to expect the unexpected.

### *14.2.1 Climate Change: More Extreme Wildfires with More Severe Impacts*

Changing climate is already influencing fires worldwide, and it will become increasingly important as climate change trends continue. The impacts vary regionally. In general, more extreme wildfires are occurring as a combination of the weather and drought conditions, the fire proneness of the landscapes, and more people and property in the path of large fires. The example of the "Black Summer" fires in Australia in 2019–2020 illustrates these changes (See Sect. 14.2.3).

In southern Europe, aggressive fire suppression since the 1990s has been generally successful in decreasing the area burned in many countries despite increasing trends in fire danger and landscape flammability (Turco et al. 2016; Curt and Frejaville 2018). Some of the most tragic wildfire events occurred in Spain (1994, 2006 and 2017), Portugal (2003, 2005 and 2017) and Greece (2000, 2007, and 2018) suggesting a new wildfire context in Europe defined by extreme surges in fire growth and heat release (Rego et al. 2018).

The effect of global warming on the area burned is clear. In California, Williams et al. (2019) attributed much of the five-fold increase in areas burned in recent decades to anthropogenic climate warming. Increased temperature of 1.4 °C since 1970 has contributed to more summer and fall fires by increasing evaporation from soils and vegetation and drying fuels. Williams and Abatzoglou (2016) similarly attributed more than half of the increase in area burned in recent decades across the conterminous United States to anthropogenic climate change. Williams et al. (2019) also highlighted the challenges of continuing warming for increased area burned in the future with impacts varying from place to place as they are altered by fire and land management, ignitions by people and lightning, vegetation types, and their interactions.

The effect of changing precipitation with global warming is also clear. Warmer droughts foster vegetation stress and mortality and favor fires, though these effects vary from place to place and it is more difficult to predict changes in precipitation than changes in temperature. Holden et al. (2018) found that the annual area of forest burned was greater when low precipitation occurred during the fire season (summer and fall) in the western USA. They found that the influence of the number of rainy days on area burned was more than 2.5 times greater than the net effect of short-term drought as indicated by vapor pressure deficit, and both were substantially more important than winter snowpack. If these relationships hold into the future, the combination of warmer temperatures and more frequent droughts, especially during the fire season, will have many and far-reaching ecological and socioeconomic implications in addition to fires themselves. If there is less water in streams in late summer because streamflow peaked earlier, and less moisture in the soils to support plant growth and establishment, this could result in tree and shrub crowns dry enough to fuel intensely burning fires and alter ecosystem recovery from fires. Already, Davis et al. (2019), Stevens-Rumann and Morgan (2019) and Stevens-Rumann et al. (2018) found that many warm, dry sites now forested may have crossed a threshold for successful tree establishment following large forest fires in the western USA. If so, then some forests could be replaced by shrublands or other vegetation, especially at lower timberline. Similarly, trees are failing to regenerate on many sites in the Mediterranean basin following more severe or more frequent fires, namely in evergreen oak woodland (Acácio et al. 2009; Guiomar et al. 2015) and mountain pine forests (Martín-Alcón and Coll 2016). See Chap. 9 and Case Study 12.3 for more discussion on post-fire vegetation recovery changing with changing climate.

Changing climate has influenced the area burned directly and indirectly through interaction with fuels. In the western USA, less snowpack in the spring due to warmer springs, warmer summer temperatures leading to lower fuel moisture, and decreased summer precipitation are all implicated, yet few analyses include all three or their interactions. Further, ongoing changes in vegetation interact with climate changes to influence future fires, yet few studies have investigated the effects of interactions among changing climate, fuel complexes, fires and other disturbances on the future area burned. Hurteau et al. (2019) found that relative to considering climate only, including fuels as affected by previous fires reduced estimates of future area burned by 14% while emissions of carbon and particulates were reduced by 12% and 13%, respectively when fuels and climate were simulated together for forests of the Sierra Nevada mountains of California. Most importantly, the vegetation-fuels-fire feedbacks were more pronounced for the largest fires. The effect of altered fuels is short-lived and depends on repeated fires, including prescribed burns that could be used to help manage forests at low and middle elevations (Hurteau et al. 2019). Wet periods that promote grass followed by dry periods resulting in low fuel moisture can be especially important in open “fuel-limited” systems where fine fuels that accumulate with moisture and then dry are important for fueling fire spread (Williams et al. 2019). Climate influences vegetation directly and indirectly through fires, while burn severity and consequent vegetation recovery are also influenced by other factors such as topography that also interact in multiple ways to complicate the interplay between climate, fuels, and fire.

On a global scale, fires influence the carbon cycle. Carbon, both terrestrial and atmospheric, is affected by fire regimes, but the process is not simple. Even when fires burn severely, much carbon remains in burned trees and logs, as well as in many unburned areas, and this is not reflected in many of the simulation models used to forecast the implications of fires for carbon emissions from burned forests (Stenzel et al. 2019). Forests stored less carbon and had lower carbon uptake where fires burned with high severity (Hurteau et al. 2019; Stenzel et al. 2019).

In summary, fires burn large areas annually across Earth's land area (Fig. 14.3), and fire seasons are getting longer all around the globe (Jolly et al. 2015). Likely this reflects earlier springs, later falls and warmer droughts, all of which will influence fires directly and also indirectly through effects on vegetation and people, and these will, in turn, affect the carbon sequestered (or not) in ecosystems. See our discussion of burn severity in Sect. 9.6 and 12.2, carbon in Sect. 9.5, and changing fire regimes in Sect. 12.5.

