Report on field experiments in Northumberland, March 2010

*a multidisciplinary approach to assess

fire behaviour and effects in a temperate climate*

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Abstract

A moorland site in Northumberland in the northeast of England was used for a series of experimental burns in heather-dominated vegetation (*Calluna vulgaris*) and one burn in a stand of gorse (*Ulex europaeus*) towards the end of March 2010. This article summarises the main aspects of the exercise, its context and objectives, methods used and some of its findings. These experimental burns were part of an ongoing programme of such tests to be carried out in the UK for studying rural vegetation fires or bushfires. Participants from eight academic groups were involved in this first exercise, in partnership with fire services, deploying a range of scientific instrumentation, sampling and burn strategies.

Although the UK can experience long dry periods that create ideal conditions for severe rural vegetation fires (as in the spring and summer of 2003, for example), the weather during the experimental period was less ‘ideal’. Conditions were dry enough for burning on only one and a half days over the planned five day period. The burns carried out were closer to marginal than severe conditions for flammability of the heather, although the small-scale gorse plot was found to be highly flammable in spite of rain a few hours earlier.
The techniques put to use in the burns, although not at all plots, included:

- terrestrial LiDAR before and after the burns for mapping topography and structure of vegetation, as well as changes in structure;
- destructive sampling of biomass, before and after the fires, to examine fuel load, type and proportion burnt;
- fuel moisture content sampling of fine fuels;
- characterising smoke emissions using Fourier transform infrared measurements;
- helicopter-borne infrared imaging of fire spread;
- aircraft mounted LiDAR and hyperspectral reflectance imaging;
- field spectroradiometry of pre-fire and post-fire reflectance;
- thermocouple temperature measurements at points in the vegetation and the soil;
- soil sampling for analysis of fire-effects;
- use of different ignition patterns.

The objectives of this and future exercises range from fundamental understanding of rural fire spread and its effects on vegetation, soil and the environment, along with the development and use of remote sensing techniques for analysis of vegetation, fire damage, emissions, etc., to managed burning for vegetation or fuel-load control and the development of a knowledge base for practical fire suppression tactics and techniques in the UK.

**Keywords:** field burns, fire effects on soil, carbon budget, emissions, heather moorland fire, gorse fire

1. **Field burn programme in the UK**

A collaborative programme has been initiated in the UK for an ongoing series of experimental burns to investigate fire in a variety of vegetation types. The first of these experiments was carried out in Northumberland, in the north of England, burning plots of heather (Calluna vulgaris) and gorse (Ulex europaeus) mainly as a pilot study to develop the necessary techniques. Several teams from across the UK were involved and contributed to the exercise in late March 2010.

The dates set aside for the burns followed an unusually cold winter for the region with prolonged snow cover. This provided a considerable constraint on the time available for preparing the site. It also meant that the vegetation was partly affected by the cold weather so that burn conditions were not necessarily the same as might have been experienced if there had been less possibility of damage due to prolonged frost.

In the event, although five days of experiment had been planned, rain made it impossible to use more than one and a half of these days. Clearly, in a frequently rainy and windy temperate climate, planning well in advance for such an exercise has its problems. However, the broader issue is not so much that it often rains as that there are frequently long periods without rain and shrubland fuels can dry very quickly. Drying of heather can be particularly rapid and extreme in early spring when the aerial ‘live’ fuel has been damaged by frost in the preceding winter (Hancock et al 2008, Davies & Legg 2010); gorse shrubs retain a high load of find dead fuel suspended in the canopy which also dries rapidly (Anderson & Anderson 2009). These are the times when fires can and sometimes do become a major problem for the UK, particularly in vulnerable moorland and peatland areas, which are also often areas of special scientific interest. The country is not as well prepared for wildfire, when it does arise, as drier countries and this can lead to consequences well out of proportion to the perceived scale of the threat.
Figure 1: The left image is of a moorland site at Debdon in Northumberland where plots of heather (Calluna vulgaris) were prepared for experimental burning. The image on the right is of a smaller site at an ancient hill fort near Thropton, about 2 km west of the Debdon site, where a stand of gorse (Ulex europaeus) was burnt.

