The interaction of fire and mankind: Introduction.

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Abstract
Fire has been an important part of the Earth System for over 350 million years. Humans evolved in this fiery world and are the only animals to have used and controlled fire. The interaction of mankind with fire is a complex one, with both positive and negative aspects. Humans have long used fire for heating, cooking, landscape management and agriculture, as well as for pyrotechnologies and in industrial processes over more recent centuries. Many landscapes need fire but population expansion into wildland areas creates a tension between different interest groups. Extinguishing wildfires may not always be the correct solution. A combination of factors, including the problem of invasive plants, landscape change, climate change, population growth, human health, economic, social and cultural attitudes that may be transnational make a re-evaluation of fire and mankind necessary. The Royal Society meeting on Fire and Mankind was held to address these issues and the results of these deliberations are published in this volume.

"We are uniquely fire creatures on a uniquely fire planet"
S.J.Pyne.

1. Introduction

The evidence of fire on Earth goes back over 400 million years [1, 2] and has been a significant part of the Earth System for 350 million years [3]. The occurrence of fire from the study of fossil charcoal has allowed our understanding of the role fire plays on the Earth to develop rapidly over the past 30 years [4]. Fire, often referred to as wildfire, has been and is an important part of the Earth System [5]. At times in Earth history, fire has influenced the evolution of plants and terrestrial ecosystems and played a role in the regulation of atmospheric oxygen [6,7,8,9]. It is in a fire-rich world that hominins evolved [10] and the unique ability they developed was to create and use fire in myriad ways [11]. Added to lightning as the main ignition source [12] we now have the addition of human ignitions that have transformed our planet [13,14]. Fire is a natural phenomenon and may have a positive role to play on Earth and early humans have been able to use fire for useful and productive ends, such as a source of heat, for cooking, hunting, and agricultural practices [15]. The move by human populations from the countryside, where the use of fire is familiar, to living in cities where fire is contained, has been termed 'the pyric transition' [16]. This has led to the demonization of fire despite the fact that many types of vegetation and the ecosystems that they inhabit need fire in order to survive [17]. The encroachment of human populations into wildland areas that may naturally experience frequent fire has led to a number of disastrous consequences that have both political and economic dimensions [18]. A clearer understanding of fire on Earth and the way in which humans can interact with fire is critical for an ongoing debate on coping with the consequences of projected future climate change.

The complex interrelationships between fire and mankind transcend international borders and disciplinary boundaries [12]. Projections of future climate change and the influence that they may have on Earth's fire regimes highlights the need to disentangle these relationships and build an understanding of them both across space and though time [19]. A Discussion meeting titled 'Fire and Mankind' was held at the Royal Society in London from 14-15 September 2015. This meeting examined historical, evolutionary, and biophysical tensions inherent in the fire-climate-society nexus to advance the international, interdisciplinary science necessary to address contemporary and future fire challenges.

Wildfire is increasingly seen on the news, from California, Australia, from the Mediterranean region and has aroused extreme public and media interest (both popular and scientific) [20]. The emphasis of many of these reports is that fires are 'bad' and should be extinguished. Recent research has emphasised the role of fire not only on the modern world but also in deep time [2,16,21]. There is an increasing realization that fire is a major Earth System Process [4] affecting not only the atmosphere but also the biosphere in profound ways. Further, it has been recently established [22] that increasing global temperatures will lead to increased fire risk and indeed recent studies suggest that the increase is greater during periods of rapid global change [23]. Fire has not only an impact on the landscape and vegetation but also on humans [12]. This is a significant paradox. Fire is essential to the health of many plant communities and is used by Mankind but is also hazardous to Mankind, not only from the fire itself but also from smoke and from post-fire erosion and flooding. It was, therefore, particularly timely to bring together some of the world's leading fire scientists to discuss the impact of fire on the biosphere, including humans, to discuss the role that mankind is playing in altering the nature of fire systems and to examine the central paradox that fire is both a destructive yet essential element of the Earth System and the regulation of that system.

