Spatial pattern of wildfire distribution on the moorlands of the South Pennines

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Summary

The aim of the project was to deliver a spatial 'fire risk' map for the South Pennine Moorlands based on the methodology used to develop a fire risk map of the moorlands within the Peak District National Park (McMorrow and Lindley, 2006). 'Fire risk' here and throughout this report refers to *risk of reported wildfire occurrence*. It relates to static risk of ignition and then reporting, regardless of season and year. It does not imply risk of a fire spreading. The Peak District map was based on spatially accurate data on moorland fire incidents collected by the National Park ranger service. However, no such service or data set exists for the South Pennines. Instead, Fire and Rescue Service (FRS) fire incident data was used as the basis of the fire risk map for this region. During interviews and discussion with FRS fire fighting officers and data managers it quickly became apparent that there were issues with the spatial accuracy of FRS moorland fire data, essentially:

- The FRS incident recording is based on a street / postcode geo-reference;
- The addresses of incidents are often recorded as the street address to which appliances were mobilised, not to where the fire actually occurred;

As a result of these issues, it was not possible to produce a fire risk map comparable to that in for the Peak District as part of this project. The focus in this project instead became to work with the available fire incident data for the region to produce as spatially accurate fire incident dataset as possible. Using this dataset, we then produced fire density map for the South Pennine moorlands and provide discussion of these.

A key decision and factor in the project was the definition of moorland adopted. We used the Moorland Line as our working boundary, This boundary encloses land within England which has been defined as predominantly semi-natural upland vegetation, or predominantly of rock outcrops and semi-natural vegetation, used primarily for rough grazing; it does not focus on specific habitats or vegetation communities of particular value or interest. Adoption of this definition had significant implications for mapping spatial patterns of wildfire within the region. As this project represented the first attempt to map fire risk for the region, use of the Moorland Line did produced a robust, and spatially comprehensive, overview and on the issue of wildfire risk within the region on which more future investigations with more specific aims (for example, habitats, land use, importance) might build.

We collected data on past wildfire occurrence from three FRSs: Greater Manchester, Lancashire and West Yorkshire. Of the data collected, data for the years 2000-2008 inclusive were available for all

three counties – enabling an eight year study period. Within this data set ‘moorland’ fires are not explicitly indentified. To identify moorland fires we mapped the locations of fires identify those occurring within the Moorland Line (moorland fires). As stated above, from discussions with FRS staff at the start of the project we were aware of issues with the spatial reliability of the recorded locations of fires; predominantly that locations might represent the turnout location (where fire fighting appliances turned out to) rather than the actual location of the incident, which would lead to moorland fires recorded at nearest street address. This would clearly potentially lead to some moorland fires being mapped just off moorlands on nearest access roads. To capture these incidents, we created a 250 m buffer around the Moorland Line and identified the subset of incident contained therein. This buffer, from visual inspection of maps, represented the general distance from the Moorland Line to the nearest road. We then searched the detailed fire incident logs (records of the communications between the fire incident commander and the control station) with a string search for the term “moor” to identify moorland fires within this region. For logistical reasons we were only able to do this for West Yorkshire. Just 3% of fire incidents in the 250 m buffer were positively classified as moorland fires (however, the absence of additional information in fire logs did not mean an incident was not a moorland fire, just that no information was recorded). Overall, we estimate there have been ~388 moorland fires on the South Pennines Moorlands (excluding North Yorkshire) between 2000 and 2008.

Examination of the number of individual attendances at moorland wildfires by the three FRSs incidents relative to the area of moorland lying in the South Pennines within each respective county revealed that Greater Manchester FRS attended 187 incidents, three times as many as expected given the extent Moorland that lies within its county boundary (just 14% of that within the South Pennines). West Yorkshire and Lancashire attended fewer incidents than expected (G_{adj} = 271.67, df = 2, P<0.001). This reflected a general finding that the majority of fires were seen to occur in the more densely populated southern area of the study region – particularly in the regions surrounding Greater Manchester, and to the south west of the West Yorkshire county boundary. This also closely correlated with a number of major transport arteries for the north of England – namely the M62 running directly through this region, cutting between Saddleworth and Rishworth Moors.

In fact, much of the moorland in the South Pennines lies within close proximity of urban/ developed areas, allowing easy access to moorlands from conurbations, called a Wildland (moorland) – Urban Interface (W-UI). The moorland within the South Pennines comprises 142 ‘fragments,’ 121 (85 %) of which are less than 1 km^2 in size, with just nine bigger than 10 km^2. These fragments are highly accessible by the inhabitants of nearby conurbations, a situation that contrasts markedly with that in the PDNP where the moorland is generally contiguous and by far the majority is rural and remote. We suggest that the South Pennines can potentially learn from the Urban Heaths Partnership in Dorset (UHP). This project has successfully addressed the issue of wildfire risk on heathlands that are in close proximity to urban areas, highly accessible and heavily utilised by the local population.

