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Prescribed fire and its impacts on ecosystem services in the UK

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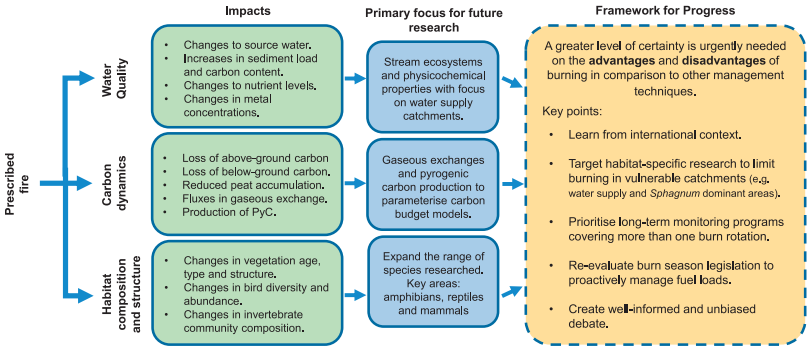
HIGHLIGHTS

- Prescribed fire is a controversial and highly debated topic in UK land management.
- Water supply catchments are at risk from water quality impacts of fire.
- Irresponsible burning in the UK uplands threatens to reduce vital carbon storage.
- Prescribed burning over inappropriate time-scales reduces faunal and floral diversity.
- More research is needed to reliably inform management practices in the UK.

GRAPHICAL ABSTRACT



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ABSTRACT

The impacts of vegetation fires on ecosystems are complex and varied affecting a range of important ecosystem services. Fire has the potential to affect the physicochemical and ecological status of water systems, alter several aspects of the carbon cycle (e.g. above- and below-ground carbon storage) and trigger changes in vegetation type and structure. Globally, fire is an essential part of land management in fire-prone regions in, e.g. Australia, the USA and some Mediterranean countries to mitigate the likelihood of catastrophic wildfires and sustain healthy ecosystems. In the less-fire prone UK, fire has a long history of usage in management for enhancing the productivity of heather, red grouse and sheep. This distinctly different socioeconomic tradition of burning underlies some of the controversy in recent decades in the UK around the use of fire. Negative public opinion and opposition from popular media have highlighted concerns around the detrimental impacts burning can have on the health and diversity of upland habitats. It is evident there are many gaps in the current knowledge around the environmental impacts of prescribed burning in less fire-prone regions (e.g. UK). Land owners and managers require a greater level of certainty on the advantages and disadvantages of prescribed burning in comparison to other techniques to better inform management practices. This paper addresses this gap by providing a critical review of published work and future research directions related to the impacts of prescribed fire on three key aspects of ecosystem services: (i) water quality, (ii) carbon dynamics and (iii) habitat composition and structure (biodiversity). Its overall aims are to provide guidance based on the current state-of-the-art for researchers, land owners, managers and policy makers on the potential effects of the use of burning and to inform the wider debate about the place of fire in modern conservation and land management in humid temperate ecosystems.

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1. Introduction

Fire is an important ecological process for many ecosystems and has played a complex role in shaping landscapes across the globe (Bixby et al., 2015). Throughout the last millennium, humans have used fire as a means of clearing land, facilitating hunting, and maintaining favourable grazing and leisure habitats (Goodfellow, 1998; Worrall et al., 2010a). During the last century, prescribed fire (i.e. controlled or management burning) has been used increasingly as a management tool across parts of the Mediterranean, and the seasonally dry regions of Australia and North America to control natural fire regimes and reduce the risk of severe wildfires spread by managing fuel loads (Burrows and McCaw, 2013; Fernandes et al., 2013; Ryan et al., 2013). The scientific literature on prescribed fire is dominated by research from these regions where fire is also part of the natural ecosystem cycles. Management burning, however, is also a common practice in non-fire prone ecosystems in the world's temperate zones (e.g. New Zealand, Tasmania, Northern Europe, South America and East Asia) (Holden et al., 2007), and the need to fully understand its impacts maybe even greater. The UK uplands have been burnt by humans for centuries (Worrall et al., 2010a). This paper aims, therefore, to provide (i) a comprehensive review of the existing knowledge on the impacts of this practice on key ecosystem services and (ii) to identify future research directions, with a focus on providing guidance to land managers and policy makers on the potential effects of the use of burning.

Early evidence of human management burning in the UK begins in the late Mesolithic/early Neolithic times (approx. 4000 years ago) as a hunting strategy and for clearing land (Fyfe et al., 2003; Tucker, 2003; Davies et al., 2008). By the late medieval period, burning was recorded as a common land management practice, notably in southern England and Scotland (1300s) (Rackham, 1986; Fyfe et al., 2003). It was not until the mid-19th century, however, that the use of burning for habitat management spread rapidly because of grouse moors (Worrall et al., 2010a). Over the last 150 years, this practice has taken the form of rotational prescribed burning (Davies and Legg, 2008). Rotational prescribed burning consists of using deliberately-ignited fires to create a mosaic of burnt patches of different ages. This produces a diverse vegetation structure, allowing the regeneration of younger, more palatable shoots (Worrall et al., 2010a). Burning occurs over a variety of patch sizes with individual patches being burnt on cycles of between 8 and 25 years. Some burning ideally takes place within a given area every year (Davies et al., 2008). This is deemed beneficial for the productivity of livestock-grazing pasture and increasing red grouse population for sports shooting where relevant (Worrall et al., 2010a).

