or ice. However, in regions of rapid upward transport by deep convection, VSLSs and their decay products can reach the stratosphere and deplete the ozone layer. In Eastern China, for example, chloroform emitted near the Earth's surface can be transported rapidly to the upper troposphere and lower stratosphere by the Asian monsoon. Fang and colleagues estimate that if chloroform emissions continue to increase at current rates, the recovery of the ozone layer could be delayed by 4 to 8 years.

Continuous observations of ozone-depleting substances are not only crucial to ensure compliance with environmental regulations, such as the Montreal Protocol, but are also essential to detect changes in unregulated compounds such as chlorinated VSLSs. We need to understand sources of halogenated VSLSs, including their location and change over time, to represent them realistically in models and to assess their effects on the ozone layer. Such knowledge relies heavily on global in-situ measurement networks and the interpretation of the data from high-resolution inverse modelling.

Fang and colleagues[1] present multiple pieces of evidence that atmospheric concentrations of chloroform are increasing globally, and that China's industrial emissions are responsible for this increase. The findings mark an important step towards opening the discussion of regulating the anthropogenic VSLS emissions. ❐

Susann Tegtmeier
GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany.
e-mail: stegtmeier@geomar.de

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FIRE ECOLOGY

Burning questions about ecosystems

Cumulative wildfires or prescribed burning produce different outcomes for the vegetation, suggest two long-term analyses of fire-affected ecosystems. Climate change and land management practices are altering how ecosystems function.

Mark A. Cochrane

Wildfires are often thought of as solely destructive in nature. They are also frequently forgotten about once the flames are out. However, most terrestrial vegetation has evolved over millions of years in the presence of periodic wildfires[1]. Consequently, long-term persistence and health of many ecosystems is tied to experiencing wildfires with characteristic fire regimes — patterns of frequency, size, seasonal timing, fire behaviour and ecosystem effects. Within a given climate, neither the vegetation nor the associated fire regime can be changed in isolation. To alter one is to set in motion changes in the other. The interplay between fire and vegetation landscapes has important ecosystem-specific implications for sustainable land management and climate change mitigation practices. Writing in *Nature Geoscience*, Marrs et al.[2] and Bowd et al.[3] report how indirect effects of fires can persist long after the flames are quenched and can be linked to sustainable management and land use practices in boreal moorlands and Australian forests, respectively.

Peat forms as partially decayed vegetation builds up in a variety of wetland ecosystems over many years. Substantial amounts of atmospheric carbon are sequestered during the process. Peat accumulation is fastest when soils are saturated or flooded. Much of the world's peat has formed in boreal regions over the past 12,000 years[4], in layers that can be metres thick. Warming and erratic climates threaten long-term carbon storage in many peatlands. For example, drought and heat enable aerobic decomposition and wildfires that consume the accumulated peat soils and turn these carbon sinks into sources of atmospheric carbon. It is an open question whether or not peatlands can be sustainably managed so that they can continue to sequester carbon as the climate changes.

Marrs et al.[2] explore net rates of peat accumulation in boreal moorlands that were subjected to different frequencies of prescribed burning over the past 150 years. They analyse the vertical structure of peat cores using diagnostic deposition layers of atmospheric pollutants that are calibrated with radiometric dating techniques to quantify peat accumulation and carbon sequestration rates associated with different burn frequencies. They find that more frequent prescribed burning improved species diversity and the abundance of peat-forming species, but the net amount of carbon sequestered was partially reduced by each fire.

In the absence of fire, woody species progressively dominate moorlands. As large quantities of woody fuel accumulate, the risk that intense wildfires will ignite the peat soils grows. Wildfires are a natural, if rare, occurrence in peatlands. Fire return intervals are typically measured in centuries but they happen under the most adverse weather conditions, which can lead to rapid, deep and extensive losses of accumulated carbon[5]. Globally, wildfire danger, associated with frequent droughts, heatwaves and weather conditions that support rapid fire spread rates, is increasing[6]. Prescribed burning during moderate weather conditions causes minimal peat loss, keeps peat-forming species abundance high and lowers wildfire risk by reducing build-ups of woody fuels and species. Marrs et al. conclude that carbon sequestration benefits can be maintained in healthy and diverse moorlands through the application of a 20-year prescribed burning rotation, thereby mitigating the growing wildfire risks posed by climate change.