We highlight three case studies from West Yorkshire in this report that inform understanding of important factors or considerations included, excluded or highlighted in this study. These three case studies were discussed at an expert workshop to inform our interpretation of results and formulation of discussion:

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1) Illingworth 'moor' – an example of the implications of the data sets and spatial definitions selected to investigate moorland wildfire density on the South Pennine moorlands.
2) Baildon Moor - an example of the value of consultation of other spatial data sources to interpret and understand wildfire locations (both the position mapped and 'true' positions).
3) Ilkley Moor – an example of the correction of fire incident locations using information contained in fire logs to update the recorded location which was either the call-out location or closest feature, vantage point address.

Once we had identified moorland fires as best we could within the scope of this project we produced a fire density map on a 2 x 2 km grid across the region. We selected this grid size as it offered the highest resolution of mapping relative to the known spatial inaccuracies in the records of fire locations. This identified six areas at particular risk of wildfire:

High fire density areas:		
1	Rishworth, Soyland and Blackstone Edge Moors	Greater Manchester, West Yorkshire
2	Crompton Moor	Greater Manchester
3	Illingworth	West Yorkshire
Medium fire density areas:		
4	Ilkley Moor	West Yorkshire
5	Baildon Moor	West Yorkshire
6	Anglezarke and Rivington Moor	Greater Manchester, Lancashire
7	Ashworth Moor (Knowl Moor)	Greater Manchester

These seven moorland areas are predominantly used for local recreational purposes this information could be utilised to inform an education programme to reduce future wildfire risk. This could be targeted at local schools and focus on the conservation importance of the moorlands and the risk and impact of wildfire. Additionally given the high moorland - urban interface of these moorlands, education could also be targeted as 'road shows' at relevant local urban centres. Climate change must also be considered when considering future wildfire risk and mitigation strategies for the region. As well as direct effects on wildfire risk (e.g. on fuel loadings, vegetation composition etc) climate change will have significant indirect effects, for example, changes in land management and shifts in peoples' lifestyle to increased recreation time and activities and more 'holidays at home'. These may lead to an increase in ignition events and changes to the spatial nature of wildfire risk in the South Pennines moorland.

From April 2009 a new system for recording data on fires, the Incident Reporting System (IRS) became compulsory across all Fire and Rescue Services in the UK. In our discussions with FRS staff during this project it became apparent that while this system off a great advance in the quality and resolution of data collected on wildfires, there were nevertheless issues associated with the system which are discussed. We suggest that immediate additional and supporting actions to aid and improve data capture on wildfire incidents should include:

- Use of GPS to accurately record the location of fire incidents – recording both the fire centroid, ignition point (if known) and fire perimeter.
- Training fire-fighters or a number of dedicated 'wildfire officers' within each FRS, in the identification of moorland plants/ vegetation types and the conservation value of each.

Contents

List of Tables

List of Figures

1. Introduction

1.1. Spatial fire risk mapping

There are many different types of spatial wildfire risk maps; they can be static or dynamic and can model risk of ignition or fire 'hatching' and / or risk of spread, fire intensity post-ignition and severity of impacts. The meaning of the term risk varies between academic disciplines and user groups. So too does hazard. The FAO Global Fire Monitoring Centre (GFMC, 2008 online) Wildland Fire Management Terminology defines fire risk as '*the probability of fire initiation due to the presence and activity of a causative agent'*. In the UK's case, this is usually people. They define fire hazard in terms of fuel[1]*,* but *a broader definition of* hazard could be the physical event making the fuel more flammable, such as a prolonged dry spell or drought.

A diverse array of data is required to spatially model risk of wildfire ignition, but they can be broadly split into two types of factors; physical and anthropogenic (Figure 1). Physical factors determine the 'fire vulnerability' landscape or 'flammability potential' landscape, especially fuel load and moisture content. They are highly dynamic, changing with season and weather and over the longer-term as vegetation responds to the fire regime itself. In the UK, wildfires are usually attributable to anthropogenic causes, be they accidental or deliberate. Therefore the actual source of ignition is of anthropogenic origin and it is these factors which largely determine when and where a fire starts if physical conditions are suitable. The subsequent behaviour of the fire is a combination of both sets of factors. Static wildfire ignition risk maps do not show risk of fire *spread* after ignition*,* because they do not account for difficulty in extinguishing a fire once started. The spatial models are not temporally constrained, so do not allow for changes in management response over time or with season.