### *14.2.2 Social Changes: New Challenges and Opportunities*

Fire is increasingly recognized as a social-ecological system. Though fire is a biophysical process, fire science, management, and policy are social, political, and economic, and these all reflect peoples' perceptions about fire and fire risk. Fires have always and will increasingly reflect social, political, and economic forces. Worldwide, humans ignite many more fires than lightning does (e.g., Balch et al. 2017 for the western USA). Human values shape land use, fire response, and the policies that shape both fire response and land use. Perceptions of fire will ultimately shape the size, intensity, and effects of future fires. This will be increasingly true as human influence expands around the globe. Fires made us human, and people are reshaping the role of fire on Earth (Bowman et al. 2011; Pyne 2015).

Fire science and management are increasingly welcoming and learning from diverse perspectives and social science is fundamental. In many traditional communities, shamans and wise women and wise men taught others based on what they observed and tried. They shared traditional knowledge through stories and examples (Huffman 2014). This is the earliest fire knowledge, yet these diverse perspectives have seldom been welcomed by western science until quite recently.

The role of women in fire science and management has been often overlooked. It is true that much of the initial work on western fire science has been associated with men, as pictured in the first chapters of this book. This was caused by the historical societal biases for funding, social norms, and related opportunities. However, these historical biases have fortunately changed to a much more balanced situation in the past decades. Smith and Strand (2018) highlighted 146 women leaders in fire science. This and a similar earlier article (Smith et al. 2018a, b) have fostered many conversations about how we can all work to promote diversity in our discipline. Increasingly, women and others are contributing diverse perspectives to enrich fire science and management.

In spite of progress, discrimination is still occurring globally. McDonald (2012) highlighted how prevalent sexual harassment is. Gender discrimination and sexual harassment are widely experienced by women in wildland fire management (Fig. 14.4, AFE 2016a). This issue must be addressed if fire science and management are to benefit from the many different perspectives a diverse workforce brings. We expect that more women will work in fire science and management as the breadth of opportunities and needs become clear, and we hope that they will be increasingly represented in fire leadership roles. We believe that the groups who are generally

**Fig. 14.4** Many of the 342 male and female respondents to an international survey of fire scientists and managers said they had experienced gender discrimination or sexual harassment. (From AFE 2016b)

under-represented, including women, have unique talents and perspectives, and that they can play a critical role in advancing problem-solving in both fire science and fire management. We need more opportunities "where women and men can discuss and understand current issues and work together to build a more inclusive, supportive culture in fire" such as the Women Training Exchange (Lenya Quinn-Davidson, personal communication; Stamper 2017). We believe that the fresh approaches and insights that come with gender, racial, and disciplinary diversity will help address the increasing complexity of the fire challenges for society.

A major trend in global social changes is that human populations are increasing in many wildland-urban areas where fires are likely to threaten people and their property when surrounding vegetation burns. Many rural areas are declining in population as urban areas grow. These trends influence peoples' familiarity with fire as well as the social and political acceptance (or more often fear) of fires and smoke. While human well-being is closely linked to fires and their consequences (Huffman 2014), the often strong emotional reaction to fires reflects both fascination and fear. Social beliefs about fire vary with traditional and local knowledge, gender, social classes, and ethnicities. These beliefs influence fire management strategies around the world. Some strategies will build from embracing anecdotal, qualitative, and experience-based learning more typical of traditional knowledge and integrating that with the ideas from western science. Other strategies come with a mindful focus on social justice, including valuing ecosystems and their services. Community-based fire management strategies that focus on the challenges and knowledge of local ecosystems and people while responding to regional and national priorities will become increasingly common.

Globally, fire management is increasingly complex and challenging. There is widespread public attention, in part because fire is compelling enough that many people have an opinion. Further, global change will force attention to linkages between fire ignition, behavior, and effects, forcing us to explore where and how we can sequester carbon in fire-prone environments. See Chap. 9 for our discussion of fire and carbon in ecosystems. See Case Study 13.6 to learn how carbon sequestration can increase and cultural values increase through altering the fire and changing the season of fire use.

We expect community-based fire management to become more common globally, as billions of people worldwide depend on forests, woodlands, shrublands, and grasslands for food, grazing, watershed protection, or other social, economic, cultural, and spiritual values important to rural livelihoods (FAO 2011). Community-based fire management is useful, for it fits fire to places and people while empowering people (FAO 2011). Such approaches have developed through "grass-roots" efforts often assisted by non-governmental organizations such as the Nature Conservancy (TNC) or the World Wildlife Fund for Nature (WWF). TNC (2017) provided a framework for such efforts (Fig. 14.5). This is especially important in fire-adapted ecosystems where conservation of biodiversity and ecosystem services are objectives. As Indigenous people manage or have tenure rights to over 25% of the world's land, and their territories include much of the global biodiversity and forest carbon, their fire and vegetation management actions matter globally. Local people can foster local jobs and a sense of control over their future when they can manage surrounding landscapes themselves or in shared stewardship with other land managers (TNC 2017). Despite development pressures, giving voice to locals that informs their choices and fosters action is critical to sustaining efforts for conservation and thriving communities (Fig. 14.5).

Fires are increasingly managed across boundaries (Schultz and Moseley 2019). Those boundaries are often geographical, as fires spread from land managed by one entity to adjacent land managed by another entity. Fires also move across social boundaries as different groups of people affected by a single fire may have very different perceptions and experiences with fire. It is not easy to manage fire across all lands, engaging all the different agencies and other land managers with their variety of objectives, yet fires do not respect boundaries, and effective response depends on

**Fig. 14.5** Fire can be part of the community-based management that is part of thriving communities filled with people whose voices are heard in making collaborative choices about actions that further community goals. This encompasses fire and broader social-ecological system goals. (Adapted from TNC 2017)

changing policies and practices at multiple scales (Schultz and Moseley 2019). At the landscape scale, we can begin to address fire for "all lands, all hands" as called for in the National Cohesive Wildland Fire Management Strategy in the USA and similar policies in other countries. At the landscape scale, the different expectations and objectives can often be met in different, complementary locations to accomplish effective fire management across boundaries.