Scientific research on wildfire is scattered among a wide range of scientific communities, each publishing in their own scholarly journals: from those involved in

Earth observation; those involved in fire modelling including the linkage between fire and climate change; those studying the physics and chemistry of fire; the impact of fire on vegetation, including the soil; those interested in fire as a hazard at the human/vegetation interface including those studying post-fire erosion and flooding and impacts on human health and the societal impact of fires. We believe that this is the first meeting integrating all these aspects of wildfire, which crosses both the sciences and the humanities. The results of this meeting will help raise the profile of the fire research that has such an impact on a wide range of disciplines and help contribute to many ongoing debates in the community, which includes both science and the humanities. We wanted to emphasise four of these debates. 1. The role of fire in the Earth System: What was the impact and role of fire before the evolution of humans? How has the human use of fire changed the nature of fire on Earth? 2. What are the historic and present tensions of mankind using fire and living in a fire environment? How can a better understanding of the scientific issues inform public policy debate? 3. What are the ranges of impacts that fire has on mankind? Is there a 'one size fits all' to our understanding and perception of fire? How do humans, both populations and the media from different regions, perceive fire – as a help or hazard? 4. What are the links between climate change, vegetational change and fire and how might a better understanding of these issues help future planners and policy makers? How might our current understanding feed in to the idea of sustainable fire systems? As such under the structure of the meeting Session 1 examined the role of fire through time in the Earth System and a consideration of the historical interaction of fire with humans. The session further examined ways that the impact of humans on fire systems could be inferred from the fossil record and ended with a broad consideration of the perception of fire by human cultures. Session 2 examined the developing relationships between fire and humans from case studies in North America from the first human arrival through the changing population structure and change in climate and the complex interaction of humans in Australia and Africa. Session 3 considered current conflicts of fire and mankind, such as the impact of fire on the soil system, the impact on fire both on water supply and quality as well as the broad issue of fire and human health, particularly as a result of exposure to smoke. Session 4 examined a number of current issues of fire and mankind, in particular considered both changing climate and vegetation. The role of new satellite technology in helping to distinguish natural wildfires and those started by humans was explored. The programme ended with an analysis of how fire systems would be affected by climate change and provided a springboard for final discussions.

The London meeting appealed to a diverse group of scientists from a variety of disciplines from earth sciences to the biosciences, geography, archaeology and anthropology as well as from many other disciplines in both the sciences and humanities. In this issue, we expect that the papers that follow have similarly broad appeal and have been written with a wide readership in mind. Following the London meeting, a workshop was held at the Kavli International Centre between 16 and 17 September. Discussions at this meeting focused on reviewing the key issues, barriers and opportunities for science to contribute towards building a new understanding of the role of fire on Earth at this critical time when we are face with the management challenges of climate change and what this may mean to the general population. *From this workshop, a statement 'The Chicheley Declaration: a vision for wildfire research in 2050' was developed. All of the attendees at the Kavli workshop who have signed the declaration are presented in box 1.*

BOX 1

The Chicheley Declaration: A Vision for Wildfire Research in 2050

A two-day workshop was held on September 16-17th 2015 at the Kavli International Centre, Chicheley Hall, Buckinghamshire, United Kingdom. Over the course of plenary discussions interspersed between breakout groups over the two-day meeting, the group of participants articulated a need for a holistic, ongoing, interdisciplinary, and international scholarly framework for fire research. Summarized and restated below, we propose the following Chicheley Declaration.

Participants at the meeting and whom have agreed to the declaration are:

Professor Sally Archibald
Jonathan Aylen
Professor Jennifer K. Balch
Professor David J. Beerling FRS
Professor Claire M. Belcher
Professor Rebecca Bliege Bird
Professor William J. Bond
Professor David Bowman
Professor Matthew S. Carroll
Professor William G. Chaloner FRS
Dr. Michael R. Coughlan
Professor Stefan H. Doerr
Dr. Rory Hadden
Dr. Victoria A. Hudspith
Professor Bart R. Johnson
Dr. Fay Johnston
Dr. Nicholas Kettridge
Julia McMorrow
Dr. James D.A. Millington
Professor Susan E. Page
Professor Mitchell J. Power
Professor Stephen Pyne
Dr. Francesco Restuccia
Professor Christopher I. Roos
Dr. Cristina Santin
Professor Andrew C. Scott
Professor Toddi Steelman
Professor Thomas W. Swetnam
Nicholas G. Walding
Professor Martin Wooster

