Cambridge University Press
978-0-521-82229-9 - Fire in the Forest
Peter A. Thomas and Rob McAlpine
Excerpt
More information

1 In the beginning

Welcome to *Fire in the Forest*. The ancient Greeks considered fire as one of the classical elemental forces along with water, earth and air; and indeed fire has helped shape the world around us to such a great extent that it would be hard to argue the point. Without a doubt, there is nothing on this planet that cannot be traced back (many times over) to some kind of fiery origin, whether that be the Big Bang at the origin of the universe, the atomic fires of some long dead pre-supernova star, the liquid burning rock just below the crust of the earth or the vegetation sitting frailly on the surface of the planet. While all of these forging fires are fascinating, a tome that spans the fullness of fire would be many volumes thick. The focus of this book is to explore the various facets of fires in forests: from how a single flame works, to what determines whether a forest will burn, to why huge forest fires occur and how they can be tackled. In this we will be dealing primarily with wildland fires – fires in the natural or semi-natural forest rather than those in plantations or in urban areas. These wildland fires have shaped the planet's biotic structure so we also focus on how plants and animals cope with fire, our own interaction with fire and ultimately our overall relationship with the whole planet. We hope that this book will be of use to anyone with an interest in how forest fires work and how they affect the forest. Our aim has been to make this sometimes complex world open and approachable to anyone with or without even a hazy knowledge of science.

When the first plants began to colonise the land of the early earth they adapted to the variously forming environmental niches. Into this inhospitable place, plants took hold and grew, but fire was there too. During rainless spells, when the land and plants dried out a little, lightning and even volcanoes would ignite fires. These fires would spread out, consuming the plants and releasing the nutrients back to the environment. Following the fires, more plants arose, utilising the nutrients that were now more freely available. This cycle was repeated almost endlessly, each successive cycle consuming another generation of plant life, and slowly changing the environment. In some climate zones, seasonal moisture would produce lush growth only to have it dry out at another time of the year resulting in frequent, sometimes annual burning, while other locations, due to a lack of fuel accumulation, or of near-constant fire-prohibiting moisture, or an infrequent ignition source, would see fire much less often. These climatic effects began to be drivers of evolution for plants, with species beginning to adapt to different degrees of burning and exploit the elemental force of fire as they would the other elements.

From the beginning our (human) relationship with fire has been two-sided. We exploited the use of fire for hunting and warmth, and our safety was threatened by fire. As civilisation evolved, our relationship with fire included cooking, forging of metals and further. However, this evolution eventually began to weaken our understanding of fire as a natural process. As civilisation has grown, fire has been increasingly containerised, first into the hearth then into internal combustion engines and power-generating plants, so we lost our experience and appreciation of the benefits of open fires while keeping our fear. Thus, to many, fire in the landscape became a wholly negative thing (more on that later!).

If we fast forward to today, we find fire is still an essential natural process in many ecosystems across the planet. Plants have evolved since they first colonised the land, not only into more complex organisms adapted to the weather and climate of various regions, but also adapted to the frequency and intensity of fires. Indeed many plants and animals have evolved to influence the fire cycle and to use fire to their own ends, thereby out-competing other organisms not so well adapted to fire, or adapted to a different fire regime. The range and ingenuity of these adaptations is as varied as life itself. Certainly we know that the world would look very different without fire. If we could completely remove all fire, grasslands would diminish greatly in size, and forest cover would increase from 30% to an estimated 56% of the vegetated land surface (Bond *et al.* 2004, Bowman 2005).

In this single volume we could not begin to address the wide range of fire effects and cover the breadth of fire management across the globe. Instead we have chosen some key fire-prone areas around the planet – the global fire powers of Canada, USA and Australia – and focused on them, with occasional diversions to neighbouring places for illustrative purposes. The boreal forest, dominated by pines and spruces, is a large fire-prone ecosystem, encircling the northern hemisphere. Over a third of the boreal forest lies within Canada and here lies one of our areas of focus. The USA contains a good deal of even more flammable forest vegetation which has its own story to tell. Australia is an island continent that perhaps lives with the most frequent and intense fire regime on the planet. From the arid grassland to the eucalypt forests, fire is an integral part of the land and the people.