Research is needed to understand more fully what the real threats are: how much damage fires do within the various ecosystems; the potential for using controlled burning to limit the scale and effects of uncontrolled bushfires, or wildfires; the relationship of fires to carbon sequestration or loss and climate change; as well as the development of appropriate firefighting and management techniques (Davies et al 2008). To these ends, research is most needed at times when fuel is at its most flammable, usually in late winter and early spring or during summer drought, which necessitates a flexible approach to planning field burns or developing an ability to extract useful research data from genuine wildfires.

2. General description

Burns were carried out at two sites, illustrated in Figure 1. The main site at Debdon covered a total area of a few hectares and was divided by fuel breaks into numerous burn plots, only a few of which were used in the end. The vegetation here was dominated by heather (Calluna vulgaris). A much smaller site at an ancient hill fort, near Thropton, contained an area of gorse (Ulex europaeus) which was the first plot to be burnt. The burns provided an opportunity to bring a variety of means of investigation into play:

- remote sensing via multispectral reflectance (both airborne and ground based) to calibrate methods for estimating moisture and vegetation properties before burning and surface residues after burning;
- HD video recording of each burn from several angles to help in reconstructing the dynamics of fire spread as well as flame shape;
- thermocouple measurements for data on temperature, including ground surface heating and vegetation engagement in the fire;
o destructive sampling to determine fuel loads, structures and moisture properties shortly before each burn;
o destructive sampling after each burn to analyse unburnt and charred residue and to extract estimates for the fuel load actually consumed in each fire;
o spectrally resolved Fourier transform infrared absorption measurements of the smoke plume to extract data on its composition;
o soil sampling before and after the burns to determine soil effects, including effects on seed banks, etc.;
o use of helicopter borne infrared video to follow fire spread and radiative intensity;
o use of terrestrial and airborne LiDAR for surface mapping, including vegetation loss resulting from the fire;
o using ignition patterns, including carefully sustained boundary ignition, to generate desired forms of fire spread.

Not all of this is reported in this brief article which mainly offers a summary of the exercise leaving aside aspects that are mostly still work in progress.

Having brought these research approaches into play in this pilot study, valuable experience has been gained that will help to focus the research well and effectively in future burns that are now being planned.

Figure 2: The images show the spread of fire through a stand of gorse at the Thropton site, with thermocouple temperature traces taken from two locations within the stand.
3. The Thropton hill fort burn

The gorse plot was on a slope and was ignited in a stiff upslope wind using two drip torches moving apart from the mid-point of its base, leading to very rapid fire spread and flames of around 20 m in length, forced close to ground level by the strength of the wind. The only available data for the moment concerning this burn, comes from some thermocouples and video images taken of the fire. The plot was also used to study soil-effects of the fire, with samples extracted before and after burning along with further thermocouple records. These data are still being analysed and collated.

The images in Figure 2 show the scale of the fire, which burnt very vigorously. The thermocouple traces that are also shown indicate a fairly short and rapid burn duration.

4. Fuel moisture content at the Debdon site

Fuel moisture was measured at both sites but only the Debdon site is detailed here. The data shown in Table 1 were obtained for the heather at the site, sampled in the upper canopy comprising the finest fuel, including mostly live shoots with a small proportion of dead foliage. Samples were taken a short time before ignition. It is notable that the moisture contents were low by comparison with most live fuels, but relatively high for management burning conditions in heather (Davies & Legg 2010), suggesting that the fuels were close to marginal in terms of their potential to support fire.

This was indeed found to be the case in some of the attempted ignitions where fires failed to be self-sustaining. This was particularly true of plots 13 to 20 (see Figure 1) where ignition was attempted at a time of almost zero wind. In other plots, namely 1 to 4, a moderate wind was blowing that seemed to be essential for maintaining fire spread. This was aided in plots 3 and 4 by the fact that ignition was initiated up a slope as well as having supporting wind. The fires were typically very smoky, showing that combustion was incomplete.