The Chicheley Declaration:

By 2050, global mean temperatures are expected to be at least 1-2° C warmer than the early 20th century, potentially altering fire regimes by transforming vegetation in fire-prone landscapes and making previously low fire-risk regions more flammable. With globally interconnected economies and population exceeding 9 Billion by 2050, all fire challenges will be human-fire challenges. It is therefore imperative that wildfire research that has heretofore been fragmented as sub-disciplines among physical, biological and social sciences, engineering, and humanities be integrated across disciplinary and national academic frameworks so that research and policy can tackle 21st century fire problems. We believe that wildfire should be considered in terms that recognize diverse natural and human tensions that may vary across cultural settings.

To continue the forward momentum in shaping this newly integrated field we wish to:

- *Encourage the development of National and International funding programmes that are cross- and multi-disciplinary in nature in relation to wildfire and mankind.*
- *Encourage scientific, public, media, and political discussion that will lead to informed decisions relating to wildfire and help shape forward planning.*
- *Encourage the means of further disseminating high quality multidisciplinary research on wildfire so as to support meaningful debate and further growth in the holistic, transdisciplinary study of wildfire on Earth across space and time.*

There has been increasing recognition of the science behind our understanding of fire [24]. This is highlighted by the fact that fire is one of the most newsworthy hazards and features heavily in media reports [22] even the role of fire in the fossil record features [23]. What is important, however, is to reach not only the general public but also the politicians and decision makers. There needs to be an increasing awareness of the nature of fire as mankind continues to move into flammable systems at the wildland urban interface ecosystems. Equally there needs to be a wider recognition of changes to fire risk due to climatic change in areas that currently experience little fire activity. Fire may not only have an impact on the vegetation (and houses built within the burnt area) but is also a threat to human health from fire produced smoke and fire's influence on post-fire erosion, flooding and its potential to contaminate water supplies. The role of exotic invasive plants fueling fire is now also receiving attention [25, 16]. In countries with a fire history there is increasing realization of the need to understand fire and to plan ahead. However, in other countries where fire is not common this is not so – for example in England, Surrey is one of the most forested areas and changing climate may increase the risk of catastrophic fire (beyond small yet important fires [26]). There is little appreciation of this potential risk by the local population and the potential impact that a major wildfire would have.

Broadly speaking, sustainability safeguards contemporary human health, property, and livelihoods without compromising those of future generations or the integrity of our environment. These dimensions have fire at their core – it is capable of threatening or enhancing them. This meeting explored the interrelationships of these four pillars in the context of a fifth – climate change – with implications for socio-environmental sustainability.

This Themed Issue contains a cross section of current research, much of which is fundamentally cross- and inter-disciplinary in nature.

2. Fire and Early Humans

Our understanding of fire in deep time comes mainly from the fossil record of charcoal [3] and in some cases its botanical identity that can reveal information on the vegetation being burned. More recently attempts to understand ancient fires have included data from charcoal reflectance that provides some information regarding pyrolysis intensity [3,27]. New approaches have the potential of providing further information about ancient fire systems that includes not only quantitative analysis of charcoal distribution but combine additional palaeontological data with experimental observations in order to better understand palaeoecological changes in ecosystems. Belcher [28] takes an innovative experimental approach by examining the flammability of 15 species of conifer litter in order to explore the relationships between litter fire behaviour and leaf traits that can be more broadly applied to ancient fire records.

