

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

44 world that hominins evolved [10] and the unique ability they developed was to create
45 and use fire in myriad ways [11]. Added to lightning as the main ignition source [12]
46 we now have the addition of human ignitions that have transformed our planet
47 [13,14]. Fire is a natural phenomenon and may have a positive role to play on Earth
48 and early humans have been able to use fire for useful and productive ends, such as a
49 source of heat, for cooking, hunting, and agricultural practices [15]. The move by
50 human populations from the countryside, where the use of fire is familiar, to living in
51 cities where fire is contained, has been termed ‘the pyric transition’ [16]. This has led
52 to the demonization of fire despite the fact that many types of vegetation and the
53 ecosystems that they inhabit need fire in order to survive [17]. The encroachment of
54 human populations into wildland areas that may naturally experience frequent fire has
55 led to a number of disastrous consequences that have both political and economic
56 dimensions [18]. A clearer understanding of fire on Earth and the way in which
57 humans can interact with fire is critical for an ongoing debate on coping with the
58 consequences of projected future climate change.

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

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

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

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

124 The London meeting appealed to a diverse group of scientists from a variety
125 of disciplines from earth sciences to the biosciences, geography, archaeology and
126 anthropology as well as from many other disciplines in both the sciences and
127 humanities. In this issue, we expect that the papers that follow have similarly broad
128 appeal and have been written with a wide readership in mind. Following the London
129 meeting, a workshop was held at the Kavli International Centre between 16 and 17
130 September. Discussions at this meeting focused on reviewing the key issues, barriers
131 and opportunities for science to contribute towards building a new understanding of

132 the role of fire on Earth at this critical time when we are face with the management
 133 challenges of climate change and what this may mean to the general population. *From*
 134 *this workshop, a statement 'The Chicheley Declaration: a vision for wildfire research*
 135 *in 2050' was developed. All of the attendees at the Kavli workshop who have signed*
 136 *the declaration are presented in box 1.*

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138 BOX 1

139 The Chicheley Declaration: A Vision for Wildfire Research in 2050

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

147

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

149

150 Professor Sally Archibald	165 Dr. Fay Johnston
151 Jonathan Aylen	166 Dr. Nicholas Kettridge
152 Professor Jennifer K. Balch	167 Julia McMorrow
153 Professor David J. Beerling FRS	168 Dr. James D.A. Millington
154 Professor Claire M. Belcher	169 Professor Susan E. Page
155 Professor Rebecca Bliege Bird	170 Professor Mitchell J. Power
156 Professor William J. Bond	171 Professor Stephen Pyne
157 Professor David Bowman	172 Dr. Francesco Restuccia
158 Professor Matthew S. Carroll	173 Professor Christopher I. Roos
159 Professor William G. Chaloner FRS	174 Dr. Cristina Santin
160 Dr. Michael R. Coughlan	175 Professor Andrew C. Scott
161 Professor Stefan H. Doerr	176 Professor Toddi Steelman
162 Dr. Rory Hadden	177 Professor Thomas W. Swetnam
163 Dr. Victoria A. Hudspith	178 Nicholas G. Walding
164 Professor Bart R. Johnson	179 Professor Martin Wooster

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181 The Chicheley Declaration:

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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

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

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

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255 3. The developing relationship of fire and humans.

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

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

268 Trying to unravel the influence of natural and human-started fire in palaeoecological
269 records is complex and the competing signals are faint. The well-dated arrival of humans into
270 North America around 13,000 years before present (13kbp) may offer a unique opportunity to
271 unravel the knot. Hardiman and co-workers [33] document the fire history of the California
272 Channel Islands especially as seen in Arlington Canyon on Santa Rosa Island from 19-11kbp.
273 These authors use macroscopic charcoal in fluvial sediments to interpret the fire history. The
274 charcoal is dated but importantly these authors selected young wood or charcoal from herbaceous

275 plants to eliminate the ‘old wood’ problem [34, 35] as well as to minimize the chance of
276 reworking. They show that fire is important before human arrival on the island but increases
277 between 14 and 12.5 kbp at the time of human arrival but also at a time of major climate changes.
278 The fire history does not support a single fire event but an increase over a 1000-year period. While
279 the evidence is equivocal, it is probable that human activity had a significant impact on the natural
280 fire system that was already changing as a result of climate change.

281 The interaction of human and natural fire and climate is also considered by Swetnam and
282 co-workers [36] looking at the past 700 years of fire history in Western North America across
283 spatial scales. Much of these data comes from tree-ring and fire scar data from more than 800
284 forest stands over an area of around 4 million km². These authors are able to show that the
285 abundance and continuity of fuel is the most important variable in fire regimes in this area and that
286 ancient human influence reduced widespread fire by promoting many small fires that ultimately
287 reduced fuel continuity.

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

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

307

308 4. Fire and humans: Current conflicts

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

317 The influence of fire and water supply is the focus of the paper by Martin [40]. The impacts
318 of water are diverse, not just from the changing water availability from greater human use but also
319 as a result of climate change. Recent research has highlighted the problem of post-fire erosion and

320 the potential of water contamination as has been seen following the 2002 Hayman fire near Denver,
321 USA. Other cities may also experience problems with their water supply following fire such as the
322 major Australian cities of Sydney, Canberra, Melbourne and Adelaide. The problem of water is
323 highlighted not only because of its use for drinking or agriculture but also as a method of
324 extinguishing fires. For those not familiar with fire, the thought of water contamination may not
325 have been considered.

