A collaborative agenda for archaeology and fire science

Article *in* Nature Ecology & Evolution · May 2022

DOI: 10.1038/s41559-022-01759-2

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A collaborative agenda for archaeology and fire science

Humans have influenced global fire activity for millennia and will continue to do so into the future. Given the long-term interaction between humans and fire, we propose a collaborative research agenda linking archaeology and fire science that emphasizes the socioecological histories and consequences of anthropogenic fire in the development of fire management strategies today.

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Humans and fire are inextricably linked at global and millennial scales. On a daily basis, we are reminded that fire suppression and changing land-use patterns have produced hazardous fuel conditions and that human-caused ignitions are the principal source of fire worldwide[1]. Anthropogenic climate change is exacerbating these trends by creating unprecedented droughts and heatwaves that are connected to changes in global fire activity. Human actions have directly influenced past fire regimes, are the principal drivers of contemporary fire activity and will be influential factors into the foreseeable future. Thus, it is not tenable to frame fire science as purely ecological or ahistorical. To broaden the scope of fire research, we propose that archaeology can merge the social and ecological dimensions of fire over extended time scales, providing insights into fire's coevolving relationship with communities and landscapes. Here we highlight the collaborative intersections between archaeology and fire science that can inform a unified approach for managing the causes and consequences of fire today by considering the enduring social institutions, values and practices associated with fire, as well as the historical precedents that contribute to current fire conditions. As we envision the future of collaborative research on humans and fire, archaeological perspectives will be essential components in crafting practices and policies for living with fire.

Table 1 | Diverse methodological approaches in archaeology and associated disciplines for investigating anthropogenic fire

Methods	Research topic	Data sources	Examples
Archaeobotany and palynology	Nature and extent of fire-dependent ruderal cultivation	Excavated habitation structures and features, and extramural processing facilities	Ref. [17]
Dendrochronology and geoarchaeology	Effects of low-intensity burning on wildland–urban interface dynamics	Fire scars on ancient and modern trees, and sediment records of fire and erosion	Ref. [14]
Ethnoarchaeology	Burning practices for food production and their effects on landscapes and ecosystems	Modern human behaviour for comparison to archaeological datasets	Refs. [19,24]
Palynology, sedimentary charcoal, pedoanthracology and phytoliths	Scale and timing of anthropogenic fire-induced vegetation change, and evidence for changing fire regimes	Terrestrial sediments (meadow and lake) and radiocarbon summed probabilities	Refs. [15,25,26]
Simulation modelling	Modelling vegetation dynamics and charcoal record formation in human-influenced disturbance regimes	Palaeoecological records, inferred climate records and distribution of archaeological sites	Refs. [18,27]
Archaeodemography	Changes in population and land-use strategies related to changes in fire	Archaeological sites, dendrochronology, radiocarbon summed probabilities and historical records	Ref. [23]

Role for archaeology in fire science

Anthropogenic fire has deep roots in human biological and social evolution. Human ancestors evolved in tropical environments — which contain some of the most flammable biomes on the planet — where landscape fires were arguably a consequential force on hominin evolution for two million years[2]. A recent synthesis of global archaeological evidence suggests that fire had become a vital component of hominin life by the Middle Pleistocene (about 0.4 million years ago)[3]. From the Holocene onward, anthropogenic burning had a fundamental role in shaping most of the planet's terrestrial landscapes[4]. Worldwide, anthropogenic fire was — and still is — a tool for facilitating local ecological change and maintaining biodiversity[5]. For instance, hunter–gatherers have applied fire to landscapes to increase encounters with prey and modify the distribution and reliability of resource patches[6,7], and agropastoralists have used fire to clear land and improve soils for crops and livestock forage[8]. In some places, these traditions remain critical components of current land-use strategies, and where they do not, their legacies can persist on contemporary landscapes. The spatial patterns, frequency, seasonality and severity of human-caused fire in the past were driven by a variety of cultural and ecological objectives, much like those underpinning