The nature of fire

Within the ancient Greeks' four elemental forces, all except fire are matter based – earth, air and water are things that today are understood to be composed of matter. Only fire is different, and rather than an 'object' so to speak, it is a process. Certainly the other elements can be involved in processes (water for example can be an agent of change in erosion), but it is only fire that is really intangible and ephemeral. At the same time, fire is the only one of these elemental forces that we can unleash and to a certain extent control as a major ecological force. We can light fires but cannot start a volcanic eruption, hurricane or widespread flood. These facts demand a better understanding of what fire is. In chemical terms, fire is an oxidising agent – it combines one lump of matter with oxygen to produce another form of matter. Oxidation is often quite slow (as when oxidised iron turns to rust, for example) but in other cases, such as fire, it is a more rapid process. Some forms of matter when oxidised (combined with oxygen) react and release heat. In some cases (phosphorus for example) no heat is required to start this reaction, but in most cases (including fire) heat is required to initiate the reaction. The extra heat then generated by oxidation is sufficient to sustain the process until all the matter is transformed (or in the case of wood – fuel consumed).

To lay a broad background, fire is in essence the opposite of photosynthesis. Plants grow using photosynthesis to capture the energy of the sun and convert carbon dioxide and water into glucose (for plant structures) and release oxygen and water back into the atmosphere.

A simplified equation for photosynthesis is:

$$6CO_2 + 12\,H_2O + \text{sunlight yields } C_6H_{12}O_6 + 6\,O_2 + 6\,H_2O.$$

Or the same equation in recipe format:

6 parts carbon dioxide (CO_2) +
12 parts water (H_2O) +
sunlight

Yields:

One part glucose ($C_6H_{12}O_6$) +
6 parts oxygen (O_2) +
6 parts water (H_2O).

Of course, plants are composed of more than glucose, but glucose is the major building block of most structures (e.g. cellulose, wood) and for our purposes the essential element of concern. Additionally, there are a host of micronutrients and minerals required for the health of the plant (supplied by the soil). Where photosynthesis converts water and carbon dioxide into glucose, fire reverses this reaction, oxidising the glucose back into the original constituents and releasing the stored solar energy as heat and light. The difference between photosynthesis and fire (other than one being the reverse of the other) is the rate at which the two occur. A large tree (and by extension forest) collects solar energy over decades, centuries or millennia, while the stored energy can be released in minutes during a fire; consequently the energy release rates can be enormous. On a large, high-intensity wildfire, it is said that the energy equivalent of one Hiroshima-sized atomic bomb can be released every 20 minutes. It is worth remembering that the energy released during fire was captured from the sun and stored by the trees and vegetation; nature's first energy storage battery.

Looking back at the Greek philosophers, they seemed again to get things right – earth, air and water combine to form the trees and other vegetation with energy from the sun (at its heart an atomic fire). And when the process is reversed, the energy initially forged from the sun, and translated into form by trees and vegetation, is released by fire to consume the storage container and yield heat and light.

Just how widespread are forest fires?

A common question asked about fire is how much of the world's land surface is affected each year. Satellite imagery and ground-based estimates suggest that between 2000 and 2004 (a fairly normal period) the area burnt varied between 2.97 and 3.74 million km^2 each year, most of this in forests (Giglio *et al.* 2006, FAO 2007). This area, approximately the size of India, burnt each year you can see isolated in dark colours in Fig. 1.1. Or if you prefer, this is equivalent to just under a third of Canada, a little less of the USA, 40% of Australia or 12 times the area of the UK.

The next question usually asked is which parts of the world burn most often. Today across the planet, biomes (major vegetation types) have fallen into balance with the local climatic conditions, the soil richness and the preponderance of fire. There are few places that are immune to fire (Antarctica being one) but of a higher importance perhaps is the frequency that fires return to an area. This fire return interval within an area impacts the vegetation most profoundly.