The Peak District project produced a static map of the *risk of reported wildfire occurrence,* referred to hereafter for brevity as *'fire risk map'*. It was not a fire danger map as defined by GFMC as it excluded variable factors of the fire environment like fuel load and fuel moisture, and did not attempt to cover ease of ignition, rate of spread, difficulty of control, or fire impact[2]. It was similar to GFMC's definition

[1] '**Fire hazard:** fuel complex, defined by volume, type, condition, arrangement, and location, that determines the degree both of ease of ignition and of fire suppression difficulty.

[2] **'Fire danger:** a general term used to express an assessment of both fixed and variable factors of the fire environment that determine the ease of ignition, rate of spread, difficulty of control, and fire impact; often expressed as an index (http://www.fire.uni-freiburg.de/literature/glossary.htm, accessed 12 June 2009)

of a constant fire danger map[3], but excluded values of property or services at risk. It related to the risk of ignition by human factors and took some account of physical factors.

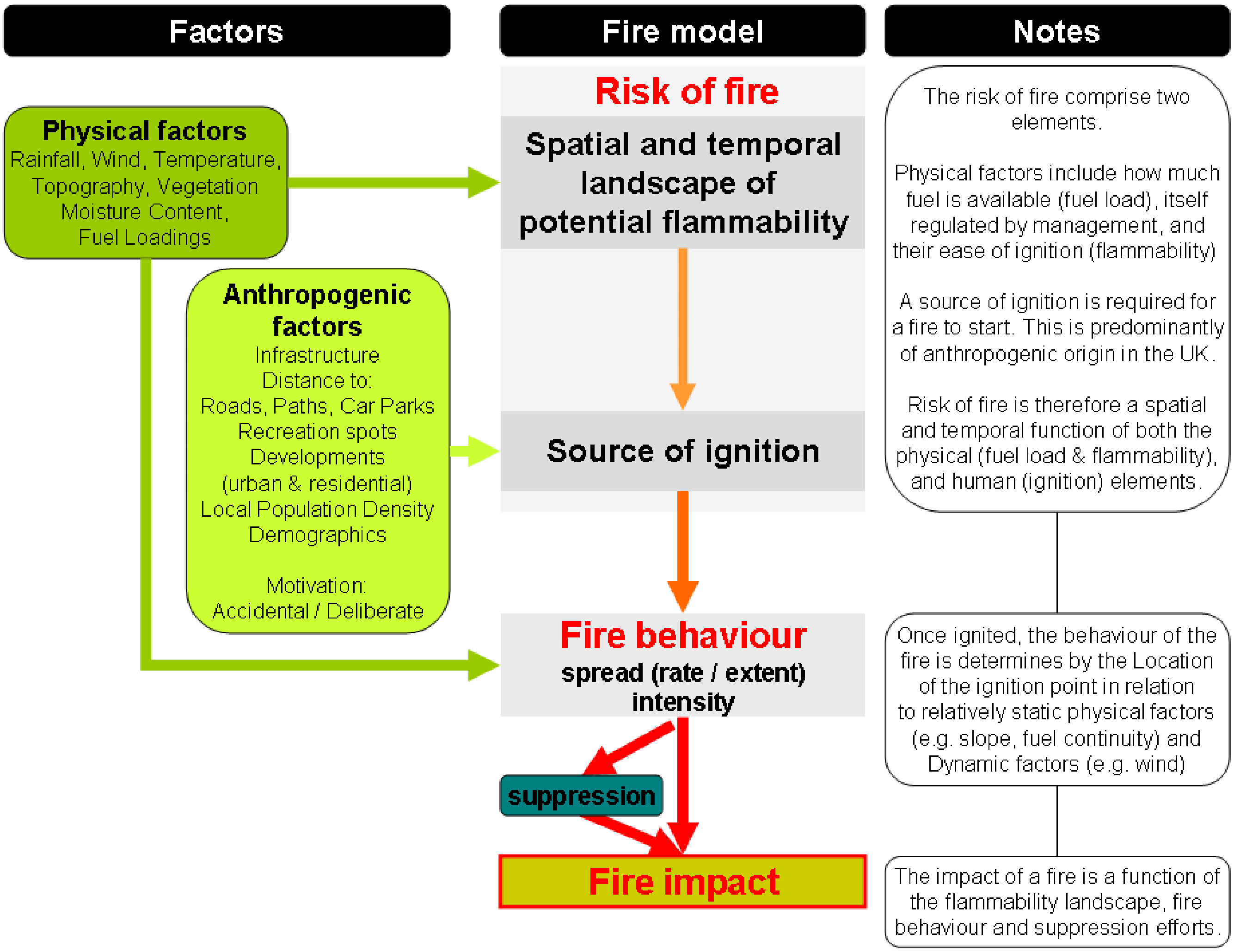

Figure 1. Factors and modelling wildfire risk and impact

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[3] **Constant Fire Danger'** The resultant of all fire danger factors that are relatively unchanging in a given area, e.g. values at risk, topography, fuel type, exposure to prevailing wind (http://www.fire.uni-freiburg.de/literature/glossary.htm, accessed 12 June 2009).

