FORUM ARTICLE

AUSTRALIA—A MODEL SYSTEM FOR THE DEVELOPMENT OF PYROGEOGRAPHY

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ABSTRACT

We define pyrogeography as an integrative, multidisciplinary perspective of landscape fire, its ecological effects, and its relationships with human societies. Like biogeography, this program spans geographic scales from the local to the global, has an evolutionary frame, and thus a geological dimension. And, like other geographic disciplines, pyrogeography has a clear commitment to understanding the interrelationships between cultures and their environment. We illustrate our approach by considering the pyrogeography of Australia. We demonstrate how a long history of fire has had a pervasive influence on the continent's biota. While Aborigines coexisted with flammable landscapes for millennia, contemporary Australian society is still learning to live in a land of fire.

Keywords: Australia; climate change, eucalypts, *Eucalyptus*, fire regimes, natural disasters

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INTRODUCTION

Fire is an ever-present and essential feature of our lives, without which we would not be the species we are, given our dependence on cooked food (Wrangham *et al.* 1999). It is ironic, therefore, that industrial civilization, with its rich scientific traditions, has struggled to meaningfully understand the totality of fire that necessarily spans many fields of science (including physics, chemistry, biology, geology, and medicine) and the humanities (including the arts, economics, planning, and governance). Pyne (2009) notes that the rise of scientific disciplines since the enlightenment fragmented understandings and theories about fire and its numerous effects. Fire was reduced from being an essential element to a physiochemical process. As a consequence, fire is now studied in numerous fields of inquiry with no common intellectual tradition. This diversity has had the unintended consequence of obscuring our capacity to think about fire in a holistic way. Here, we present our personal perspective on the development of modern Western views of landscape fire along with the nascent field of pyrogeography.

HOW DARWIN MISUNDERSTOOD FIRE

Despite visiting Australia, Charles Darwin did not recognize the importance of fire as an ecological and evolutionary factor worthy of inquiry and reflection. A search of the *Origin of Species* reveals that the word 'fire' is only used once and then only as a metaphor to describe the abundant evidence of past climate change associated with recent glaciations in the northern hemisphere:

The ruins of a house burnt by fire do not tell their tale more plainly, than do the mountains of Scotland and Wales, with their scored flanks, polished surfaces, and perched boulders, of the icy streams with which their valleys were lately filled. (Darwin 1859)

Yet there is no question that Darwin was exposed to fire-patterned landscapes in his journeys, such as in his traverse of the Blue Mountains near Sydney, Australia, where he observed a bushfire on an extremely hot day (Nicholas and Nicholas 2002). In the Blue Mountains, his attention was focused on the geology and geomorphology of the sandstone plateau, and he made no mention of the anomalous small stands of temperate rainforests in fire refugia in the bases of canyons that he explored. Indeed, uncharacteristically for such a brilliant naturalist, Darwin showed no curiosity about the ubiquity and diversity of fire-tolerant eucalypts (*Eucalyptus* L'Hér.) that he observed in Tasmania, New South Wales, and Western Australia. Darwin dismissed the burnt eucalypt forest of the Blue Mountains as boring, recording in his diary on 19 January 1836 that:

...in the whole country I scarcely saw a place, without the marks of fire; whether these may be more or less recent, whether the stumps are more or less black, is the greatest change, which breaks the universal monotony that wearies the eyes of a traveller. (Nicholas and Nicholas 2002)

In sum, Darwin did not understand fire and fire-patterned vegetation, failing to think about the role of fire in a geological or evolutionary framework. By the late nineteenth century, Schimper's extraordinary *Plant-Geography upon a Physiological Basis* (Schimper 1903) described the close correspondence between global climate and vegetation zones that left no place for fire in explaining global vegetation distributions. However, this view was soon challenged (Sauer 1950), and today it is widely accepted that fire decouples vegetation from climate (Bond *et al.* 2005).