Fig. 1.1 begins to describe a global picture of fire frequency. Darker areas of the map have a greater percentage of the 1° × 1° (latitude by longitude) cells burnt by fire annually, indicating a higher fire frequency. For fires of natural origin (that is, not started by humans – see Chapter 3) we see the darkest areas in the world's grasslands and savannahs. Unfortunately, Fig. 1.1 may be distorted from a 'natural'

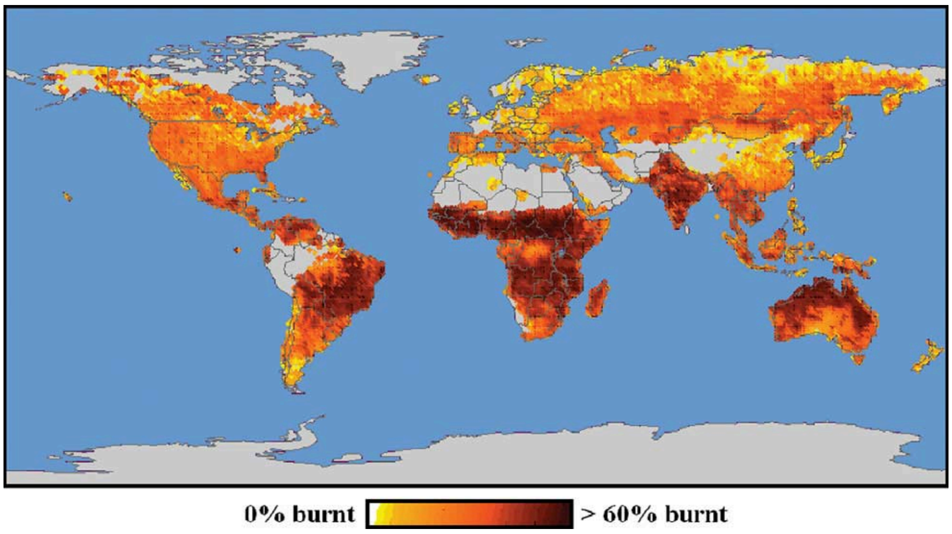

Figure 1.1
A 1° × 1° global map of average annual area burnt (% of cell burnt) for 1960–2000. © International Association of Wildland Fire 2009. Reproduced with permission from the *International Journal of Wildland Fire* **18**(5): 483–507 (Flannigan, M.D., Krachuck, M.A., de Groot, W.J., Wotton, M & Gowman, L.M.) DOI 10.1071/WF08187. Published by CSIRO Publishing, Melbourne, Australia.

fire cycle by tropical rainforest burning activities in South America and South-East Asia. Although the tropics are often too wet to burn, as described in Chapter 4, people clearing the forest, aided by El Niño droughts, let in fire. These can be huge fires: the Great Fire of Borneo between September 1982 and July 1983 burnt between 35 and 37 thousand km^2 – a hundredth of the normal global area burnt per year in just one fire (Johnson 1984).

However, a striking fact clearly visible from Fig. 1.1 is that generally where there is vegetation, there is fire (with few exceptions). The vast majority of these fires are not monitored or documented due to remoteness and so go largely unnoticed by the wider world. Some grassland areas burn almost every year (consequently keeping them grasslands!). This link between grasslands and high fire frequency begins to show us the linkage between the two – repeated fires on a near-annual basis do not allow longer-lived organisms to survive – they are repeatedly burnt back and not allowed to get a start. So the grassland ecosystem, home to many species of both flora and fauna, is dependent on frequent fire to maintain its character. Another example, although very different ecologically, is the eucalypt forests in many parts of Australia (Fig. 1.2). And as we see later in Chapter 6, most ecosystems are dependent on some level of fire frequency.

However, this understanding of the necessary role of fire in the ecosystem is only a relatively recent revelation for modern civilisation. This raises the perennial question of whether forest fires are indeed friend or foe. It was not until the 1960s that the essential role of fire was first suggested, and acceptance into the mainstream has taken decades. Even in the 1970s fire was mostly thought to be a bad thing: a Canadian Forestry Service publication called *Forest Enemies* (Anon 1973) included a section on fire. At the same time, the Canadian company Bombardier, who build water bombers, produced an educational video that described their machines as fighting the number one enemy of the forest. But our perspective has changed and our depth of understanding of fire has increased so that we now see some fires as useful and others as harmful. So the same dichotomy of the nature of fire exists for us; fire is useful (technologically) and an essential part of the ecosystems, but unmanaged/uncontrolled it can threaten lives, structures, infrastructure (and the dependent economies), and our way of life. This produces a problem; as Putz (2003) points out:

> In the glare of the conflagrations that consume forests and kill firefighters in western and northern North America every fire season, special care is required when trying to present fire in a positive light.