If we are to live with and benefit from fires, we need fire-adapted homes and communities in fire-resilient landscapes. Policies and programs are responding to fires, but we hope and expect that fire response will be increasingly proactive and based on understanding. To engage effectively with fire, people will have to accept and manage risk and communicate that effectively, collaborate with partners who may have different values, objectives, and experiences than their own, and build trust and credibility around local solutions to regional and global challenges (Enquist et al. 2017) including fire.

### *14.2.3 Global Change and the Australian "Black Summer" Fires*

Vegetation fires are an intrinsic element of terrestrial ecosystems under seasonally dry climates. Fires affect an annual average of about 4.5 million $km^2$ of the Earth's surface. However, until recently the global relevance of fire was hardly acknowledged because most of the burned area coincided with sparsely populated regions, such as tropical and temperate savannas, grasslands, and boreal forests. Wildfires have become more prominent in recent years, a consequence of their heightened impacts as measured by the loss of human life and assets. The tragic fires of 2017, 2018, 2019, and 2020 in Portugal, Chile, Greece, the USA, and Australia are vivid in the collective memory. Tragic fires have spurred policy review and changes in the past, just as they are doing now in Australia (Morgan et al. 2020).

Wildfires in the Brazilian Amazon and in southeastern Australia were the highlights of 2019 and early 2020. The fires in the Amazon were mainly a collateral consequence of the loss or degradation of natural forest cover, rather than its cause. They reflect slash and agricultural burning in recently deforested areas, as the moist environment of evergreen tropical forests typically inhibits fire spread. In contrast, the Australian fires have been influenced by climate change, which induces more severe and lengthy fire seasons, social change that has more people and cities in the path of the fires and smoke, and changing fuel conditions as a result of fewer low-intensity fires in the recent compared to the historical past. What then are the implications? What are the lessons to be learned from the Australian "Black Summer" fires? Climate change, fuels, and social change have all contributed. Are the very large fires that burned in Australia in 2019–2020 harbingers of the future?

Southeastern Australia is no stranger to devastating fires, well documented in the region since the nineteenth century. Nonetheless, the recent wildfires are a new

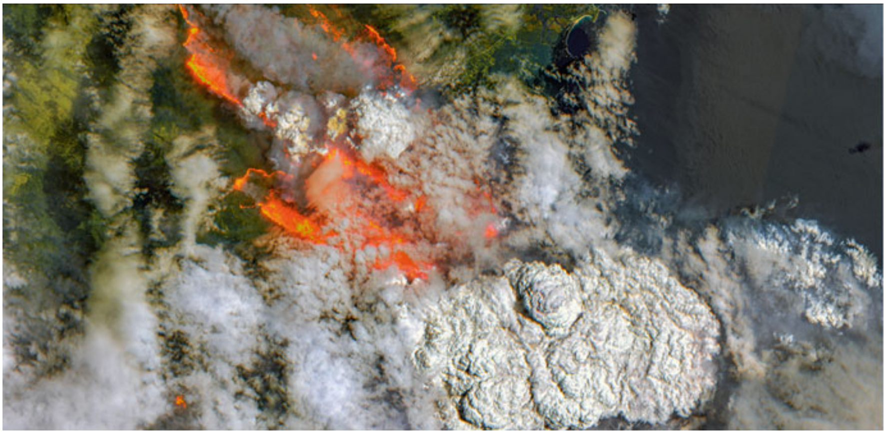

**Fig. 14.6** Wildfires burning on 31 Dec 2019 near Bateman's Bay in southeastern Australia. Flames are readily apparent as are the clouds of smoke and the top of the dense pyrocumulus cloud evident in the lower right (Contains modified Copernicus Sentinel data [2019]/Sentinel Hub/Processed by Pierre Markuse)

phenomenon, given their overall extent. In 2019–2020, many individual fires burned more than 100,000 hectares (Boer et al. 2020), and the fires and their smoke were readily visible from space (Fig. 14.6). Boer et al. (2020) analyzed satellite data worldwide for the past 20 years and found that the 2019–2020 Australian fires burned an unprecedented 21% of the area of Australian temperate broadleaf forest, a far higher proportion than other biomes with <5% burned for most and 8–9% for Asian and African tropical and subtropical dry broadleaf forest biomes. As contributing factors, Boer et al. (2020) and others cited deep, extended drought and extreme heat associated with sea surface temperature anomalies in the Indian Ocean, as well as wind and many ignitions. Worldwide, this is the first time that fires of this extent have burned in forest-dominated landscapes adjoined by areas densely populated by people. In Australia, the recent fires burned in many forests, including some without prior historical records of fire, and some adapted to very infrequent fires (Gill 1975); this could signal a tipping point that will result in changed vegetation types. Between June 2019 and March 2020, the fires burned 18.6 million ha, likely killed more than one billion animals, burned almost 5900 buildings, and killed 34 people while displacing and inconveniencing thousands of people. Smoke from fires exposed people to harmful air quality in many Australian cities even when those were far from the flames, resulting in 417 estimated excess deaths, 3151 hospitalizations, and 1305 asthma-related emergency presentations (Borchers Arriagada et al. 2020). In just 2 months, the fires released more than 350 million tonnes of $CO_2$ into the atmosphere (Sanderson and Fisher 2020). The cost of A$4.4 billion will likely exceed the cost of the Black Saturday fires that burned in 2009, with additional financial impacts on businesses and local communities.

