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Supplementary material

Policy challenges and research agenda for the UK

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1. Policy Issues

Against the background described in the main paper, the UK Working Group identified a set of policy issues and scientific challenges for the UK (Table 1). For further information on UK wildfire policy, see Gazzard *et al.* [2]. Current controversies and research needs for fire in peatlands are discussed in Davies et al [106].

Table 1*: Wildfire policy Issues and their associated scientific challenges for the U.K.*

Policy issues	Scientific challenges	References
The need for an integrated, multi-agency approach to wildfire at national level, which combines land and fire management; making a transition from 'command and control' to risk management approach of 'accept and adapt'	Evidencing the need for an integrated approach by testing whether lessons learned from fire-prone areas apply to the UK; e.g. • Does zero tolerance to vegetation fire result in more severe fires? Do managed burns help protect against future wildfires or increase them? *i.e.* a better understanding of fire regime, especially the relationship between prescribed land management fire and wildfire. Overall, an improved understanding of the relationship between fire frequency, fire behaviour, fuel status and fire ecology for UK conditions over the whole range of fire severity. • How do changes in land management policy (grazing, drainage, *etc*) and socio-economic trends affect wildfire risk? Conduct integrated socio-ecological case studies.	[13, 102, 106, 116, 146, 147]
Acceptance of wildfire risk management as an ecosystem service in its own right, including recognition and management of conflict between ecosystem services and stakeholders.	• Evidencing why management of ecosystem services should be 'wildfire-aware' (e.g. effect of fire on water quality and flood risk) • Evidence why wildfire management should also be 'ecosystem service-aware' (e.g. conflicts with public access and biodiversity) • Which fire regime for which ecosystem service? • Political ecology and governance of fire in the UK • Incorporation of a wider range of knowledge; peer-reviewed research, land managers' expertise, fire fighters' knowledge and amenity groups understanding • Local case studies, acknowledging cultural and other difference between communities and sectors. e.g. Evaluate introduction of Firewise community at Thursley Common, Surrey	[85, 96, 97, 109, 148]
Support for fire groups at local level.	• Analysis of good practice in local fire operations groups	[2, 114]
Improved recording of vegetation fires to provide a robust evidence base for scientists and international reporting, especially fire behaviour, fire perimeter, ignition point and cause of wildfire	• Evidence-based recommendations for improved spatial reporting. • Agreed definitions of UK wildfire and other categories of vegetation fire using national fire statistics	[149, 150]
Assessment of the spatial and temporal risk of wildfire	• Baseline assessment and monitoring of UK pyrogeography. • Improved fire danger rating system, including wildfire forecasting which integrates weather forecasts with human factors • Test applicability of risk management tools to UK, e.g. Wildfire Threat Analysis. This includes: - Risk of ignition modelling	[81, 83, 146, 151, 152, 153]

	- Fire hazard assessment (fire climate and fuel mapping, and customised fire spread models for UK fuels) - Tools to assess and prioritise values at risk, including defining the rural-urban interface for the U.K.	
Replacing polarised view of fire as 'good' or 'bad' with acceptance of a fire continuum and the concept of fire regime	- An agreed lexicon of non-emotive terms - Good science communication of key messages, including uncertainty.	[144,147]
Recognition of interactions of fire with other hazards	- Interdisciplinary approach to multi-hazard , combined stressors of fire, drought and plant disease	[102]

Solutions: a proposed U.K. research agenda

Consensus suggests research on wildfire in temperate zones such as the UK is needed at two scales; national, and local or regional level (Table 2). These research priorities reflect gaps in existing knowledge about wildfire in the UK environment.

At national level there are two priorities – improved data across the physical, biological and social sciences and tools for risk assessment before the event, and a rapid scientific response to assess the impacts of wildfire incidents when they do occur. There is also scope for knowledge exchange between the stakeholders involved at each stage of wildfire management: prevention and preparedness, suppression and post-fire recovery. UK Fire and Rescue Services have great expertise, but it is focussed on suppression and is often in the form of tacit knowledge which is only just beginning to be codified. Some land managers may similarly have tacit knowledge of fire practices.

At regional and local levels, vegetation fire needs to be better understood as a socio-ecological system [13], including its positive effects in promoting some ecosystem services [117]. This requires an integrated physical, environmental and social science perspective, which might best be researched at "super-sites", representing key fire-prone UK environments: for example peat moorlands, lowland heaths, and woodlands. Overlapping research topics include fire behaviour, fire ecology, and socio-economic impacts and cultural practices (Table 2). The rationale is that living with fire in a sustainable future will require an interdisciplinary approach to research and policy, and one where land management, which may include prescribed burning where appropriate, is seen as an integral part of managing wildfire.