We therefore try and tread carefully in this book, aiming to give you the facts on how fires work in the landscape and why and how we try to control them, and to leave you to decide how you feel about the pros and cons of different fires.

Acceptance of fire has been hampered by the long-time ingrained desire and belief that nature can be tamed and dominated. This attitude not only drove fire

Figure 1.2
Recently burnt forest in Western Australia with greening vegetation immediately post-fire. Photograph by Rob McAlpine.

and land-management policies, but facilitated attitudes that people could build homes in 'natural' environments and expect their homes to be protected from fire. Governments have met this challenge and built complex firefighting organisations. Society now depends on these firefighters to protect people, homes, communities and the infrastructure that the economy depends upon (pipelines, hydro lines, telecommunication towers, railroads, crops, timber for homes etc.).

How firefighters meet the daily challenge that nature has set out, is a story unto itself. Complex organisations utilising state-of-the-art technology, adapting to various situations, meet the challenge of fire to protect what society demands it protects. However, as in all cases when humans contend with nature, there are wins and losses. New technologies improve capabilities, at an ever-increasing price tag, but on some days, the elemental force of fire conquers all.

Fire then is a conundrum – a basic elemental force of nature that cannot be held back, with ecosystems evolved the world over that require rebirth or rejuvenation

Figure 1.3
A fire burning in the boreal forest of Northern Ontario. Ontario Ministry of Natural Resources, copyright 2006 Queens Printer Ontario.

through fire; and humans who need to protect their lives and property from the destructive force of fire. Meeting that balance will challenge us all.

The Greeks recognised the fire shown in Fig. 1.3 as an element of nature. In this book we will look at wildland fire in several key locations around the world to understand how forest fires burn (Chapters 3 and 4), how ecosystems have integrated fire into their function (Chapters 5 and 6) and how we humans meet the challenge of fire (Chapter 7). From there we may start, from looking at the modern world, to understand why fire – a process and not a physical element – became part of the Ancients' elements. And finally we look to the future (Chapter 8) and the continuing and increasingly complex challenge of finding the balance for fire in the forest.

2 Historical review

The earliest beginnings of fire in geological time

Fires could not blaze until there was enough oxygen in the atmosphere and enough vegetation to burn. Oxygen began to appear in our atmosphere around 2 billion years ago (in the Archaean subdivision of the Precambrian Era) and reached its present-day level (21% of the atmosphere) around 600 million years ago. Life was still in the seas at this point – in fact it was only when oxygen reached these high levels that ozone could be formed high in the atmosphere which screened out harmful ultraviolet radiation and allowed complex life to invade the shallows and finally land. Oxygen levels since then have fluctuated between 15–35% of the atmosphere (Fig. 2.1). Coincidentally, fire needs a minimum of 13–15% oxygen to burn and above 35% spontaneous combustion is likely.

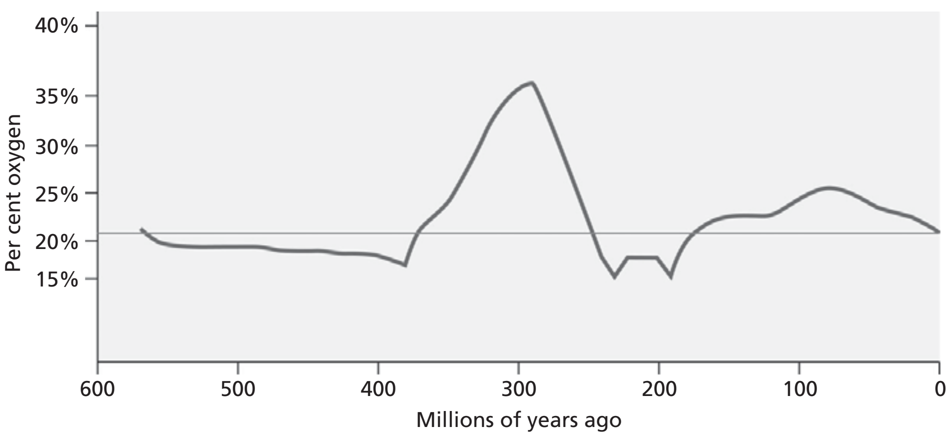

Figure 2.1
Changes in atmospheric oxygen level over the past 550 million years (the Phanerozoic Eon). The horizontal line shows the current concentration of 21%. Data from Dudley (1998) and Berner (1999).