What contributed to these fires, and what are the long-term implications? Eucalypt forests in the region form very large and continuous patches, and the patches have become more continuous as many of the historically frequent fires were suppressed or limited by land use. Human activities such as prescribed fires and vegetation management have been constrained in many of the parks and public forests, and fire hazard reduction has been mostly limited to the immediate vicinity of urban areas. This is a combined outcome of increasingly passive forest management and a focus on emergency response to wildfire rather than on mitigation. Vegetation moisture was at critically low levels following extended drought with multiple years with below-normal precipitation. Maximum daily temperatures in excess of 40 °C combined with very dry and strong winds and unstable atmosphere favored fast and intense fire spread. Finally, the region was swept by successive waves of dry lightning that ignited most of the fires. The relationship between fire and climate is complex, however, and vegetation conditions have contributed as well in Australia and globally (Forkel et al. 2019).

Fighting fires will be increasingly unsuccessful in preventing large fires and their threats to people and property unless we also address the social and political conditions (Morgan et al. 2020), including public attitudes that abdicate responsibility for learning to live with and protect homes from fires. Fires here and elsewhere around the globe may well be the agent of climate change, but they are also partially the result of policy and land use. Whether the likelihood of extreme fire weather conditions will increase in the future will depend on the long-term and uncertain results of the individual and societal policies addressing climate change. Society will have to learn to live with and adapt to this new fire environment, by enabling both long-known and new fire risk reduction strategies conducive to fire-resilient communities and ecosystems. Thus, although fires are a biophysical force, fires also reflect social and political attitudes.

Currently, Australian authorities are again discussing ways to increase prescribed burning, including cultural burning (Morgan et al. 2020), for reducing fire hazard and for biodiversity conservation in Australian landscapes. Likely the burned areas and fuel treatments will need to extend well beyond the areas immediately adjacent to or within the wildland-urban interface. Another potentially useful strategy is managing the burned areas as the vegetation recovers, for burning, thinning, or other treatments could to help foster the desired vegetation conditions into the future. Perhaps Australia will change their fire staffing and equipment which currently relies very heavily upon local volunteer fire fighters. Some have suggested that such "firies" be paid or have other financial incentives for the extensive time they spent on fires this year and may spend on fires in the future.

Worldwide, with attention heightened by the fires, people are demanding Australia and other nations to address climate change. Some scientists, citizens, and policymakers have viewed these fires as a sign of changing climate. That the large fires and smoke have affected most Australian citizens directly or indirectly could foster conversations about changing climate and societal response. The social impacts that are highly visible on social media, the millions of wild and domestic animals injured or killed, and the immense cost of fire fighting even when many of the fire fighters are volunteers, have all led to public and private anger that could fuel societal efforts to address climate change. Cultural burning and other uses of fires offer viable alternative fire management. Certainly, time will tell if the fires of 2019–2020 are recognized as agents of climate change. We encourage people to adapt and mitigate future climate change effects.

Turning the complex challenges of fire into opportunities in Australia and elsewhere will require innovative and integrated fire management (Chap. 13, Morgan et al. 2020). In Australia and across the globe, people must rethink our approaches to fire. We can recognize and fear fire as a destructive force even as we use and celebrate fires as forces of renewal and tools for managing healthy social-ecological systems. Using fire, including prescribed burning for cultural values and for managing fire hazard, and in sustainable vegetation management, is part of embracing fire as a means for caring for our planet.

For more on extreme fires see Chap. 8. For more on the relative influence of climate, fuels, and people on fires see Sect. 12.5. See Case Study 13.1 for the success of strategically burning at the landscape scale and treating more than the area immediately adjacent to the wildland-urban interface in southwestern Australia. See Case Study 13.6 where prescribed burning in during the early dry season in northern Australia has reduced carbon emissions, provided cultural values, and increased biodiversity.

## 14.3 Developing Technology and Bigger Data

Although technology has long been useful in advancing fire science and management, recent advances in computing and communication technologies have led to the emergence of next-generation data collection techniques, data analytics, and advanced modeling and simulation capabilities. These technologies are currently capable of generating terabytes, even petabytes, of data, challenging the way we think about data management and analysis. However, these tools are allowing us to address increasingly complex questions at finer spatial and temporal resolutions and across increasingly broad areas.

Although there are a number of emerging technologies that have the potential to impact the future of fire science and management we focus on five major advancements in data collection, data analysis, and simulation including:

1. Increasing resolution of spatial, spectral, and temporal data from satellite imagery
2. Light Detection and Ranging (LiDAR)
3. Digital aerial photogrammetry and Unmanned Aircraft Systems (UAVs)
4. Wireless sensor networks
5. “Big data” and simulation