It is important to distinguish between natural fire systems from those that have been influenced by humans. As is well understood, the use of fire distinguishes hominins from other animals. Finding how hominins first used and controlled fire is complex and as Gowlett [29] points out the discovery of fire use may be seen as a set of processes happening over a long period of time rather than being a discrete event. Once discovered, used, and controlled fire, has had a number of influences, perhaps among its early benefits was providing the ability to cook food, thereby changing the quality of human diet with attendant increases in brain size [30]. Gowlett shows that although evidence of fire use may be as old as 1.5 million years it is only over the past 40,000 years that widespread use of fire can be more easily documented and postulates such as the cooking hypothesis or the social brain can be evaluated. It is clear, however, that fire control had a major impact in the course of human evolution. Gowlett shows that the interaction of humans with fire changes through time where initial contact and use of fire was opportunistic, subsequently limited or conserved before becoming important in human activities, actively kindled and used in more modern ways.

3. The developing relationship of fire and humans.

Even at periods when human impact on fire may be widespread there is still a clear climatic signal on fire occurrence in the more recent past. Power and others [31] examine the microscopic charcoal record from a series of boreholes and construct fire history, climate change and vegetation dynamics over a 12,000 year period in Bolivia. Their data indicates that it is moisture variability that is the dominant control upon community turnover in the ecosystem. The data is important as it is demonstrated that although there is a resilience of the vegetation to fire this may not necessarily continue into the future where there will not only be increased temperatures and drought but also because of increasing human ignitions.

The human interaction with fire is a complex one. As Pyne [32] shows, fire has played an important role even in the intellectual development of western culture. The concept of fire has changed in the minds of humans polarizing between fire that is revered, worshiped and used to being feared and suppressed as the population moves within the landscape.

Trying to unravel the influence of natural and human-started fire in palaeoecological records is complex and the competing signals are faint. The well-dated arrival of humans into North America around 13,000 years before present (13kabp) may offer a unique opportunity to unravel the knot. Hardiman and co-workers [33] document the fire history of the California Channel Islands especially as seen in Arlington Canyon on Santa Rosa Island from 19-11kabp. These authors use macroscopic charcoal in fluvial sediments to interpret the fire history. The charcoal is dated but importantly these authors selected young wood or charcoal from herbaceous plants to eliminate the 'old wood' problem [34, 35] as well as to minimize the chance of reworking. They show that fire is important before human arrival on the island but increases between 14 and 12.5 kabp at the time of human arrival but also at a time of major climate changes. The fire history does not support a single fire event but an increase over a 1000-year period. While the evidence is equivocal, it is probable that human activity had a significant impact on the natural fire system that was already changing as a result of climate change.

The interaction of human and natural fire and climate is also considered by Swetnam and co-workers [36] looking at the past 700 years of fire history in Western North America across spatial scales. Much of these data comes from tree-ring and fire scar data from more than 800 forest stands over an area of around 4 million km^2. These authors are able to show that the abundance and continuity of fuel is the most important variable in fire regimes in this area and that ancient human influence reduced widespread fire by promoting many small fires that ultimately reduced fuel continuity.

Our understanding of the complexity of modern fire systems has increased significantly over the past few years. Bowman and others [37] demonstrate that the diversity of fire systems, or pyrodiversity, must be understood in terms of feedbacks between fire regimes, biodiversity and ecological processes. These authors are not just concerned with the natural fire system but also consider how humans shape pyrodiversity both directly and indirectly. Understanding these complex interactions is important not just in terms of human-fire inter-relationships but also in the context of climate change and ecological conservation.

Nowhere has the complexity between humans and natural fire environments been shown more vividly than in Africa, the cradle of human evolution. Bond and Zaloumis [38] consider the problem of the extent of C4 grassy biomes that are highly flammable. These savannas grow in areas that are warm and wet enough to support closed forests but frequent fires keep these grasslands open. This has often been attributed to the activities of humans igniting frequent fires. This new research, however, throws doubt on the importance of human activities on the maintenance of these significant biomes. They show that these grassy biomes are ancient and that that the fires that maintain them are also ancient and the idea that humans caused large-scale deforestation is not supported. This is significant as it is important to distinguish between ancient grasslands that should not be afforested and secondary grasslands that may be suitable for reforestation, using indicators of old growth grasslands that include the recognition of fire tolerant species.