How do we know when fires first started to appear? Fortunately, rock and coal layers contain a charcoal-like substance called fusain; small black fragments that often still contain the original cellular structure (Fig. 2.2). There has been a long debate about whether fusain is indeed a result of fire or whether it is from the much longer and slower oxidation process of weathering – see Box 2.1. But the consensus

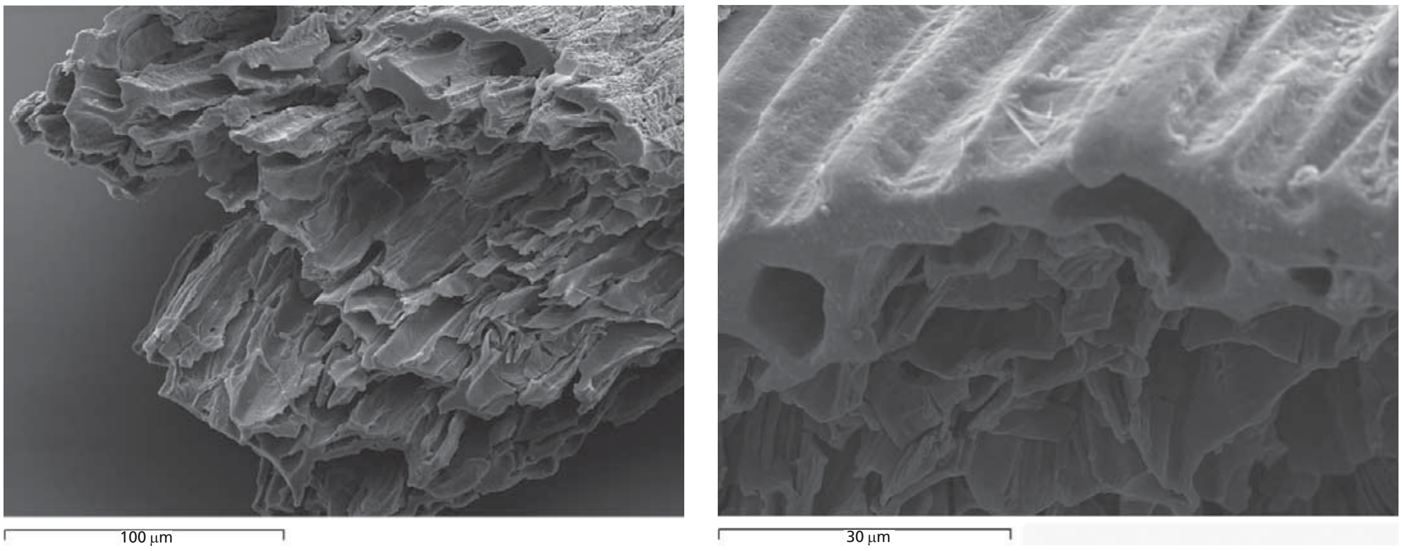

Figure 2.2
Charred plant fragments extracted from siltstone rocks found at Ludlow, England. These are evidence of the earliest wildfire so far documented that dates from the late Silurian (419 million years ago). The plant involved is a rhyniophyte, probably *Hollandophyton colliculum*, one of the first land plants just a few tens of centimetres tall, with leafless branched green stems and spore-producing cones. Photographs courtesy of Ian Glasspool, Dianne Edwards and Lindsey Axe.

Box 2.1. Is all black material from burning?

Blackened plant material may immediately makes us think of burning – as in the picture on the left of Fig. 2.3. But if plant material, such as the wood of the roots and old branches on the bristlecone pine on the right, is exposed for many years to the elements it weathers to the same chemical composition and approximate appearance as charcoal. In effect, slow oxidation in weathering and fast oxidation in fire create end products that superficially look similar. Weathering, however, normally produces a thinner more superficial layer of 'char' simply because the material is likely to finally rot or break apart before it has long enough to develop deep weathering. Moreover, oxidation by fire tends to lead to melting and blistering of the waxy cuticle over the plant surface (the epidermis) which can be seen even in fossil fragments, and most importantly experiments have shown that black fragments with a high reflectance are indicative of fire temperatures of at least 400 °C and generally the greater the reflectance, the greater the fire temperature.

