Feature

Learning to live with landscape fires

Catastrophic wildfires have become more frequent in the last few decades. The standard depiction in the media of fires as a disaster that has to be avoided and stopped at all cost fails to do justice to a more complex ecological balance of destruction and new growth. The emerging discipline of pyrogeography aims to gain a holistic understanding of the role that fire plays in nature and the ways in which we can manage it sustainably. **Michael Gross** reports.

On Monday July 27th, southern France was burning, yet again, in several places. In the Gironde region southwest of Bordeaux, where vast pine forests were planted in the 19th century to stabilise and secure swamps and marshland, close to 600 hectares of forest were destroyed during the weekend before hundreds of fire fighters supported by the legendary Canadair water bombing airplanes managed to contain the flames. Around 270 residents had to be evacuated from their homes in threatened areas.

Some 700 km further east, in the department Var, a fresh mistral wind fanned the flames of several smaller fires forcing the evacuation of close to 10,000 people from campsites in the area. A day later, new fires threatened holidaymakers a bit further west, in the area of the Rhone river delta.

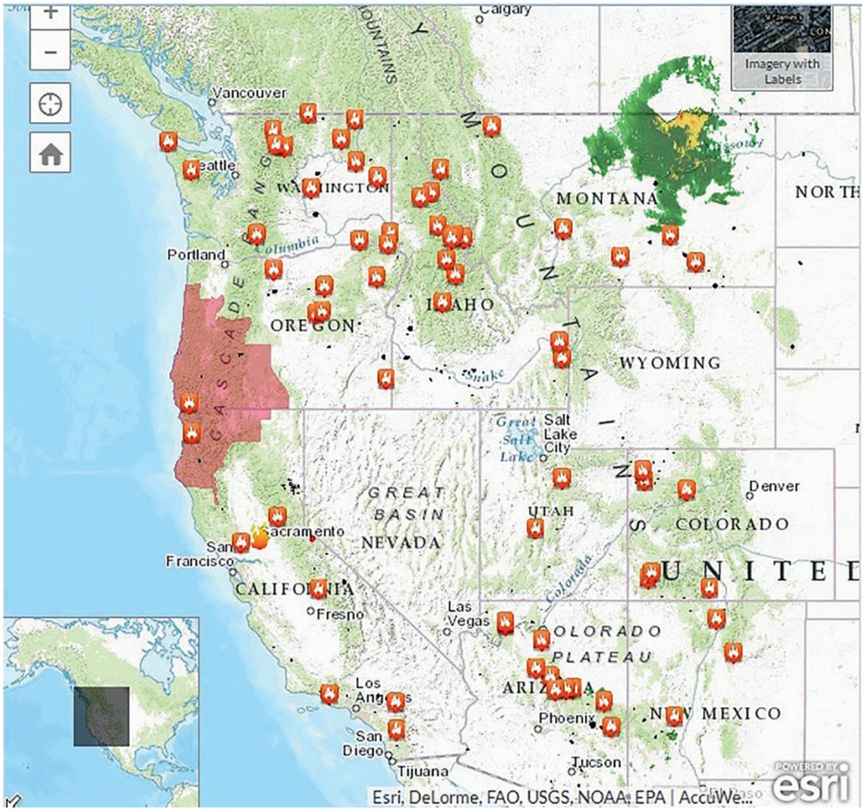
President François Hollande, visiting the Var on that Monday to show support, blamed the dry weather, called for extra vigilance and denounced the “negligence and stupidity” of people who accidentally start wildfires. However, he failed to draw attention to other important contributors to fire problems — such as the accumulation of biomass that can serve as fuel, disruption of natural fire cycles, and settlement in dangerous environments. The media, yet again, described this summer’s fires as disasters avoidable with sufficient care, but scientists who will be gathering at the Royal Society in London for a discussion meeting on *The Interaction of Fire and Mankind* on the 14th and 15th of September are painting a much more complex picture of the role that fire plays in many terrestrial ecosystems around the world.