An interesting thought experiment is to wonder how we would conceptualize and study fire had Darwin recognized that fire is an essential feature of life on Earth. This exercise is more than idle musing, because our industrial civilization's mode of thinking about fire is clearly inadequate. The global surge of catastrophic fires challenges the intellectual basis of the fire suppression paradigms that have sustained the political belief that, with sufficient investment and technology, landscape fire can be effectively controlled, rendering inherently flammable landscapes safe for urban development (e.g., Wuerthner 2006, Boxall and Cart 2008). Yet more disturbing than the ingrained debates about fire management, is the dawning realization that landscape fires are having long-term and insidious effects on the Earth system that could drive a feedback between climate change, increasingly hostile fire regimes, and the loss of ecosystem services (Bowman *et al.* 2009). We need to understand fire in a more holistic way if we are to achieve sustainability and safe flammable landscapes, especially in a period of rapid global environmental change. But what would such holistic thinking look like?

We suggest that understanding fire demands many different perspectives that are difficult to disaggregrate, yet can be broadly divided into the domains of nature and culture. Indeed, Western cultural attitudes may have impeded appreciation of fire as a fundamental ecological factor in many ecosystems, as seems the case for Charles Darwin. While fire is a purely natural phenomenon with a deep geological history on Earth, wielded by humans it has become an emergent property of nature and culture. This has profound implications for management of flammable landscapes, and makes returning fire regimes to a natural, pre-human state a futile objective. We illustrate our path to understanding fire on Earth in this way by reference to a number of Australian case studies.

AUSTRALIA—A LAND OF FIRE

The Australian continent is an ideal model to illustrate the capacity of pyrogeography to develop a more holistic view of fire. Australia is dominated by fire-adapted vegetation that spans a range of climate zones including temperate, Mediterranean, arid, and the monsoon and humid tropics. Humans arrived around 50 thousand years ago from southeast Asia (Roberts *et al.* 1990, Turney *et al.* 2001); yet despite this ancient human presence, industrialized cultures did not establish effective colonies until the early nineteenth century. This mixed human history makes it possible to study the ecological impacts of hunter-gatherer fire and chart what happens when their tradition of fire use is disrupted. Given the recent spate of destructive bushfires in southern Australia, understanding the drivers of uncontrolled fires is of considerable policy relevance. Why fire should so dominate the ecology of Australia remains a major research challenge, and is at the heart of debates about Australian biogeography. Scientific recognition of fire in driving the ecology only occurred in the second half of the nineteenth century, and there remains limited acceptance of this reality amongst many Australians.

One of the classic questions in Australian fire ecology concerns the origin, evolutionary development, and ecology of rainforests. Unlike the rest of the world, the term 'rainforest' is used in Australia to define a broad variety of woody vegetation types that are more susceptible to recurrent fire than the ubiquitous, fire-adapted vegetation dominated by eucalypts (Bowman 2000). There is no agreed upon rainfall limit of rainforests, with some authors suggesting that even Acacia (*Acacia* Mill.) shrublands in the arid interior should also qualify as rainforest given their closed canopy, fire sensitivity, and fragmentary distributions in an otherwise highly flammable landscape. Australian rainforests can be considered exemplars of 'alternative stable states' of vegetation that are controlled by fire. The spatial distribution of the archipelago of rainforest patches across the Australian continent has been variously attributed to natural fire refugia associated with anomalous topographic, edaphic, or climatic conditions, and the longterm effects of Aboriginal landscape burning.

In the late twentieth century, the debate about Aboriginal fire impacts was dominated by the discovery of a charcoal spike and the transition from rainforest to sclerophyll vegetation in pollen cores from Australia's humid tropics (e.g., Kershaw 1986) coincident with the arrival of humans in the late Pleistocene. This led to the theory, popularised by Flannery (1994), that the use of fire by early Aboriginal societies had a catastrophic impact on the Australian environment, including the extinction of a diverse assemblage of large reptiles, birds, and marsupials (collectively known as the megafauna) (Johnson *et al.* 1999, Miller *et al.* 1999, Miller *et al.* 2005). However, the evidentiary basis for this interpretation is controversial because it is difficult to rule out alternative explanations for the association between human colonization and the extinctions. In any case, the debate about Aboriginal fire impacts has been radically changed because of two new lines of evidence: molecular phylogenetic analyses of the evolution of the flammable biota, and studies of contemporary Aboriginal fire use.