4. Fire and humans: Current conflicts

Fire has many significant impacts on the terrestrial Earth System. These may be both obvious but also hidden so that they are not generally appreciated. Santin and Doerr [39] consider the important issue of fire effects on soils. Soils are of major significance to human populations but fire effects are often considered less than other aspects such as intensive agricultural practices or climate change. Fire has long been used as a tool for soil fertilization and to control plant growth but until recently its role in vegetational change, erosion and desertification has received less attention. The significance of these complex interactions is coming into sharper focus when considering future climate change.

The influence of fire and water supply is the focus of the paper by Martin [40]. The impacts of water are diverse, not just from the changing water availability from greater human use but also as a result of climate change. Recent research has highlighted the problem of post-fire erosion and the potential of water contamination as has been seen following the 2002 Hayman fire near Denver, USA. Other cities may also experience problems with their water supply following fire such as the major Australian cities of Sydney, Canberra, Melbourne and Adelaide. The problem of water is highlighted not only because of its use for drinking or agriculture but also as a method of extinguishing fires. For those not familiar with fire, the thought of water contamination may not have been considered.

Smoke from fires is certainly rarely been considered in relation to human health and may now be categorized as a silent killer. Johnston and colleagues [41] review the significance of air pollution from landscape fires, domestic fires as well as from fossil fuel combustion that should now be considered an important environmental risk factor for human mortality. Unraveling the different types of combustion risks is complex and these authors propose a pyrohealth transition whereby human health can be improved by reducing the environmental impacts on the Earth System that will require considerable reduction in both landscape burning and fossil fuel combustion.

5. Fire and humans: current and future problems

The reaction to the human use of fire may be extreme whereby it may be suppressed unnecessarily. Mistry and others [42] examine how fire is playing an increasingly significant role in tropical forests and ecosystems both in terms of greenhouse gas emissions and their impact upon biodiversity. Their research shows that in some areas community owned solutions for fire management may be the way ahead. It is important for policy makers to accept that fire suppression is not the only mechanism and that sustainable fire management maybe possible given a co-operative environment whereby all stakeholders have a say.

Unrestricted logging, drainage of tropical peatlands and land use changes may also have a significant impact upon not only the environment but also on the nature of fires and their consequences. Page and Hooijer [43] review the problem of the peatlands of Southeast Asia. These peatlands are a significant component of the global carbon cycle and they have become increasingly unstable through human interaction. Not only does drainage of peatlands lead to an increasing tendency for fire but also long-term effects on the Earth System are only now becoming apparent. The impacts of these peat fires are of international scope not only from introducing more carbon dioxide into the atmosphere but also from smoke pollution that crosses international boundaries. The problems of these tropical peatlands may become increasingly relevant to northern latitude peatlands as the climate changes.

Unraveling the emissions of carbon dioxide from a range of combustion sources is no easy matter as pointed out by Balch and Colleagues [44] (part of the International Pyrogeography Research Group). This problem is important as the world seeks agreement to reduce carbon dioxide emissions from fossil fuel burning. What is often forgotten is the contribution of carbon dioxide emissions from landscape (biomass) burning. What is also often forgotten is that the carbon dioxide released by biomass burning was part of the general atmospheric content until it was fixed by photosynthesis within the last few hundred years. This places it in a different category from the carbon dioxide released by fossil fuel burning, where the carbon released into the atmosphere has been 'out of circulation' for many millions of years. In terms of impact on long-term climate change, this makes these two sources of carbon significantly different. There has been a significant change between 1997 and 2010 of the proportion of carbon emissions from landscape and fossil fuel burning with the global average annual carbon emissions from landscape biomass burning being approximately 1/3 of the fossil fuel emissions. These different emissions types varied across the globe and suggest that combustion practices may be shifting from open landscape burning to contained combustion for industrial purposes. An understanding of different emission types and how they change through not only climate change but also through population movements and industrial development is, and will be, important for future policy makers considering the impact of climate change.

Our understanding of natural and human induced fire systems has been further complicated by global climate change. In an important addition to the debate on the impacts of climate change Westerling [45] provides new data that shows in the Western US forests wildfire activity has changed as a direct result of changes in the timing of spring, especially snowmelt. He demonstrates that increases in large wildfires associated with earlier spring snowmelt scale exponentially with changes in moisture deficit.