Burning for 450 million years

The history of vegetation fire on our planet, which will be discussed during the first day of the Royal Society discussion meeting, spans 450 million years. Ignition from lightning was always available, so once vascular plants had begun to cover the continents with biomass and photosynthesis had added sufficient amounts of oxygen to the atmosphere, fire became a force of nature that helped to shape life on Earth. “For the last 450 million years of Earth’s history wildfires have had a major impact on the Earth system,” explains Claire Belcher from the wildFIRE Lab at the University of Exeter, who has edited the recent book *Fire Phenomena and the Earth System, an Interdisciplinary Guide to Fire Science* (Wiley 2013) and reviewed this field in chapter 12. “Over millions of years fires regulate the abundance of oxygen in the air that we breathe and are intimately tied to the evolutionary history of our ecosystems.”

There have then been four phases of fire ecology, which appeared successively with increasing impact produced by humans, but to some extent persist simultaneously today (for a review see D.M.J.S. Bowman *et al.*, Annu. Rev. Environ. Resourc. (2013) *38*, 57–80). First came the natural fire regime, which was in place before humans entered the scene and started to use fire for their purposes. It evolved as an equilibrium between the available biomass fuel, the local weather conditions, and the oxygen concentration in the air. The most fire-prone landscapes would have been those with intermediate humidity and seasonal dry periods, as permanently wet vegetation wouldn’t burn and permanently dry locations wouldn’t build up enough biomass to serve as fuel. In those intermediate climate conditions where fire became a regular event, plants evolved multiple adaptations both to resist fire and even to use it to their advantage. These include mechanisms of seed dispersal (serotiny in many species, including some *Pinus* and *Banksia*) and retention or shedding of combustible leaves or branches helping to direct the fire to areas where it is less damaging to the tree. Grasses with their reproductive systems shielded underground emerged as combustible but ultimately fire-resistant vegetation, explaining the dominance of savannah in subtropical areas around the globe that in the absence of fire would naturally be covered by forests. As

Fighting fire: A forest fire near Sydney, Australia, dwarfs a fire truck sent to contain it. (Photo: Stefan Doerr, Swansea University.)



Fire map: Current fire activity in the western United States in July 2015. (Source: http://www.esri.com/services/disaster-response/wildlandfire/latest-news-map)

our hominin ancestors are believed to have emerged in the African savannahs, fire has also shaped our evolution even before we learned to use it.

The second phase in the history of fire is defined by the deliberate use of fire by hunter-gatherer societies. While many animals display adaptive behaviours in response to fire and some raptors are believed to exploit the situation in preying on fleeing animals, humans are unique in domesticating fire and producing it at will, which became a defining feature of our species and also shaped our eating habits and thus the evolution of our physiology and anatomy. As David Bowman and colleagues point out, the likely emergence of fire use in the savannah landscape with frequent natural fires makes it impossible to trace the beginnings of this phase, but the earliest known use of fire by hominins is dated to around one million years ago. Around 400,000 years ago, fire use appears to be the standard for hominins.

With the beginnings of agriculture in the fertile crescent in the Levante and in a small number of other locations (Curr. Biol. (2013) *23*, R667–R670), additional uses of fire — beyond heating and cooking — entered the frame. It was used to clear land for cultivation and also to burn off residue after harvest. Studies of pre-industrial societies colonising new land, such as the Maori in New Zealand, have shown that the agricultural use of fire can profoundly shape the landscape and ecosystems.

Native Americans also used fire in sophisticated ways to shape their environment. During the Ecological Society's Annual Meeting of August 2014, for instance, Frank Lake, an ecologist with the US Forest Service's Pacific Southwest Station, and Don Hankins, a faculty associate at California State University at Chico and a member of the Miwok people, led a field trip to the Stone Lake National Wildfire Refuge for participants to learn about how Native Americans lived with wildfire. Ecosystem services provided by regular burning included regulation of the water supply.

California's native cultures burned patches of forest to access a sequence of different resources. The first year after a fire yielded sprouts for forage and basket-making. Within three to five years, shrubs produced a rich harvest of berries. Mature trees survived and provided the acorn harvest, but burning also made way for the next generation of trees, to ensure a consistent future crop. By opening the landscape, this pattern known as 'pyrodiversity' facilitated hunting and travelling.

"They were aware of the succession, so they staggered burns by 5 to 10 years to create mosaics of forest in different stages, which added a lot of diversity for a short proximity area of the same forest type," Lake said ahead of the conference. "Complex tribal knowledge of that pattern across the landscape gave them access to different serial stages of soil and vegetation when tribes made their seasonal rounds."