### 14.3.1 Increasing Resolution of Spatial, Spectral, and Temporal Data from Satellite Imagery

Satellite-based remote sensing has become an important cost-effective data source for mapping fuels, detecting fires, assessing fire behavior and effects, and for planning fuel treatments and post-fire vegetation response. Current satellite- and airborne-based platforms include a variety of sensor types (e.g., optical, thermal, hyperspectral, LiDAR, active and passive microwave) and cover a wide range of spatial, spectral, and temporal resolutions and extents. Although the spatial coverage provided by satellite-based remote sensing is an important tool for assessing vegetation, fuels, and fires across large areas, satellite systems with global coverage often do not contain sufficient spatial or temporal resolution to provide the detailed characterization of fuels complexes and fire behavior often required for local management decisions. Continued developments in sensor design and improved affordability of sensor platforms are providing new opportunities for satellite-based remote sensing to provide data at increasingly fine spatial, temporal, and spectral resolutions. For example, DigitalGlobe's WorldView-3 and 4 satellites are capable of providing panchromatic imagery at a resolution of 31 cm, 8-band multispectral imagery with a resolution of 1.24 m, and shortwave infrared imagery at a resolution of 3.7 m and clouds, aerosols, vapors, ice and snow data at a resolution of 30 m at a specific location every 24 h. Next-generation satellite sensors are currently being evaluated as tools to produce high-resolution maps of wildland fuels for planning, including fuel treatments, restoration, assessing burn severity and monitoring long-term effects of fire on vegetation (Warner et al. 2017). In addition to increased spatial resolution, future investments in the development of multi- and hyperspectral sensors are likely to play an important role in advancing satellite-based remote sensing capabilities (NAS 2018). In addition to advancements in sensor capabilities, there is an increase in the use of data collected by microsatellites. Microsatellites are relatively low cost, small satellites that can be deployed in relatively large numbers relative to traditional satellites (Butler 2014). The use of a relatively large number of satellites increases their overall temporal resolution and ground coverage of the data (Butler 2014). Ultimately, large networks of microsatellites could provide nearly real-time capabilities to fire scientists and managers to detect and monitor fires even in remote areas.

### 14.3.2 Light Detection and Ranging (LiDAR)

Light Detection and Ranging (LiDAR) technology is another increasingly important data collection tool in fire science and management. LiDAR works by rapidly emitting light from a laser and measuring the time it takes for each emitted light particle to travel to an object and back, enabling users to precisely calculate the location and spatial configuration of objects. LiDAR data can be collected from a number of platforms including airborne, terrestrial, and satellite-based systems. While airborne-based LiDAR data are commonly used to quantify forest structure for several decades (Lefsky et al. 1999; Lim et al. 2003; Hall et al. 2005; Roberts et al. 2005; González-Olabarria et al. 2012), recent developments in LiDAR sensor design have reduced acquisition costs. For example, several countries (e.g., Finland, Poland, England, Sweden, USA, and Spain) currently have or are pursuing national airborne based LiDAR datasets to assist in forest and fuels inventories.

In addition to advancements in airborne LiDAR, there have also been a number of technological breakthroughs in the development and use of satellite-based LiDAR platforms. One example of such technology is NASA's Global Ecosystem Dynamics Investigation LiDAR (GEDI) mission which deployed a high-resolution LIDAR on the International Space Station. One advantage of satellite-based LiDAR sensors is that they have the potential to provide global data.

While airborne and satellite-based platforms are allowing for LiDAR data to be collected across greater extents and at lower costs (Wulder et al. 2008), there are still challenges with using such technologies to quantify surface and ladder fuels that are not directly visible to the sensor due to the foliage and branches above them (Lovell et al. 2003, Andersen et al. 2005). As a complement to airborne-based lidar platforms, a number of researchers are investigating the potential use of terrestrial-based LiDAR platforms (Newnham et al. 2015; Loudermilk et al. 2009). Although terrestrial LiDAR is not commonplace in fire science and management it has shown considerable promise for characterizing surface and canopy fuels at fine scales and in three dimensions (Rowell and Seielstad 2012; Rowell et al. 2016) and in a supporting role along with airborne based LIDAR in broad-scale fuels inventory that can aid in planning for fire and vegetation management.

### *14.3.3 Digital Aerial Photogrammetry and Unmanned Aircraft Systems (UAVs)*

Low weight, low-cost unmanned aircraft (UAV) are another tool that is revolutionizing data collection in fire science and management. UAVs can come in a range of sizes, have various flight times that can be scheduled to accomplish desired tasks, and be equipped with a variety of sensors that allow them to quantify the fuel complex, locate and map fire perimeters, estimate the rate of spread and fireline intensity, identify spot fires, quantify current meteorological conditions across a fire area, provide data on air quality, and other data before, during, and after fires (Casbeer et al. 2005, Merino et al. 2006, 2012; Chisholm et al. 2013, Shin et al. 2018, Lin et al. 2018, Moran et al. 2019). While it is possible for UAV platforms to provide 3D characterizations of the fuels complex using LiDAR, recent developments in Structure for Motion (SfM) and multi-view stereo algorithms allow for three-dimensional (3D) information to be characterized using sequences of overlapping two-dimensional (2D) images. The combination of relatively low-cost

UAV platforms, cameras, and SfM approaches to produce 3D characterizations of vegetation structure similar to airborne LiDAR systems has led to a rapid increase in UAV-based SfM approaches in fire science and management (Leberi et al. 2010; Iglhaut et al. 2019). UAVs can also be equipped with communications technology allowing them to improve communications among the many different people involved during fire incidents (Merwaday and Guvenc 2015). Because of the relatively low-cost, high resolution and flexibility of UAVs to attach various types of sensors (e.g., multi- and hyperspectral, LiDAR), UAV platforms may be useful in assessing burn severity with an accuracy on par with or above those of the satellite-based sensors that are currently used (Fernández-Guisuraga et al. 2018, Samiappan et al. 2019, McKenna et al. 2017). Ultimately UAVs provide a major step forward in ensuring that fire scientists and managers can collect appropriate data at spatial and temporal scales in a cost-effective manner.