6. Contradiction, conflict, and compromise: addressing the many dimensions of sustainability in human-fire-climate relationships

An additional meeting at the Kavli International Centre at Chicheley Hall followed the discussion meeting in London. Here some of the issues raised were tackled in more depth taking into account the additional problems caused by climate change. Several keynote papers were given to help focus discussions later in the meeting.

Australia has often been used as a place where natural and human fire has been widely discussed and debated. Bliege Bird and colleagues [46] provide a useful case study examining these complex relationships. The rich historic and ethnographic evidence of Aboriginal burning has led some scholars to suggest that the Australian continent was transformed by anthropogenic burning [47], only to have this position dismissed when palaeofire records demonstrate significant correlations with climate variation [48,49]. In their novel analysis, both anthropogenic and lightning fire regimes respond to antecedent rainfall, albeit in divergent ways and for different reasons, thus suggesting that strong fire-climate relationships can coexist with anthropogenic fire regimes that have significant impacts on biodiversity and ecosystem structure.

Africa also has concerns about human ignitions and their negative impacts as discussed by Archibald [50]. However, the research presented here shows the different ways that people impact fire regimes in these grassy ecosystems in Africa and that currently the area burned is now less than over the past several thousand years. The efforts to change these fire regimes as a method to control carbon dioxide emissions may, therefore, be misplaced. The importance may not simply be how much burns but how it burns and much more informed political, environmental and scientific debate is needed.

If there is significant uncertainty on the impact of climate change may have on fire systems where fire is well known and studied, then this is even more so for areas, such as the United Kingdom, where fire is not widely considered as significant. In England fire has been used for centuries to manage many cultural landscapes. Recent attitudes among the public, media and policy makers have tended to consider burning as an ecologically damaging practice. This problem is highlighted by an important synthesis of Davies and colleagues [51]. These authors highlight the nature of different types of fire and the need to distinguish between the impacts of fires with different severity and frequency. These authors highlight the importance of unbiased and informed debate on the use of fire as an ecological management tool. This is and will be an important discussion in the context of future climate change.

The attitude of the public to both natural and human ignitions is complex. How populations consider the risk of living in a fire-prone system is highlighted by Carroll and Paveglio [52]. This is becoming increasingly important, as there is a significant expansion of the wildland-urban interface in many parts of the world. The challenge that is faced is in how to increase human community 'adaptiveness' to deal with risk and reality of fire in a variety of landscapes.

If the challenges considering risk in landscapes where fire is common then problems in countries, such as England, of developing wildfire policy where fire is uncommon but where this may change in the future, is more complex. Gazzard and colleagues [53] highlight how public policy has changed over the past two decades. Surprisingly fire statistics have only allowed wildfires to be spatially documented on a national scale since 2009. Just as in America with the 1988 Yellowstone fires or the 2002 Hayman fire near Denver, Colorado, the 2011 Swinley Forest fire that threatened critical infrastructure and communities 50 miles from London was important in changing attitudes and perceptions. These authors conclude that a co-coordinated policy is now needed to identify best practice and promote understanding of the role of fire in the ecosystem.

From local to global scale many of the issues are still the same. In their important analysis Doerr and Santín [54] look at the Global trends in wildfire and their impacts and our reaction to those changing risks. They highlight the changing perception of fire and risk in many different societies. While direct fatalities from fire and economic losses show no clear trends over the past 30 years despite media claims, our knowledge of indirect effects is much less. The paper highlights the need to consider a more sustainable coexistence of fire and Mankind in the light of global predictions for increased fire under a warming climate.

These papers were presented in advance of group discussions at the Kavli Centre that were held under three broad themes. Discussion group one considered transnational issues for fire in a warming world: domestic and international policy on health, economic and community impacts of fire across borders, led by Fay Johnston and Toddi Steelman. Discussion group two led by Michael Coughlan and Bart Johnson considered sustainable communities in fire-prone settings: cultural, institutional and ecological challenges. Discussion group three looked at living in a future with fire: challenges for sustainable communities with little history of fire challenges and was led by Julia McMorrow and Jonathan Aylan. These discussions have been summarized by Christopher Roos, the meeting organizers and the discussion group leaders [55]. This summary paper represents an important attempt to clarify major scientific, economic, cultural and political issues in relation to fire in a world undergoing climate change and makes recommendations aimed at helping inform national and international policy debates on fire.