In southeastern Australia, Bowd et al.[3] investigate soils from a 168-year chronosequence of wildfires and logging disturbance in mountain ash (*Eucalyptus regnans*) forests to uncover the depth and

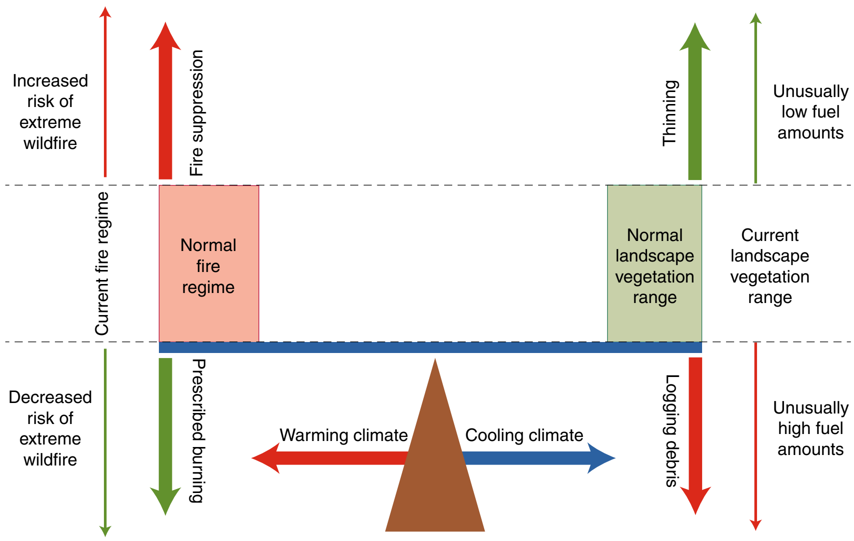

Fig. 1 | The balance between fire regimes and vegetation. Under historical conditions, fire regimes and vegetation exist in equilibrium on landscape scales. Climate change alters the balance, which forces eventual changes both to fire regimes and vegetation to achieve a new equilibrium. Human resource management and land use activities can intensify or mitigate these effects by reducing or increasing the risk of extreme, ecosystem-altering wildfires. Marrs et al.[2] and Bowd et al.[3], respectively, illustrate the interactions between wildfire and ecosystems by showing the sustained carbon storage potential during climate change in fire-managed peatlands in the UK and significant, cumulative biogeochemical impacts to soils in mountain ash forests that have been disturbed by frequent logging and wildfires in Australia.

duration of post-disturbance soil attribute changes underlying some of the tallest trees the world has ever known[7]. They find significant changes of soil composition and fertility in a range of near-surface and deeper soils that endure for eight decades after wildfire, and three decades after logging. Larger impacts were observed at sites subjected to multiple disturbance events.

Bowd and co-authors emphasize that these forests are being subjected to a much greater frequency of disturbance than would have occurred naturally — fire return intervals are normally in the range of 75–150 years. Human activities and exacerbated climate conditions are rapidly changing disturbance regimes experienced by the forests. During the past century, many forest stands have experienced multiple disturbances. Five high-intensity wildfires and various post-fire logging and clear-felling operations have swept across the landscape. Little understanding, however, has been gained about how the accumulating legacy of soil impacts will affect these ecosystems.

Bowd et al. do not postulate linkages between the altered soil traits they observed and potential vegetation impacts, so what these changes may mean for the future of mountain ash forests is speculative. Cumulative losses of nutrients, such as available phosphorous and nitrate, are perhaps the clearest threat to future regrowth potential. Regrettably, their methods do not allow partitioning of soil nutrient losses between those volatized during wildfires or exported off the site through post-fire soil erosion and those pulled from the soils into rapidly regrowing trees. Additional study is clearly needed, but the research does indicate that soils underneath these forests are effectively being mined and degraded by prevalent wildfire and logging disturbances.

Climate change is initiating a process of shifting fire regimes, altering vegetation beyond what human land use choices have already wrought (Fig. 1). Bowd et al. provide evidence that these changes can be cryptic, invisibly accumulating within the soils that support entire ecosystems, and that this process is accelerated by increased disturbance. Marrs et al. turn the process around, intentionally altering moorland fire regimes to essentially fight fire with fire by controlling when and under what conditions these ecosystems burn. Managing moorlands in this way may mitigate future wildfire risks and sustain their carbon sequestration and environmental services.

The studies by Bowd et al.[3] and Marrs et al.[2] explore dynamic connections between fire effects and ecosystems. They also illustrate the level of understanding that will be needed for ecosystem management everywhere if we are going to foresee, mitigate, or potentially forestall deleterious environmental developments across a changing planet. ❐

Mark A. Cochrane
Appalachian Laboratory, University of Maryland Center for Environmental Science (UMCES), Frostburg, MD, USA.
e-mail: mark.cochrane@umces.edu

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