Figure 2.3
On the left, logs burnt in a fire in New Brunswick, Canada showing extensive charring. On the right, a bristlecone pine (*Pinus aristata*) in the White Mountains, California that is probably over 4000 years old and which shows slow weathering of the exposed roots and old branches over millennia that superficially looks as though they have been burnt.

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now is that the majority of this fusain does indeed result from past fires to provide clues as to the origins of fire.

Fusain deposits suggest that fires have been burning since the Silurian, 419 million years ago (see Glasspool *et al.* 2004 for further information). These fires, started by abundant lightning, would have burnt through the first land plants that appeared around 430 million years ago (early Silurian). The immense coal-producing swamps of the Carboniferous (360–290 million years ago) provided abundant material to burn with their lush forests of giant ferns, horsetails and clubmosses (Fig. 2.4). Moreover, oxygen levels had risen to a peak at this time – up to around 35% of the atmosphere (Fig. 2.1) – helping fires burn more vigorously. But was there more fire then? Well, charcoal deposits became more common through the early to late Carboniferous, including in tropical wetland peats, but there is less than expected, probably due to a wet climate putting a damper on things. However, it is tempting to think that the first signs of adaptations in plants that allowed them to cope with fire began to appear during this period (although they may have evolved initially for other reasons). For example, the living tissue buried deep in the bark of the clubmoss-trees likely made them very fire tolerant.

As new types of plants evolved they would have met with a baptism of fire. Flammable conifers became abundant in the Triassic (around 245–208 million years ago) and would have met fire (See Uhl & Montenari, 2010). Oxygen levels dropped to 15% about 200 million years ago (the Jurassic) to rise again to around current levels as the broad-leaved hardwoods appeared in the early Cretaceous (120 million years ago). Fire must have played an important role in their evolution.

It is often suggested that the extinction of the dinosaurs at the Cretaceous–Tertiary (K–T) boundary 65 million years ago was due to the meteorite impact that created the 180-km diameter Chicxulub crater on the Yucatán Peninsula in Mexico, accompanied by huge 'global wildfires', the like of which had not occurred before or since. The evidence for the impact is overwhelming but the evidence for the fires is not compelling; the soot and charcoal in the rocks of this time could have been produced by fires that burnt gradually through lots of dry, dead vegetation killed by the sudden change in climate (Belcher *et al.* 2005). Evidence for this comes from microscopic examination which shows that more than 50% of charcoal fragments from the K–T boundary show signs of rotting, compared with less than 5% observed in modern fires. Moreover, studies in North America north of the Chicxulub crater found between four and eight times *less* charcoal in K–T rocks than in rocks above and below the boundary, suggesting that the huge meteor impact resulted in relatively few fires. Also, the structure of the soot associated with the charcoal from the K–T boundary appears to come primarily from the vaporisation of hydrocarbon-rich rocks rather than burning vegetation. Nichols & Johnson (2008) give an excellent account of the vegetation either side of the boundary.

Figure 2.4
What a clubmoss forest of the Carboniferous Period may have looked like. The cone-bearing trees in the middle distance and the fallen one in the middle are *Lepidodendron* (an early clubmoss). The trunk on the right is a tree fern and some of its foliage can just be seen at the top. The dead tree on the left is an early ancestor of the conifers, and, more centrally, an unbranched species of *Sigillaria*, another clubmoss. Grasses and flowering plants had not yet evolved but mosses, ferns and small horsetails (seen behind the tree fern) were abundant. The animal in the foreground is a labyrinthodont amphibian that spent most of its life in the water but which could walk on land. On the fallen trunk is a member of the extinct 'griffenflies' which included the largest insects ever to live, and which gave rise to modern dragonflies. These huge insects and abundance of fire are both attributable to the high levels of oxygen in the atmosphere (see Fig. 2.1). Drawn by Peter R. Hobson. From Thomas & Packham (2007).