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Endnote

Fire and Mankind, The Royal Society, London, 14-15 September 2015. Followed by Contradiction, conflict, and compromise: addressing the many dimensions of sustainability in human-fire-climate relationships, The Royal Society, Chicheley Hall, 16-17 September 2015

Guest editor biographies

Andrew C. Scott is a Distinguished Research Fellow and Emeritus Professor of Geology in the Department of Earth Sciences at Royal Holloway, University of London. His first teaching post was at Chelsea College, University of London and the department merged with Kings College and Bedford College Geology Departments to form the new Geology Department at Royal Holloway University of London in 1985. He was awarded a personal chair in Applied Palaeobotany in 1996. He held a visiting Professorship at Yale University in 2006-7. His research has dealt with aspects of palaeobotany, palynology, coal geology (for which he was awarded the Geological Society of America Cady Award), petrology and geochemistry and the geological history of wildfire. His work on charcoal in deep time had led to not only an understanding of the role of fire in the Earth System but also involved the use of charcoal in coal as an atmospheric oxygen proxy. He is the lead author of the book “Fire on Earth: An Introduction”.

Bill Chaloner is Emeritus Professor of Botany in the Earth Sciences Department at Royal Holloway, University of London, and Visiting Professor in Earth Sciences at University College, London. His first teaching post was in Botany at University College, moving to take the Chair of Botany at Birkbeck College, and thence to Bedford College until its merger with Royal Holloway

College. He has held visiting professorships at the University of Nigeria, at Penn State University and at the University of Massachusetts. His research has dealt with the fossil record of the history of plant life on land from the Silurian to the present and the response of plant life to changes in atmospheric composition and climate. He has also explored the relationship between the fossil spore (palynological) record and that of plant macrofossils as a means of elucidating the palaeoecology of the terrestrial environment.

Claire Belcher is an Earth scientist specialising in the study of natural fires and the role that they play in regulating the Earth system. She graduated from Royal Holloway University of London with a degree in Geology in 2000. She then undertook an MSc in Micropalaeontology at University College London, graduating in 2001 before returning to Royal Holloway to undertake her PhD. She completed her PhD in 2005 entitled "Assessing the evidence for extensive wildfires at the Cretaceous-Tertiary Boundary" and has continued to build on this fiery start ever since. She then moved to University College Dublin to work at the Programme for Experimental Atmospheres and Climate (PEAC) facility where she focused on the relationship between ancient wildfires and variations in palaeoatmospheric composition. In 2010 she moved to The University of Edinburgh to hold a unique position joint between BRE Centre for Fire Safety Engineering and the School of Geosciences. Since January 2012 she has been a Senior Lecturer in Earth System Science at the University of Exeter. Claire is the team leader of a 1.52 million euro European Research Council Starter Grant that seeks to understand the impact of plant evolution on wildfires in ancient ecosystems. Her research is internationally recognised for integrating state-of-the-art modern experimental methods into studies of Earth's ancient past, an approach which is well highlighted by her recently published edited book "Fire Phenomena and the Earth System an Interdisciplinary Guide to Fire Science".

Christopher I. Roos is an environmental archaeologist and Associate Professor in the Department of Anthropology, Southern Methodist University, and is a Faculty Associate of the Laboratory of Tree-Ring Research at the University of Arizona. His primary research investigates multi-century to multi-millennial dynamics of human-fire-climate relationships to inform contemporary fire management discussions. For more than a decade, he has been directing interdisciplinary archaeological and paleoecological research programs in the Southwestern United States to evaluate how traditional land-use by American Indian hunting and farming communities altered the vulnerability of fire-prone dry conifer forests to severe droughts. In addition to his Southwest US projects, he has active human-fire-climate research projects in the Republic of Fiji and in the North American Great Plains.

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