Upland habitats form the primary focus of this review. In the UK, prescribed burning is conducted almost entirely in upland areas, focused on controlling the density, structure and age of *Calluna vulgaris* and *Molinia caerulea* dominated communities (Tucker, 2003). Upland areas are categorised as areas above the upper limits of agricultural enclosure, between 250 and 600 m altitude, depending on climatic conditions (Reed et al., 2009). Uplands cover approximately one-third of the land surface in the UK and support a diverse range of semi-natural habitats (Reed et al., 2009). These incorporate a range of ecosystem types from blanket bog, heathland and grassland assemblages, containing a variety of both vegetal and animal species (rare and priority conservation species; e.g. Hen harrier - *Circus cyancus*, Black grouse - *Lagopus lagopus scoticus* and *Sphagnum* sp.) and different operating land management practices (e.g. burning, grazing, cutting and predator control) (Natural England, 2001).

It is widely established that these upland regions provide a range of 'ecosystem services' (i.e. services the environment provides for the well-being of humans) benefiting multiple stakeholders (Provisioning services; food, fuel and freshwater. Regulating services; water regulation, climate regulation. Supporting services; nutrient cycling, primary production.) (MEA, 2005; Reed et al., 2009). As a result, a large portion of upland habitats fall within areas awarded with special conservation and research significance (e.g. National Parks; Sites of Special Scientific Interest (SSSI); Special Areas of Conservation (SAC)) (Tucker, 2003).

There are concerns around the application of prescribed burning in these important upland ecosystems in the UK. Burning has been implicated in several potentially negative impacts on the health and diversity of upland habitats (Ramchunder et al., 2009; Brown et al., 2015; Davies et al., 2016). In recent decades, the use of prescribed fire in the UK has become a source of heightened controversy with negative public opinion fueled by opposition from popular media (Davies et al., 2008; Brown et al., 2014; Allen et al., 2016; Monbiot, 2016). This highlighted several important limitations within the subject knowledge and resulted in land managers requesting further clarification on the impacts of prescribed burning. This, in addition to several other driving forces, has produced a substantial increase in research output with 77% of the literature captured for this review being published since 2000, 37% since 2010. It is, therefore, timely to review these areas of focus (water quality, carbon dynamics and habitat composition and structure) not least to also provide a synthesis for land managers in the UK and in regions with comparable ecosystems.

Three key aspects of ecosystem services form the focus of this review due to their vulnerability and the significance of potential impacts:

i) Water quality: A prominent concern for the management of upland catchments as they provide 70% of the UK's freshwater resource and are heavily regulated and monitored (Bonn et al., 2009).
ii) Carbon storage: Upland areas in the UK are vitally important for carbon storage with 3000 Mt carbon estimated to be stored in moorlands alone, equating to a globally significant carbon store over 6 times the gaseous carbon emitted by the UK in 2015 (SEERAD, 2007; Department for Business, Energy and Industrial Strategy (DBEIS), 2017).
iii) Habitat composition and structure (biodiversity)[1]: Globally rare fauna and flora are found in the UK uplands with a variety of UK BAP (Biodiversity Action Plan) Priority Habitats and 75% of the total area of the world's natural heather moorland (Tucker, 2003).[1]

These three aspects of ecosystem services have been consistently cited as important features needing to be closely monitored when implementing burn practices. All of which require further research to clarify possible impacts (Tucker, 2003; Ramchunder et al., 2009; Worrall et al., 2010a; Glaves et al., 2013; Brown et al., 2015; Davies et al., 2016).

To collect the relevant literature used in this review searches in scientific journals were conducted using several online databases, assessing articles at title and abstract level (Scopus, Web of Science and Google Scholar). Extensive searches for non-peer reviewed work through key UK agency sites were also undertaken resulting in an overall bibliography of 95 publications (Natural England, Natural Resources Wales, Scottish Environmental Protection Agency, Forestry Commission, Yorkshire Water, Severn Trent Water, and Welsh Water).

Of the 95 publications identified, 64 were peer-reviewed research papers, 10 peer-reviewed review papers and 21 agency reports. A systematic outline of the captured publications is given in the supplementary information (Table S1). The following section provides a brief overview of the current use of fire in the UK, which is followed by sections on the three key ecosystem services. The final two sections highlight the major research gaps and suggest future directions followed by the overall conclusions and a framework for progress. An executive summary is also provided in the Supplementary Information to make

[1] In this review the broad term of habitat composition and structure has been used instead of biodiversity as the relevant literature discussed includes the assessment of widely different levels of biodiversity.