The growing number of molecular phylogenies of quintessentially Australian plants and animals has fundamentally framed the debates about the impacts of Aboriginal fire use (Bowman and Yeates 2006). For example, a recent molecular phylogeny of Australian livistona palms (*Livistona* R. Br.) reveals that the closest relative of the fire-tolerant savanna species is a southeast Asian ancestor that molecular dating suggests colonised the Australian monsoon tropics some 10 million years ago (Crisp *et al.* 2009). The analysis by Crisp *et al.* (2009) suggests that this ancestoral form had traits that pre-adapted it to tolerate frequent burning, which was occurring in the north of the Australian continent. Contrary to the widely held view that fire-sensitive rainforest species are axiomatically ancestral, this analysis showed that the two rainforest species are the most recently derived. Similarly, the antiquity of fire on the Australian continent is reinforced by the evolutionary development of eucalypts' epicormic bud structure that provides these trees with a remarkable capacity to recover from fire damage. Burrows (2002) has shown that unlike any other known plant lineages that have fully developed dormant buds on their trunks, eucalypts and related taxa in the family Myrtaceae have strips of 'precursor' cells that span the cambium layer and, given the right cues, develop rapidly into epicormic buds should the crown be defoliated by fire. The available molecular phylogeny of Myrtaceae suggests that this trait existed for at least 30 million years, given that it occurs in two lineages that diverged at this time.

A growing body of research has shown that Aboriginal fire use is skilful and responsible for the functioning of ecosystems that were encountered by European colonists (Bowman 1998). A prime example of the importance of Aboriginal fire management concerns the ecological effects when this tradition of fire management is disrupted. For example, across large areas of northern Australia's savannas, the cessation of Aboriginal fire management has resulted in the decline of the cypress pine (*Callitris intratropica* R.T. Baker and H.G. Smith), a fire sensitive obligate seeder (Bowman and Panton 1993). Mature trees have thick bark and can survive mild but not intense fires and, if stems are killed, has no capacity for vegetative recovery. Seedlings cannot survive even the coolest fires. The survival of cypress pine was a consequence of Aboriginal patch burning that occurred for a number of reasons, including but not limited to preserving patches of wild yams (Russell-Smith *et al.* 1997), managing country for spiritual obligations (Yibarbuk *et al.* 2001), preserving unburnt areas for fire drives of wild game later in the year (Haynes 1985), and maintaining grazing habitat for game (Murphy and Bowman 2007). It seems that the creation of habitat heterogenity was critical for the survival of a range of plants and animals that are currently undergoing precipitous declines following the cessation of Aboriginal fire management (Franklin 1999, Woinarski *et al.* 2010).

European settlers have struggled to comprehend the ecology of fire in Australia and have made only halting progress toward the accommodation of fire in their environment. The extreme fire events in southern Australia since the beginning of the twenty-first century highlight the vulnerability of Australian society to catastrophic fire. There remains a heated debate about the cause of these extreme events, with a Royal Commission inquiring into the bushfires in Victoria on 7 February 2009, which saw the loss of 173 lives, 3500 structures destroyed, and 450 000 ha burnt by over 400 individual fires.

There is no question that settlement patterns in highly flammable vegetation, with heavy fuel loads and extreme fire conditions, were major contributory factors in the recent Victorian bushfires. Indeed, the fire conditions on 7 February 2009 were unprecedented, reflecting the combined effects of a sustained heatwave, prolonged drought, and strong winds. To place this event into context, consider that the McArthur Forest Fire Danger Index (FFDI: Luke and McArthur 1978) was created such that values >50 indicate extreme fire weather, and Black Friday, on 13 January 1937, had an FFDI of 100; yet on Black Saturday, 7 February 2009, the FFDI reached as high as 180, the worst fire conditions ever recorded. So severe were the fire conditions that a new category of fire danger rating, catastrophic, was created (Country Fire Authority 2010). Under such conditions, voluntary evacuation is recommended, thereby effectively superceding the older Australian policy of 'stay and defend or leave early.' Alarmingly, with much of the continent expected to become increasingly dry under future climate change, there is serious concern about the potential for more frequent and extreme fires (Hennessy *et al.* 2007).