One research priority is the area of fire 'severity' which has different meanings across sectors. During a fire, Fire and Rescue Services are concerned with fire severity – fireline intensity and rate of spread – as these factors determine the potential danger to fire crews and the level of resources required to fight the fire. After the event, the focus of conservation and forestry groups is on burn severity as this determines the impact and the likely recurrence interval [107, 147, 154]. There is need for collaborative work to link fire characteristics with ecological effects over the whole range of fire intensity and frequency. This will enable better fire management practices with regard to both safety and the management of ecosystems and ecosystem services.

Table 2: *A Proposed Scientific Research Programme for the U.K.*

Scientific Issue	**Work Package**
Understanding wildfire at a national level	
Improved national risk assessment tools	Improved dynamic fire danger rating system; improved fire reporting and definition of wildfire events; national mapping of fuel, wildfire hazard map and values at risk. Understanding of risk of ignition (causes, spatial location, timing, etc.)
Rapid scientific response to wildfire events	Rapid response team of specialists, including Fire and Rescue Services, land managers, agencies and researchers. Provision of equipment, management structure and protocols for post-fire survey and monitoring.
Knowledge exchange programme	Stakeholder engagement in national and regional projects co-produced with researchers. Embedding findings of research within operational procedures and policy. Two-way secondments and shadowing between stakeholder bodies and universities.
Integrated case studies at a regional and local level; peat moorland, heathland, woodland	
Better understanding of relationships between fire characteristics, especially fire severity, and ecological effects	Lab and field studies of fire dynamics, heat flux, fuel parameters, vegetation burn severity, soil burn severity, ecohydrology; leading to UK ecosystem-specific models of fire behaviour and ecosystem feedbacks. Develop standards as a baseline for research.
Smoke and emissions	Plume modelling, characterising emissions, impacts on human health (drawing on international expertise on plume models and UK knowledge on chemical spills.)
Socio-economic drivers; understanding local knowledge and use of fire [5, 155, 156, 157]	History and cultural uses of fire. Variations in individual responses and public attitudes to fire across communities. Adaptive responses and economic and institutional constraints to action. Stakeholder engagement in science work packages.
Effects of fire on health, infrastructure, ecosystem services	Understanding the values at risk from wildfire, including human well-being, damage to property and critical infrastructure, and varied effects on ecosystem services.
Spatial risk assessment	Improving spatial reporting. Spatial analysis, e.g. mapping fire perimeters and fire spread. Local risk of Ignition; potential fire spread; values at risk.
Influencing the policy process	Cost-benefit studies of Fire and Rescue Service suppression costs. Costing positive and negative effects of fire on ecosystem services, social disruption and health effects of wildfire. Evidencing wildfire prevalence and costs using maps and infographics e.g. within a Parliamentary Office of Science and technology Briefing Note[1].

[1] http://www.parliament.uk/mps-lords-and-offices/offices/bicameral/post/publications/

Conclusion

Climate change looks set to increase the fuel load and the ignition risk in temperate locations that have yet to witness regular severe wildfires. Continuing decline in traditional rural culture and growing urbanisation of the rural fringe are likely to increase conflicts at the rural-urban interface. There are evident links between socio-economic factors and fire ecology and a need to build sustainable ecosystems into the future. Therefore, it will become necessary to take a longer term view of landscape fire in the past, present and future. There is growing international awareness that landscape-scale solutions can reduce the threat of wildfire, particularly at the rural-urban interface [115]. In effect, wildfire management can be viewed as a form of risk management [116]. Countries like the UK and New Zealand, with intermittent experience of fire have begun to recognise that wildfire risk can be integrated into an overall land management regime [102, 152]. Not all fire is damaging – controlled fire is a traditional management tool in fire-tolerant ecosystems and indeed may be beneficial to some ecosystems [117]. Zero tolerance to all fire can ultimately create larger fires through fuel load accumulation and horizontal and vertical continuity of fuels, but this needs testing for UK conditions. A scientific response is required to increase understanding of fire behaviour and effects in national contexts, to improve reporting and risk assessment, and to link the environmental and social aspects of fire regime. Fire is best understood as a socio-ecological system with complex interactions between fire, ecosystems and people. Countries with, as yet, relatively low awareness of wildfire can learn important lessons from more fire-prone areas. It is clear that investment and more intensive research is required in order to understand and build a sustainable future for wildfire management in temperate ecosystems.

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