### *14.3.4 Wireless Sensor Networks*

Wireless sensor networks are another emerging technology being used in fire science and management. Wireless sensor networks expand the current sampling capabilities by enabling data collection across large areas with high temporal frequency. Wireless sensors can collect a variety of physical parameters (e.g., temperature, humidity, wind speed), chemical data (e.g., carbon dioxide, volatile organic compounds and particulate matter) or images (e.g., infrared detectors). The data collected by the sensor network is then transmitted via cyberinfrastructure to the end-user for analysis and interpretation. Data processing can be embedded within wireless networks so that information can be used to assess data quality and update sampling protocols in real-time (e.g., increasing sampling rates in response to a perturbation detected in the data). Wireless network sensors are currently being used to improve fire detection (Hefeeda and Bagheri 2009; Lloret et al. 2009; Aslan et al. 2012; Bouabdellah et al. 2013), conduct real-time monitoring of fire weather and behavior (Hartung and Han 2006; Gao et al. 2014), and to predict fire behavior and assess risk (Son 2006; García et al. 2008). Although current technologies can only support relatively small sensor networks, further advancements in power generation technology such as solar power and bio-batteries along with low power sensors along with advancements in computing technologies, cyberinfrastructure, and software (Porter et al. 2005; Allen et al. 2018) will continue to increase the size, coverage and sampling frequency of wireless sensor networks in fire science and management.

### *14.3.5 "Big Data" and Simulation*

The advancements in data collection capabilities along with the availability and access to open data (i.e., data that anyone is free to use, reuse and redistribute, Culina et al. 2018) have resulted in the rapid ability to collect and access large volumes of data. The volume of data worldwide increased by over 800% over the last 5 years and is expected to continue to double every 2 years (Gantz and Reinsel 2011; Chen et al. 2014). While the volume of data collected is a key aspect of "big data", the variety of data (e.g., tabular, image, and text) and the velocity or speed at which data are collected, and the reliability (often referred to as veracity) are also important aspects of working with and using "big data" (LaDeau et al. 2017; Farley et al. 2018). We expect that "big data" will support major breakthroughs in science, enough so that some scientists suggest that this represents a distinct fourth scientific paradigm complementing empirical descriptions of natural phenomena, theoretical modeling, and generalization, and simulation approaches (Hey 2009). In addition to paving the way to new scientific discovery, "big data" is expected to transform the way we prepare for, respond to, manage, and recover from fires. However, for fire scientists and managers to take advantage of "big data", they need continued development of:

1. Cyberinfrastructure that allows for a wide variety of data to be integrated and made available,
2. Statistical approaches that can integrate a wide variety of data types across spatial and temporal scales,
3. Computing infrastructure that can effectively deal with the volume and velocity of data being collected,
4. Training and education that includes data science skills

Evolving cyberinfrastructure will support the storage, management, integration, and sharing of various sources of data, and allow data visualization and analysis. The continued development of these technologies will be particularly important as big-data solutions become increasingly used in real-time decision making during fires. For example, next-generation cyberinfrastructures will need to access and process a variety of data sources (e.g., satellite, UAV, and networks of sensors) to make real-time predictions that then allow managers to make predictions of fire spread and intensity that can inform fire management actions. Future advances in cyberinfrastructure will continue to increase data transfer speeds, improve data storage and management efficiencies, and connect and link data sets from around the world.

The large sample sizes and high dimensionality of "big data" presents a number of statistical challenges, including spurious correlations among explanatory variables, increased risk of type-two error, nonnormality, and spatial/temporal autocorrelation. All of these limit the usefulness of many classical statistical approaches (Dray et al. 2012; Fan et al. 2014; Durden et al. 2017). Two approaches that are being increasingly used to overcome this challenge are Bayesian statistics and machine learning. Bayesian statistics are highly flexible. They can deal with multiple data types that span a range of spatial scales, and they represent the uncertainty present in the data (McCarthy 2007; Cressie et al. 2009). However, there are challenges with scaling Bayesian approaches to "big data", leading to increasing computational needs. Machine learning techniques are another increasingly common and flexible approach for working with “big data”. Similar to Bayesian methods, machine learning techniques are highly flexible in that they can deal with multiple types of data that are highly correlated and nonlinear. Machine learning methods are a relatively broad class of approaches that are classified depending upon the desired outcome (Olden et al. 2008). Supervised learning approaches, including classification and regression trees and artificial neural networks, build mathematical models from data that contain both the dependent and independent data similar to many of the traditional statistical methods. On the other hand, unsupervised machine learning methods use only input data and are thus useful for identifying clusters or other patterns similar to classical clustering methods. Although the results of machine learning approaches can often be difficult to interpret, they are powerful tools for making use of “big data” in science and management.

Analyses of “big data” have already allowed significant advances in characterizing fire activity and understanding of fire regimes and their drivers and the role of fire in the Earth system at regional to continental and global scales. For these purposes, worldwide databases of climate variables, lightning activity, fire weather, plant productivity, land use and land cover, and human population density and footprint come together with remotely-sensed fire detections, burned areas, and fire characteristics. Global examples include the modeling of fire incidence metrics, e.g., burned area fraction, from environmental and human-related variables (Krawchuk et al. 2009; Bistinas et al. 2014; Knorr et al. 2014; Kelley et al. 2019), quantification and modeling of fire emissions (Van der Werf et al. 2010; Andela et al. 2016), identification of global “pyromes” (i.e., multi-faceted fire regime classes, Archibald et al. 2013), analysis of fire size variation (Hantson et al. 2015), and establishment of fire-climate relationships (Abatzoglou et al. 2018).