In his presentation at the Royal Society Bowman will argue that fire, both natural and anthropogenic, must be integrated in food webs rather than seen as an external 'disturbance' — this awareness is at the core of the genius of indigenous fire usage that sustained biodiversity and created many landscapes colonised by Europeans.

To this day, agricultural fires represent an important part of the global fire activity and thus of the carbon cycle. They are estimated to account for a third of the anthropogenic combustion of vegetation. Slash-and-burn agriculture persists in some parts and has been blamed for soil erosion in Madagascar (Curr. Biol. (2012) *22*, R287–R289), although other uses of fire in agriculture are considered sustainable. Agricultural societies also went on to develop other advanced uses of fire, e.g. in pottery and metallurgy.

The final transition, adding a fourth kind of fire use to the picture, is industrialisation with its heavy reliance on burning fuels, which rapidly progressed from wood to fossil fuels, leading first to deforestation, then to the dramatic increase in the atmospheric concentration of carbon dioxide and onwards to man-made climate change and health problems caused by air pollution.

While hunter-gatherers used fire locally, farmers burned down entire forests and changed the landscapes of continents, and industrialised societies used fire to an extent that changed even the composition of the atmosphere and the trajectory of the global climate. This last phase can be linked to the Anthropocene, the as yet unofficial stage in the history of our planet in which the Earth system is shaped by human activities on a global scale (Curr. Biol. (2015) *25*, R131–R134).

These four phases overlay today to create a very complex situation. It is made more difficult by unintended consequences of human activities, including (ironically) fire suppression, land-use change, and lowering of groundwater levels through intensive water use. And the problems are not limited to the very media-friendly sights of forests going up in flames. What happens underground, in smouldering peat layers, may in fact be a bigger threat.

Staying safe: Elk escaping a wildfire in the Bitterroot National Forest in Montana, USA. As fire has been a natural part of many ecosystems for over four hundred million years, many plant and animal species have evolved suitable responses for survival. (Photo: John McColgan/USDA.)

Fire underground

Peatlands are an important natural carbon sink currently storing around a quarter of the global soil carbon, but they are under threat from human activities, including drainage, peat harvesting and land-use change (Nat. Geosci. (2015) *8*, 11–14). Susan Page from the University of Leicester, UK, has studied changes that have affected tropical peatlands in southeast Asia over the last two decades. Drainage for logging and agriculture has made these ecosystems more sensitive to fire. Due to the dense nature of peats, there is no shortage of fuel, and the spread of smouldering fires is mainly controlled by heat transfer and humidity. Since the drought caused by the El Niño event in 1997–1998, peat fires during the dry season have become a recurring problem causing carbon dioxide release on a globally significant scale, along with particulate pollution and biodiversity loss on a regional scale.

While the amount of emissions from tropical peat fires is still difficult to quantify and methods of monitoring and reporting need to be improved, there is the risk that climate change will further contribute to making these peatlands more vulnerable to burning, thus engaging them in a positive feedback loop that could accelerate the increase in atmospheric carbon dioxide concentrations. Page will describe these problems on the second day of the Royal Society discussion meeting and will also point out opportunities to reduce the impact of these anthropogenic fires with policy changes. “Any action to reduce the incidence of fire has to address human behaviours and activities,” Page explains. “There need to be strong policy initiatives followed up by strong policy implementation and ‘policing’. In addition, there needs to be much greater awareness of the increased susceptibility of the new land covers to an enhanced risk of fire. Some of the main actors involved in plantation agriculture, e.g. most of the largest palm oil producers and traders, now have policy statements on aspects of social and environmental sustainability, in part in response to international pressure for improved environmental and social practices.” These policies include a ban on burning. It is important, says Page, that such policies are also adopted by small-holders who often resort to slash-and-burn as a cheap option for land clearing.

In boreal regions, peat fires have historically been confined to the very uppermost level, regulated by humidity of the deeper layers. As such fires encourage new growth, they are believed to be carbon neutral. In disturbed peatlands, however, fire can progress to deeper layers and release carbon that has been stored for centuries, making it a significant source of carbon emissions (Nat. Geosci. (2015) *8*, 11–14).