Unlike southern Australia's forests, northern Australia's savannas are subjected to very high frequencies of fire activity. In these systems, European impacts on fire regimes have been exacerbated by the deliberate introduction of African pasture grasses. Most notably, gamba grass (*Andropogon gayanus* Kunth) rapidly invades savanna vegetation, resulting in fuels loads more than four times that observed in non-invaded savannas (Rossiter *et al.* 2003). Such fuel loads allow extremely intense savanna fires, resulting in rapid reductions in tree biomass. This has resulted in the development of a grass-fire cycle in many areas that is increasingly stretching fire management resources.

The colonisation of Australia caused the tragic clash of two fundamentally different cultures: Aboriginal, rooted in an ancient world view where human beings and nature were indivisably united metaphysically; and European, with beliefs that stressed a divinely sanctioned separation of humanity from the Earth. While much anthropological research has explored many aspects of indigenous cultures, and indeed other cultures, there remains a remarkable silence about humans' fundamental relationship with fire. There can be no question that conceptions of fire are profoundly culturally constructed, to such a degree that thinking about fire objectively is difficult. To someone with a typical Western world view, this is well demonstrated by undertaking fieldwork with Australian Aborigines who have a continuing tradition of landscape burning; in such a situation, it is initially difficult not to be puzzled or shocked by the apparently careless and carefree use of landscape fire. However, research in northern Australia has revealed an underlying logic to Aboriginal landscape burning (Lewis 1982, Head and Fullagar 1997, Russell-Smith *et al.* 1997, Bowman and Prior 2004, Vigilante and Bowman 2004, Murphy and Bowman 2007), although appreciation of the full complexity remains beyond our grasp. A key lesson from working with Aborigines who continue to burn their land is that their cultural constructions of fire are fundamentally different from the modern Western view.

Given cultural constraints in understanding landscape fire, it is no surprise that in both northern and southern Australia, European settlers have misread the fire ecology of Australia. Sadly, this misreading is at the root of the bushfire disasters that have affected modern Australia. Adaptation to flammable landscapes demands new ways of conceptualizing fire beyond the 'disaster' mode. We suggest that this is a prime role for pyrogeographic research.

CONCLUSION

Managing wildfire is a major climate-change challenge in Australia and elsewhere, perhaps comparable to the threats posed by sea level rise. Yet fire is quite unlike other natural processes, such as floods and cyclones, given the complex web of interactions and numerous short- and long-range feedbacks. Indeed, some ecologists have suggested that landscape fires should be considered as being 'biologically constructed,' and have drawn parallels with herbivory (Bond and Keeley 2005) or decomposition (Pyne 2007). Such tight coupling between fire and life bedevils simple attribution of cause and effect, and raises fascinating questions about the potential co-evolution of fire, life, and human cultures. To meet this challenge, we need more research to understand fire patterns and processes from the local to the global scale, and how and why human cultures use fire, manage flammable landscapes, and conceptualize their relationship with fire.

More extreme fire behavior and events are expected, but without a coherent intellectual framework, mitigation and adaptation efforts are likely to be of marginal effectiveness. For example, it will not be possible to develop global climate models and carbon budgets that effectively and realistically incorporate fire into the overall functioning Earth system until we better understand how fire regimes interact with, and feed back into, vegetation, human land use patterns, and climate. Fundamentally, we must rethink our relationship with flammable landscapes and understand why some cultures have achieved an apparently sustainable relationship with fire while other cultures have not. Such a new understanding demands an integrative and trans-disciplinary perspective of landscape fire. Adaptation to the novel fire regimes caused by global environmental change, and abatement of greenhouse gas emissions from uncontrolled fires, hinges on the integration of evolutionary, geographic, and cultural perspectives; an approach we describe as pyrogeography.

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