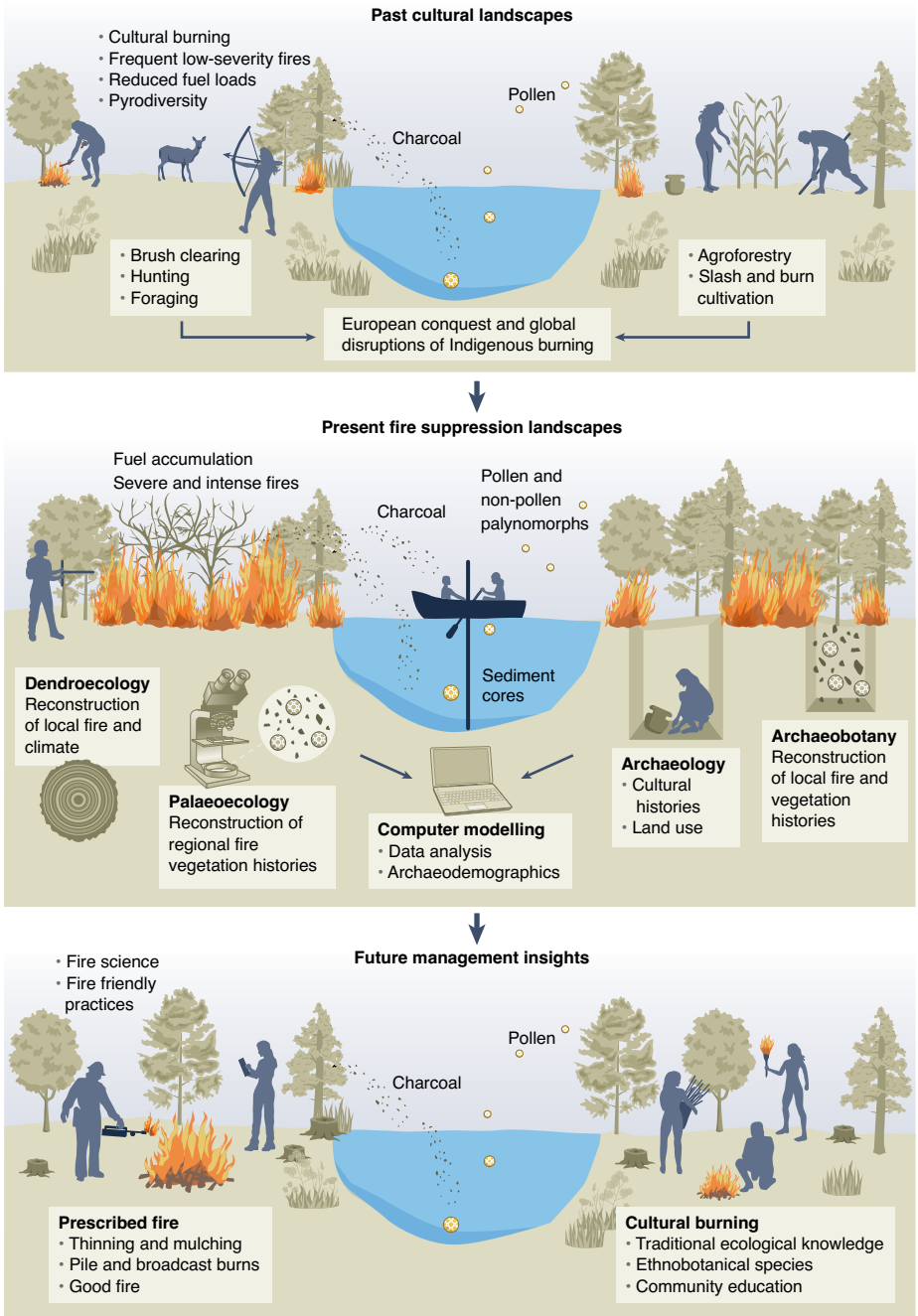

Fig. 1 | Connecting archaeology and fire science. The role of archaeology in understanding socioecological histories and the consequences of cultural burning in developing fire management strategies today.

many modern fuel reduction targets and suppression efforts[9].