A major challenge in the assessment of the carbon balance of peat fires results from the fact that they happen underground and it is difficult to monitor key parameters like temperature and chemical composition in situ. Victoria Hudspith from the University of Exeter, UK, and colleagues have recently demonstrated that light reflectance analysis of charcoal residues retrieved after a peat fire can be used to assess the minimum temperature during the charring process (Front. Plant Sci. (2014) *5*, article 714). Specifically, the researchers investigated a partially drained peat bog in Ireland after a fire and could associate different amounts of heating with specific types of fuel in the peatland.

Charcoal and other types of pyrogenic (black) carbon can also play an important role in the carbon balance of wildfires in general, as Cristina Santín from Swansea University, UK,

New growth: The scene of a large fire in Yellowstone National Park, USA, photographed in 2006, almost 20 years after the event. (Photo: Daniel Mayer/Wikimedia Commons.)

and colleagues have pointed out in a recent review (Global Change Biol. (2015) http://dx.doi.org/10.1111/gcb.12985). While the carbon balance of wildfires in natural fire regimes is generally assumed to be neutral on the timescale of decades, with CO_2 emissions balanced out by the growth of new vegetation, pyrogenic carbon such as charcoal and soot can persist in the environment for centuries, thus acting as an efficient carbon sink.

Fire at the wildland–urban interface

Wildfires in the remote wilderness, such as much of the Australian outback, can still run their course as they did before humans arrived, producing mosaic patterns of burnt and regenerating areas. Serious problems arise where fire-prone vegetation meets human settlements sprawling out from the cities. Known as the wildland–urban interface or WUI, the picturesque landscape with houses scattered among vegetation has increased dramatically since the 1970s, particularly in fire-prone areas of the western United States, where the phenomenon has been studied in some detail.

In a recent review, Max Moritz from the University of California at Berkeley and colleagues have analysed the problem in three regions (western US, Australia, Mediterranean) using a coupled socioecological systems (SES) approach (Nature (2014) *515*, 58–66). Site-specific climatic and ecological parameters as well as divergent sociological context render this problem highly complex, the authors find, such that no generalisable solutions exist.

In the Mediterranean, for instance, human influences have shaped the landscape for millennia to an extent that any natural or even pre-agricultural fire regime that may have existed before cannot serve as a model. In Australia and the US, by contrast, natural and hunter-gatherer fire regimes (such as the Native American management regimes described above) are known and can serve at least as a reference in more remote areas where there is no immediate danger to human lives and infrastructures.

The emerging consensus acknowledges that generalised fire suppression in fire-prone landscapes, as practiced throughout the 20th century, is counterproductive, as it suppresses ecosystem services that natural fires supply and allows dangerous amounts of fuel to build up, such that fires will become more devastating and dangerous when they inevitably do happen. Instead, depending on the ecological and settlement context at the WUI, various strategies may work.

In southern California, where the combustible biomass is mostly in the shape of chaparral brush lands, land-owners can hire herds of goats to reduce the fuel and save themselves the trouble of mechanically clearing it. Controlled burning is also applied in some areas, e.g. in Australia, but is often controversial. Attention to detail is necessary if controlled burning is to emulate the ecosystem services and biodiversity benefits of natural fire regimes. Applied in the wrong place or time, burning may encourage invasive grass species and ultimately replace woods with even more combustible grasslands.

Most importantly, to stop the conflict zone from spreading further, planning and building regulation should take into account that vegetation fires will happen. Much like earthquakes, their occurrence must be considered and romantic ideas of living in a natural environment — which in reality is still man-made — may have to be scaled down in favour of living in safety. "Viewing fire as a natural and inevitable hazard should be central to most solutions, so we can anticipate its important positive and negative effects on both human and natural systems," Moritz and colleagues conclude.

The emerging discipline of pyrogeography as defined by Bowman and colleagues (Annu. Rev. Environ. Resourc. (2013) *38*, 57–80) combines biological, atmospheric and social perspectives on fire. Meg Krawchuk from Simon Fraser University at Burnaby, Canada, and Max Moritz have argued that statistical analyses of global fire data are another important component of the new discipline (Environmetrics (2014) http://dx.doi.org/10.1002/env.2287). Only quantitative understanding of when and where fires happen will enable scientists to predict how global fire activity will respond to climate change.

As the global population and its exposure at the WUI keep growing and climate change is bound to affect the environmental parameters governing wildfires, we will need a better and more comprehensive understanding of how we can live with fire.

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