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Table 1: Fuel moisture contents are shown for the upper canopy of heather at the plots in the Debdon site identified by their numbering in Figure 1.

5. Infrared imaging of fire spread

Helicopter borne infrared video was taken of the fire spread in plot 2. The path of the helicopter was tracked with GPS which was used, in conjunction with corner fires, to reconstruct the physical spread of the fire within the plot. Some details and results are
shown in Figure 3 where the location and depth of the fire is shown at times of 50, 150, 160, 200, 250 and 300 seconds after ignition along with the Fire Radiative Power.

A feature worth mentioning about the ignition of this fire was that it was sustained at two boundaries (towards the top and right sides of each image in the sequence shown in Figure 3) so as to maintain a linear fire front. Drip torches were used to continue the ignition along these edges, keeping track of the fire advancement as driven by the wind (which was blowing from the top-right direction) through the interior of the plot. The result was the satisfactory spread of a fireline, maintained as a straight line by carefully controlling the fire conditions at the boundary of the plot.

Positions of thermocouples are also marked in the reconstructions in Figure 3. Their data are compared with the time series from the infrared camera in Figure 4, omitting a

**Figure 3**: The top image is of the path taken by a helicopter carrying an infrared camera to visualise the fire on plot 2. The diagrams below it show the reconstructed path of the fire spread.
comparison with one thermocouple which was found to be faulty. The time series, before and after the mapping of the picture is satisfactory. For the mapping, information from all pixels in the IR image reconstruction is used, and the pixel size evaluation does seem adequate. Concerning the thermocouples, the error seen in Figure 4 is believed to be due to GPS information. A detailed plot survey was not made and a Differential GPS was not used, which would have located the thermocouples more precisely.

6. Infrared measurement of species

Characterisation of species in the smoke emissions, during the fire, was achieved using Fourier transform infrared measurements. The record of absorption spectra was used to identify particular species. Results for the concentrations measured through the path of an infrared beam are also plotted in Figure 4 for carbon dioxide, carbon monoxide, nitric oxide and water vapour.

7. Remote sensing

SPECIM Eagle and Hawk visible to SWIR hyperspectral images, LiDAR and aerial photography were acquired before and during the burns to investigate combustion type, and possibly fuel moisture content and post-burn change in surface cover.
Figure 5: Reflectance data are shown over a range of wavelengths from a section of Plot 1, measured before the fire (pink line) and after it (blue line) as seen in the images on the right. Thermocouple lines can be seen in these images, ending at a stake (marked by a notebook). Fine fuels in the heather canopy are seen to have been burnt in the fire, leaving charred stems, ash, exposing scorched and photosynthetically active (green) mosses.

An ASD full-wavelength field spectro-radiometer was used to record reflectance spectra before and after burning at eight thermocouple lines in plots 1 and 2 (see Figure 5). Burning of photosynthetically-active biomass in the heather canopy accounts for the sharp fall in NIR reflectance. Scorching and drying of residual vegetation increases SWIR reflectance. Post-fire spectra are found to be flatter, with less pronounced water, lignin and cellulose absorption features.

Normalised Burn Ratio, NBR expresses change in spectral shape (Kokaly et al 2007). Differenced NBR pre and post-fire (dNBR) is related to burn severity in forests (Keeley et al 2008) and will be tested for heather canopies using burn severity assessed from plot photos (as seen in Figure 5) and the active fire dataset. Other spectral indices will be used to express degree of moss scorching and relationship to fuel moisture content.

8. Conclusions

The exercise, albeit restricted by weather conditions, did provide a useful initial platform for scientific study of fires in some UK ecosystems. The burns were used to test (and to aid in developing) techniques for research and practical fire control.

The substantial approach to instrumentation and measurement that was employed was made possible by a wide cooperation between academic and Fire Service partners. A prolonged series of further experimental burns is planned in the same as well as other UK vegetation types, involving the same team of partners. The objective is to develop a sound understanding of all aspects of fires that are sometimes very damaging in this environment.
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References