In the past few decades, fire science has acknowledged the importance of long-term human influence on landscapes and fire regimes[5,10]. Still, there is considerable room to expand our understanding of the social institutions, values and economics that motivate cultural and fire histories. Cultural fire, as a central component of Indigenous land management in many regions of the world, can express Indigenous sovereignty and stewardship through its influence on current ecological conditions or a community's attitude towards fire[11,7]. Although burning and suppression operations organized by management agencies share many of the desired outcomes of cultural burning, the implementation of short-term, prescription-based plans can diverge substantially from iterative and ongoing cultural land-management practices focused on land use and resource production practiced for millennia[9].

In responding to these challenges, archaeology provides long-term perspectives on anthropogenic fire and its ecological consequences in different ecosystems and among multiple types of societies worldwide. Contemporary archaeology is a blended, multidisciplinary coalition of researchers focused on interpreting highly variable social and ecological interactions as they are expressed in the material record. Archaeological science operates at multiple time scales and spatial resolutions, with studies ranging from those that examine a momentary stop on the landscape to resharpen a stone tool to the development of complex urban centres over the course of centuries[12]. Archaeological methods include traditional approaches to recovering artefacts through surface reconnaissance and excavations, as well as specializations in cross-disciplinary methods that span the ecological, social and physical sciences (Table 1). For example, long-term human influences on fire regimes and fire-responsive vegetation communities have been reconstructed using a variety of approaches that couple ecological modelling; analysis of sediment, charcoal and pollen assemblages; and tree-ring chronologies with archaeological data[13,14]. In the context of fire science, this perspective enables archaeology to examine the role of humans in emergent spatial and biological diversity shaped by fire regimes, known as pyrodiversity, and assess its consequences at multiple scales (Fig. 1).

A collaborative research agenda

For decades, archaeological and palaeoecological research has investigated the broad realm of anthropogenic fire through time, offering insights into the feedbacks between social and environmental systems[15]. Although the current archaeological consensus is that humans have been a spatially variable, influential force acting on fire and fuels for millennia, this conclusion has not been embraced in much of the fire ecology and ecological restoration literature. This omission is an unfortunate loss for contemporary fire management as calls for the resumption of cultural burning practices and the application of traditional ecological knowledge grow[9,16].

To rectify this situation, we propose that the contributions of archaeology to advancing fire science can be most effective in three domains: (1) leading interdisciplinary research on fire, focused on long-term human-fire relationships, vulnerabilities and resilience; (2) documenting the effects of anthropogenic

Box 1 | Traditional burning practices in the Soule Valley, French western Pyrenees

Basque stock raisers in the French western Pyrenees continue the traditional use of fire as a management tool for maintaining mountain pastures[24]. The fires, set in late winter to early spring, are generally small (on average 1–5 ha) and burn at low severity. Practitioners rely on specific weather conditions and landscape features to contain their fires within pastures and to avoid any damage to adjacent stands of ancient beech (*Fagus sylvatica*) forests and built infrastructure. These burning practices are not only adapted to traditional patterns of land use and ownership but also help to maintain community resilience to wildfires. However, over the past century, economic opportunities outside the Pyrenees and increased competition from industrial agricultural operations elsewhere have led to land abandonment and depopulation of Pyrenean villages. Afforestation and encroachment of shrubs in abandoned lands has increased wildfire risk and community exposure[28].

Some scholars acknowledge that the pastoral fire is an ancient technique indigenous to the Pyrenees, but it remains popularly misunderstood and viewed negatively — especially by outsiders who value landscapes for their aesthetic qualities rather than their agricultural potential. The French state has imposed strict regulations on pastoral fire since the implementation of bureaucratic forest management in the mid-nineteenth century, and although authorities have tolerated pastoral fire it continues to be regarded as crude, and clandestine burning has been portrayed by some as environmentally destructive[24]. Palaeoenvironmental studies tend to perpetuate these views, by using terms such as 'deforestation', 'conquest', 'colonization' and 'slash-and-burn' to describe the processes that created agropastoral landscapes in the Pyrenees. Although these studies do not purposefully mislead, they do little to increase our understanding of pastoral fire as a long-term social and ecological process.