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

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335 5. Fire and humans: current and future problems

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

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

353 Unraveling the emissions of carbon dioxide from a range of combustion sources is no easy
354 matter as pointed out by Balch and Colleagues [44] (part of the International Pyrogeography
355 Research Group). This problem is important as the world seeks agreement to reduce carbon dioxide
356 emissions from fossil fuel burning. What is often forgotten is the contribution of carbon dioxide
357 emissions from landscape (biomass) burning. What is also often forgotten is that the carbon
358 dioxide released by biomass burning was part of the general atmospheric content until it was fixed
359 by photosynthesis within the last few hundred years. This places it in a different category from the
360 carbon dioxide released by fossil fuel burning, where the carbon released into the atmosphere has
361 been 'out of circulation' for many millions of years. In terms of impact on long-term climate
362 change, this makes these two sources of carbon significantly different. There has been a significant
363 change between 1997 and 2010 of the proportion of carbon emissions from landscape and fossil
364 fuel burning with the global average annual carbon emissions from landscape biomass burning

365 being approximately 1/3 of the fossil fuel emissions. These different emissions types varied across
366 the globe and suggest that combustion practices may be shifting from open landscape burning to
367 contained combustion for industrial purposes. An understanding of different emission types and
368 how they change through not only climate change but also through population movements and
369 industrial development is, and will be, important for future policy makers considering the impact of
370 climate change.

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

377

378 6. Contradiction, conflict, and compromise: addressing the many dimensions of 379 sustainability in human-fire-climate relationships

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

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

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

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

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

415 If the challenges considering risk in landscapes where fire is common then problems in
416 countries, such as England, of developing wildfire policy where fire is uncommon but where this
417 may change in the future, is more complex. Gazzard and colleagues [53] highlight how public
418 policy has changed over the past two decades. Surprisingly fire statistics have only allowed
419 wildfires to be spatially documented on a national scale since 2009. Just as in America with the
420 1988 Yellowstone fires or the 2002 Hayman fire near Denver, Colorado, the 2011 Swinley Forest
421 fire that threatened critical infrastructure and communities 50 miles from London was important in
422 changing attitudes and perceptions. These authors conclude that a co-coordinated policy is now
423 needed to identify best practice and promote understanding of the role of fire in the ecosystem.

424 From local to global scale many of the issues are still the same. In their important analysis
425 Doerr and Santín [54] look at the Global trends in wildfire and their impacts and our reaction to
426 those changing risks. They highlight the changing perception of fire and risk in many different
427 societies. While direct fatalities from fire and economic losses show no clear trends over the past
428 30 years despite media claims, our knowledge of indirect effects is much less. The paper highlights
429 the need to consider a more sustainable coexistence of fire and Mankind in the light of global
430 predictions for increased fire under a warming climate.

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

443

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453 Endnote

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

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Guest editor biographies



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

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

482 College. He has held visiting professorships at the University of Nigeria, at Penn State University
483 and at the University of Massachusetts. His research has dealt with the fossil record of the history
484 of plant life on land from the Silurian to the present and the response of plant life to changes in
485 atmospheric composition and climate. He has also explored the relationship between the fossil
486 spore (palynological) record and that of plant macrofossils as a means of elucidating the
487 palaeoecology of the terrestrial environment.
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491 Claire Belcher is an Earth scientist specialising in the study of natural fires and the role that they
492 play in regulating the Earth system. She graduated from Royal Holloway University of London
493 with a degree in Geology in 2000. She then undertook an MSc in Micropalaeontology at University
494 College London, graduating in 2001 before returning to Royal Holloway to undertake her PhD. She
495 completed her PhD in 2005 entitled "Assessing the evidence for extensive wildfires at the
496 Cretaceous-Tertiary Boundary" and has continued to build on this fiery start ever since.
497 She then moved to University College Dublin to work at the Programme for Experimental
498 Atmospheres and Climate (PEAC) facility where she focused on the relationship between ancient
499 wildfires and variations in palaeoatmospheric composition. In 2010 she moved to The University
500 of Edinburgh to hold a unique position joint between BRE Centre for Fire Safety Engineering and
501 the School of Geosciences. Since January 2012 she has been a Senior Lecturer in Earth System
502 Science at the University of Exeter. Claire is the team leader of a 1.52 million euro European
503 Research Council Starter Grant that seeks to understand the impact of plant evolution on wildfires
504 in ancient ecosystems. Her research is internationally recognised for integrating state-of-the-art
505 modern experimental methods into studies of Earth's ancient past, an approach which is well
506 highlighted by her recently published edited book "Fire Phenomena and the Earth System an
507 Interdisciplinary Guide to Fire Science".
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 510 Christopher I. Roos is an environmental archaeologist and Associate Professor in the Department
 511 of Anthropology, Southern Methodist University, and is a Faculty Associate of the Laboratory of
 512 Tree-Ring Research at the University of Arizona. His primary research investigates multi-century
 513 to multi-millennial dynamics of human-fire-climate relationships to inform contemporary fire
 514 management discussions. For more than a decade, he has been directing interdisciplinary
 515 archaeological and paleoecological research programs in the Southwestern United States to
 516 evaluate how traditional land-use by American Indian hunting and farming communities altered the
 517 vulnerability of fire-prone dry conifer forests to severe droughts. In addition to his Southwest US
 518 projects, he has active human-fire-climate research projects in the Republic of Fiji and in the North
 519 American Great Plains.
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