Process-based simulation modeling, sometimes called physics-based or mechanistic modeling, has also emerged as a powerful tool in fire science and management (Hoffman et al. 2018; Loehman et al. 2020; McLaughlan et al. 2020). Process-based models attempt to explicitly represent the relevant components, processes, and interactions that drive system behavior. These models can be viewed as a virtual world that acts as a new kind of experimental system (Winsberg 2001; Winsberg 2003; Peck 2004) that allow researchers and managers to conduct experiments that would be impossible, too risky, or costly in the real world, or to investigate novel ecosystems for which there is no historical analog (Cuddington et al. 2013; Gustafson 2013). For example, experiments which would potentially result in the ignition and spread of crown fires, such as studying the effect of bark beetles or of various fuels treatments on fire behavior, are often considered too risky, costly and difficult to conduct safely, and have therefore been studied using process-based models instead (Hoffman et al. 2012; Ziegler et al. 2017; Parsons et al. 2017; Sieg et al. 2017). Process-based models are also increasingly being used to understand the impacts of management decisions under global change (He et al. 2002; Borys et al. 2016; Keane et al. 2019). Not only can simulations foster numerical experimentation they can also complement traditional experimentation by suggesting new hypotheses that can be tested, informing sampling strategies and assisting in the interpretation of empirical data (Lenhard 2007; Hoffman et al. 2018). Such approaches will likely be used to explore alternative scenarios that could then be implemented on the ground. Nevertheless, it is important to remember that models inherently oversimplify their representation of some phenomena and necessarily ignore others, and therefore are not a complete representation of the true system being modeled. Given the inevitable limitations and uncertainties associated with models, it is critical that they are continuously evaluated through verification, validation, and uncertainty quantification. As suggested by Box (1979) "all models are wrong, but some are useful."

## 14.4 Integrating Fire Science and Management

One thing that seems clear is that the scale and complexity of challenges faced by wildland fire scientists and managers are increasing. While future fire scientists and managers will have a vast array of methods and tools to help them measure, monitor and make predictions about wildland fires, they will also increasingly engage in interdisciplinary, transdisciplinary and translational collaborative research to address these challenges (Gibbons et al. 1994, Brandt et al. 2013, Enquist et al. 2017, Smith et al. 2018, Knapp et al. 2019). As such, wildland fire science in the future will bridge the disciplinary silos that have been historically characteristic. This approach will not only include collaboration among various disciplines involved in wildland fire science (e.g., natural sciences, social sciences, and engineering) but also engage the end-users of research including land managers, policymakers, the public, and private institutions in the co-production of knowledge. We believe that this trend will mean that wildland fire sciences are directly motivated by the problems and challenges it addresses rather than the disciplinary concepts, methods, and approaches used. By engaging participants with different backgrounds, perspectives, and cultures, our fundamental understanding and applicability of wildland fire science will be enhanced. This requires shared language and strategies to integrate methods from different disciplines (Lawrence and Despres 2004; Brandt et al. 2013). Increasingly integrated fire science relies on the use of the internet and new communication tools to bring together collaborators who are geographically, temporally, and culturally separated. Integrated wildland fire science not only integrates scientists, stakeholders, and decision-makers but develops trust and a shared understanding and frequent and ongoing engagement among the participants, thus ultimately allowing for the translation of science into management strategies and tools that are applied (Kemp et al. 2015; Scholz and Steiner 2015; Blades et al. 2016).

Collaborative efforts to integrate fire science and management have also been developing worldwide. One such effort was made in the framework of the project Fire Paradox (2006–2010), funded by the European Commission, that brought together 36 partners from 16 countries, from Argentina to South Africa and Mongolia, including experts from the USA, Canada and Australia (Fig. 14.7). The project objective was to create a scientific and technical basis for new practices and integrated fire management policies. Proposals for policy change in Europe through a Fire Framework Directive towards Integrated Fire Management were suggested

**Fig. 14.7** Field discussions between fire scientists and managers during the plenary meeting of the Fire Paradox project in 2006 in Las Palmas in the Canary Islands. (Photograph by Paulo Fernandes, co-author)

(Rego et al. 2010) and a collection of best practices of fire use, including prescribed burning and suppression fire was produced (Montiel and Kraus 2010). This included the innovative development of fire professional groups for fire use and analysis (GAUF) in Portugal, which were very active in using suppression fire (Salgueiro 2010). Fire Paradox was a good example of the integration between fire science and management that has advanced both.

## 14.5 Advancing Education and Training

Education and Training are two main ways to integrate fire science in practice. Over the last several decades, wildland fire has increasingly become a critical aspect of land management, through fuels management, ecosystem restoration, and continued protection of human life and property. Although natural resource education and training programs have often included classes on wildland fire science as an elective, there is a trend to require all students in disciplines which support land and fire management (e.g., forestry, natural resources, ecology, civil service) to learn about both fire management and ecology. In addition to increased recognition of wildland fire as an essential topic in natural resources, there is also a trend for developing specialized educational programs including minors, concentrations, and even entire majors about fires at universities. Such programs often recognize the need for fire fighters, fire scientists, and fire managers to have knowledge in multiple disciplines, including physical sciences, ecology, and social sciences, while also being adept at communicating clearly, anticipating and resolving conflicts, and facilitating discussions (Schwartz et al. 2017). The curricula integrate perspectives from multiple disciplines. In Europe, the PyroLife project (Pyrolife 2019) is training 15 doctoral

**Fig. 14.8** Fire professionals learn through experience, education, and training. Effective preparation for the future will require more education, and the ability to effectively use technology while making decisions under uncertainty. (From Wells 2011)

students on integrated fire management, targeting fire risk (quantification, reduction, and communication) under the sign of diversity (interdisciplinarity, intersectionality, geography, and gender).

Furthermore, we applaud the increased recognition that fire professionals of the future will gain knowledge throughout their careers through a combination of experience, education, and training (Fig. 14.8) (Kobziar et al. 2009, Wells 2011, Spencer et al. 2015). This recognition is leading to the development of new models of wildfire training and education which integrate each of the three aspects. Recently the Association for Fire Ecology has developed both an individual and academic certification program which emphasizes the importance of linking education, training, and experiences for the development of fire professionals (AFE 2020). Training programs such as the Prescribed Fire Training Exchanges (TREX) established by The Nature Conservancy (TNC 2018) in the USA, or FlameWork in Portugal (Seamon 2019, Fig. 14.9), seek to increase local fire management capacity by creating collaborative learning opportunities which integrate experience, education, and training. Such integrated training programs also foster opportunities for fire professionals across a range of experiences, backgrounds, locations, and cultures to learn from one another while meeting land management objectives. Often, those objectives are increasingly ecological in addition to reducing fire hazard. Soft skills are included, such as communicating with the public directly and through media. See Case Study 13.5 for more on TREX.