Place-based research conducted in the vicinity of Pic d'Orhy on the border between France and Spain has begun to reveal a different story[8]. This research, focused on the coevolution of agropastoral livelihoods and mountain landscape, uses theory and method in landscape archaeology as a central approach for understanding long-term human–environmental dynamics. The approach combines systematic pedestrian survey, auger testing and excavations of archaeological features in upland pastures[29] with same-catchment palaeoenvironmental sampling of colluvial stratigraphic sections from zero-order hollows near the Pyrenean divide[30]. Findings from these studies do not evidence an intensive wave of Neolithic land conversion. Sedimentary charcoal and other palaeoenvironmental proxies show that anthropogenic burning was initiated during the Neolithic and that a frequent-fire pastoral burning regime was established by the late Neolithic (about 5,000–6,000 years ago) at all sample catchments. Importantly, peaks in the intensity of continued burning activities and erosion are not synchronous at the landscape level, but vary in their timing at each catchment. The establishment of mortuary features (stone-circle cromlechs) do coincide chronologically with peaks in burning, but these archaeological features are sparse. Stone structures used as seasonal shelters by shepherds do not appear until the late Middle Ages (about 1,000 years ago), at which time there is a slight decline in pastoral burning. These patterns suggest that rather than a rapid conversion of forest to pasture during a period of land-use intensification, pastoral landscapes coevolved over long time spans with a low-severity pastoral burning regime. As a result, the landscape was able to sustainably absorb multiple phases of intensification of use and periods of abandonment. Despite variability between sites and time periods, pastoral fire has been a reliable constant throughout this long historical record.

Small, low-severity fires set by Basque stock raisers in the French western Pyrenees to manage and maintain mountain pastures. Photograph by M.R.C.

pyrodiversity; and (3) emphasizing that fire has both social and ecological histories that can inform fire management decisions today. Here, we feature examples of current archaeological research in these domains and describe pathways for integrating their findings and perspectives into fire science.

Studies combining archaeology, archaeobotany and palaeoecology are shedding light on the extent to which fire-return intervals, vegetation diversity and landscapes were shaped by frequent, low-intensity surface fires associated with human activities[17]. Innovations in computational modelling are exploring climatological, biophysical and social dynamics that support ecosystem resilience or change under varying pyric conditions and are validated using archaeological datasets[18]. Such interdisciplinary approaches to understanding vulnerability and resilience

to climate change, the emergence of novel ecosystems and the human capacity to influence fire behaviour and landscape patterns illustrate how archaeological perspectives on these issues can speak to our own current challenges in managing fire-prone landscapes.

Pyrodiversity is an outcome of cultural burning practices and the spectrum of social and ecological feedbacks associated with them[19]. Current strategies to reduce the risk of severe wildfires and the potential adverse effects of fire centre on fuel reduction and intentional introduction of diverse types of fire through prescribed burning and management of naturally ignited fires. However, these strategies are not without social cost. Concerns about escaped or unintentionally severe prescribed fires, smoke pollution and loss of landscape aesthetics all constrain community support for active fire management[20]. This situation is particularly evident in wildland–urban interfaces, which have elevated risks of property damage and loss of life owing to their proximity to fire-prone ecosystems. Archaeological research investigating the interaction between human settlement and wildland fire has revealed the strategies that communities used to mitigate long-term wildfire hazards[14]. In the past, landscape pyrodiversity was achieved through intentional burning to modify live vegetation and fuels to accommodate an array of livelihood activities, including pest control, craft production, hunting, agricultural production, land clearing and tree felling;[21] these activities also reduced exposure to wildfire hazards, a key goal of current fire management practices.

Finally, archaeological research affirms the proposition that anthropogenic fire has both social and ecological histories, which are place-based and unique to specific societal needs and values. Although contemporary fire management incorporates ecologically defined goals, its practices are constrained by cultural attitudes and meanings that affect how fire can be applied to achieve those goals. Fire is not a panacea that can be used invariably to achieve all outcomes. Archaeological research reminds us that fire management programmes are most effective when they involve collaboration among Indigenous peoples, or other traditional landholders, and contemporary land management agencies, thereby providing continuity with the social and ecological legacy of fire. We see an opportunity to connect multiple communities of knowledge to value heritage, cultural landscapes and the preservation of traditional lifeways alongside ecological outcomes. Examples from Western Australia[19], Northern California[22] and the western Pyrenees[8] (Box 1) illustrate that successful programmes, which are focused on community-centred fire and place-based systems of traditional ecological knowledge, are enhanced by incorporating archaeological interpretations of long-term fire-management strategies.

Resolving collaborative challenges

Interdisciplinary collaboration between archaeology and fire science is strengthened by adopting a common research vernacular, appropriate project goals and outcomes, and metrics for evaluating project success. Foremost in this agenda is considering the nature of archaeological datasets themselves, which are composed of highly variable material records — including stone, bone, ceramic and other objects modified, created or appropriated by humans — that can prove challenging to non-archaeologists accustomed to more complete or replicable datasets. The cultural landscapes within which archaeological materials and sites occur are influenced by ongoing ecological processes of post-fire recovery, forest regrowth, erosional and depositional activity, and climate-influenced variations in land cover that attenuate signals of anthropogenic activity. The heterogeneity in scale of archaeological data can make comparisons to high-resolution palaeoclimate or vegetation proxies difficult to interpret, particularly in the absence of direct ethnographic or historical analogues. Furthermore, it is well understood that the technology, infrastructure and adaptive capacity of societies today are not directly comparable to those in the past. Nonetheless, archaeological research on fire has demonstrated the flexibility and capacity to address these issues in substantive ways, beyond recasting archaeological case studies as cautionary tales or just-so stories that have few practical outcomes for fire science.

The interpretive potential of archaeological datasets can be expanded with the application of new methods and new theoretical framings that place people and landscapes at the centre of fire studies. Moreover, direct linkages must be made between archaeological and palaeoecological datasets to identify social–ecological tipping points, stability and other system dynamics needed to mitigate fire risk in current landscapes. For example, changes in population size and distribution have been associated with measurable shifts in fire activity[23] and landscape transformation by anthropogenic fire has been documented as spatially heterogeneous and asynchronous, rather than a unilinear process[8]. By understanding and appropriately applying fire science concepts to the human record of the past, archaeological information becomes more easily accessible and relevant to fire researchers and managers today. Working together with fire scientists in interdisciplinary teams to investigate long-term human–fire successes and failures makes the past more than just a prologue. Archaeology provides modern societies with options for living with fire by featuring, rather than ignoring, the rich long-term history of anthropogenic fire. ❐

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Published online: 16 May 2022
https://doi.org/10.1038/s41559-022-01759-2

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Acknowledgements

This contribution developed from a forum entitled 'Archaeological approaches to anthropogenic fire and global pyrodiversity' held during the 86th Annual Meeting of the Society for American Archaeology (SAA). We are grateful to the SAA organizers for the opportunity to assemble an extensive group of archaeological researchers and practitioners. We also thank R. Baisden for her comments on an earlier draft. Additionally, G.S. was supported in part by an appointment to the United States Forest Service (USFS) Research Participation Program administered by the Oak Ridge Institute for Science and Education (ORISE) through an interagency agreement between the US Department of Energy (DOE) and the US Department of Agriculture (USDA). ORISE is managed by ORAU under DOE contract number DE-SC0014664. All opinions expressed in this paper are the authors' and do not necessarily reflect the policies and views of USDA, DOE or ORAU/ORISE. Any use of trade, product or firm names is for descriptive purposes only and does not imply endorsement by the US Government. S.Y.M. acknowledges funding from the European Commission (Marie Curie Fellowship 792197).

Author contributions

This Comment was conceptualized by G.S., C.I.R., A.P.S., S.Y.M., D.W.B., M.R.C., K.M.D. and A.K.P. G.S. wrote the original draft; G.S., C.I.R., A.P.S., S.Y.M., D.W.B., M.R.C., K.M.D., L.G., A.K.P. and R.A.L. contributed to review and editing. Visualizations were generated by S.Y.M. and M.R.C.

Competing interests

The authors declare no competing interests.