Although prescribed fire has long been accepted as an important tool in fire management, there is a trend to increase prescribed fire science (Hiers et al. 2020) and to develop a dedicated prescribed fire workforce. While it has historically been assumed that the knowledge gained from studying wildfires and tools used to suppress wildfires are appropriate for planning and conducting prescribed fire, there are a number of unique properties of prescribed fires (e.g., the ability to

**Fig. 14.9** FlameWork international prescribed burning exchanges held in Portugal in 2019 were very successful (Photograph by Carlos Trindade)

manipulate fire behavior and effects through time and space through altering ignition patterns) that differentiate them from wildfires (Hiers et al. 2020). We urge emphasizing the ongoing trend to increase prescribed fire research that spans all aspects of wildland fire science (e.g., fuels, fire behavior, fire effects, and ecological impacts, and social sciences) and use of the advancements in technology mentioned in Sect. 14.3. At the same time that prescribed fire science is increasing, there is also a trend to develop new prescribed fire training programs within a number of countries, states, and provinces. While the standards for such training programs can vary widely, they typically include a combination of practical experiences and training and education that covers a diverse set of topics including the law, public relations, fire behavior and meteorology, fire ecology, and smoke management. Thus, they support both planning for and implementing prescribed fires in comprehensive programs.

## 14.6 The Future of Fire

The trends identified in this chapter will be critical in addressing ongoing and future challenges. To prepare for future opportunities we need to address these questions and others we have not even thought to ask. What comes after people recognize fire as both an effect of and an agent of global change and especially of climate change? What is next once people accept fires as an essential and pervasive influence in forests, woodlands, shrublands, and grasslands? How might we envision managing to enable fires to move through landscapes, and where and when is that possible? What if we understand that fire can be transformed from a threat to medicine for land and a culturally important component? If we as a society are able to respond to these challenges, we can then more often celebrate some fires, use more fires in some locations, and be less threatened by wildfires. This is a fire paradox. We can respect and use the power of fire to change landscapes. Then we will use the positive feedback cycle between changing fire regimes and the landscapes that can result in more balanced landscapes with adequate fire regimes. This has substantial implications for people and nature.

The current global changes and the expected future trends call for focusing less exclusively on fire suppression and more on fire use and preparedness. What if many people become simultaneously fire fighters and fire lighters, or what if we have as many fire lighters as we have fire fighters? What if a proportion of funds now used to fight fires were instead targeted toward planning and using fires to accomplish landscape management goals, both social and biophysical? What if we had a cohesive strategy that fosters fire-adapted communities in resilient landscapes with effective use of fires and response to fires? Once we have a more nuanced and realistic view of fires, how will our perceptions and language support for innovative fire management change?

Science can inform societal reaction to the challenging complexities of fire-related issues today, including costs, threats to people and property, ecological values, and impacts of fires. Collaboration and effective multi-way communication can build trust. Proactive and strategic fire management is needed, as are innovative technologies and ways of working together strategically to adapt and mitigate climate changes and other global changes to local ecosystems and local people while responding to regional and national priorities. We must focus on clear, strategic goals. We must be clear about uncertainties but we must not let uncertainty keep us from moving forward and learning as we go.

We authors dream that people will use fires as part of effective efforts to adapt and shape future fires and smoke. Time will tell if we achieve fire-adapted homes and communities in fire-resilient landscapes in ways that are socially just and sustainable. We hope and work to shape proactive approaches to fires that are good for our planet and people. Such efforts will be place-based, and filled with people learning from each other. We need innovative approaches that provide for the essential role of fire while reducing societal and ecosystem vulnerability to fire. Then, preparing for, enduring, and recovering from fires could include celebrating and using fire.

Ultimately, people must learn to balance realities. Wildfires and smoke will occur, some of those fires will be large and smoke will affect many people. Yet fires are part of the personality of forests, woodlands, shrublands, and grasslands, and without fires, these systems change. Those fires provide many of the ecosystem services people value, so let's learn from the many successful cases how to protect people, property, and economies from the adverse effects of fire and smoke. Both can be accomplished in landscapes where fires burn with an ecologically appropriate mix of low, moderate, and high severity, and with patch sizes and spatial patterns (Moritz et al. 2018). This requires engaging with fire and with people to find ways to sustainably use landscapes in ways that are ecologically appropriate, financially feasible, and socially acceptable.

As we move forward in what some have called the "Era of Megafires" (Hessburg 2017) or the "Pyrocene" (Pyne 2018), wildfires will continue to influence vegetation change, and therefore the goods and services people receive from ecosystems. We will keep learning from fires through rapidly changing science. We can choose how to manage fires to help shape how those wildfires affect future fires, land, and people for both the short- and long-term. Indeed, managing vegetation and communities so that they are resilient to fires is a worthy goal, and wildfires can help us achieve that resilience. If we do not engage with fires, using them to help us adapt and accomplish our land and resource management goals, then there will likely be widespread vegetation change at multiple spatial scales. Increasingly, society's environmental goals will include carbon sequestration, resilience, and adaptation to global change, all while effectively managing fires and their attendant smoke to increase positive impacts and lessen negative impacts on people and ecosystem services.

We must. We can. We will. We hope that our book is a contribution in that direction.

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