1.2. The wildfire risk map of the moorlands of the Peak District National Park (McMorrow and Lindley 2006)

The approach we adopt in this project used archival fire incidents. That is, it was based on reported historical wildfires from the PDNP Rangers fire log from 1976 to 2004. This approach produced a retrospective, spatially distributed assessment of wildfire risk (of reported fires) at a fine scale (50m) using multi-criteria evaluation (MCE). The MCE GIS technique has been employed by others for fire risk mapping (Chuvieco and Salas, 1996; Martín, 2005; Vakalis *et al*., 2004) and is outlined below. This work built upon previous fire risk mapping work for the Dark Peak as part of the Climate Change and visitor economy programme (McMorrow *et al*., 2006).

1.2.1. Building the model

There were four stages to building the multi-criteria evaluation (MCE) model (Figure 2): 1) selecting layers; 2) scoring factors; 3) weighting the factors; and 4) mapping wildfire risk.

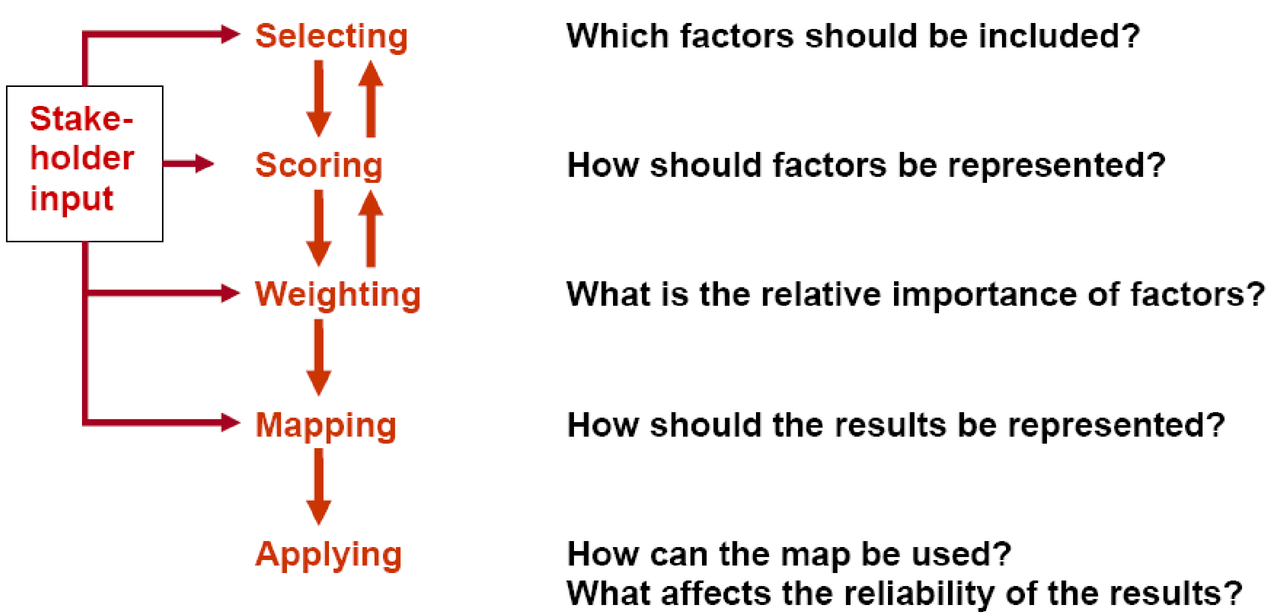


Figure 2. The production of a risk map using multi-criteria evaluation

1.2.2. Incorporating expert opinion

There was an initial consultation with members of the PDNP Fire Operations Group (FOG) in March 2006. This consultation helped to identify a set of factors to use as the basis for subsequent analysis and to determine the nature and form of stakeholder involvement in subsequent stages of the project. Stakeholder involvement was undertaken in two stages, firstly through an online questionnaire open to a wide number of stakeholders and other experts, followed by a dedicated one day workshop where the issues were explored in more detail.

1.2.3. Selecting layers

Initial consultation with stakeholders identified a set of potential factors affecting wildfire distribution. Figure 3 shows the factors considered for the MCE model; each represented as individual map layers. There were two groups of factors: vulnerability to ignition hazard (physical factors) and accessibility (human factors). Not all of the suggested factors were eventually used in the final model due to: inconclusive findings regarding the influence of each factor on wildfire distribution; perceived low importance in subsequent weighting exercises; and/or time constraints. In generating a set of models, emphasis has been given to the most important layers affecting wildfire distribution, generated from stakeholder input and/or empirical analysis.

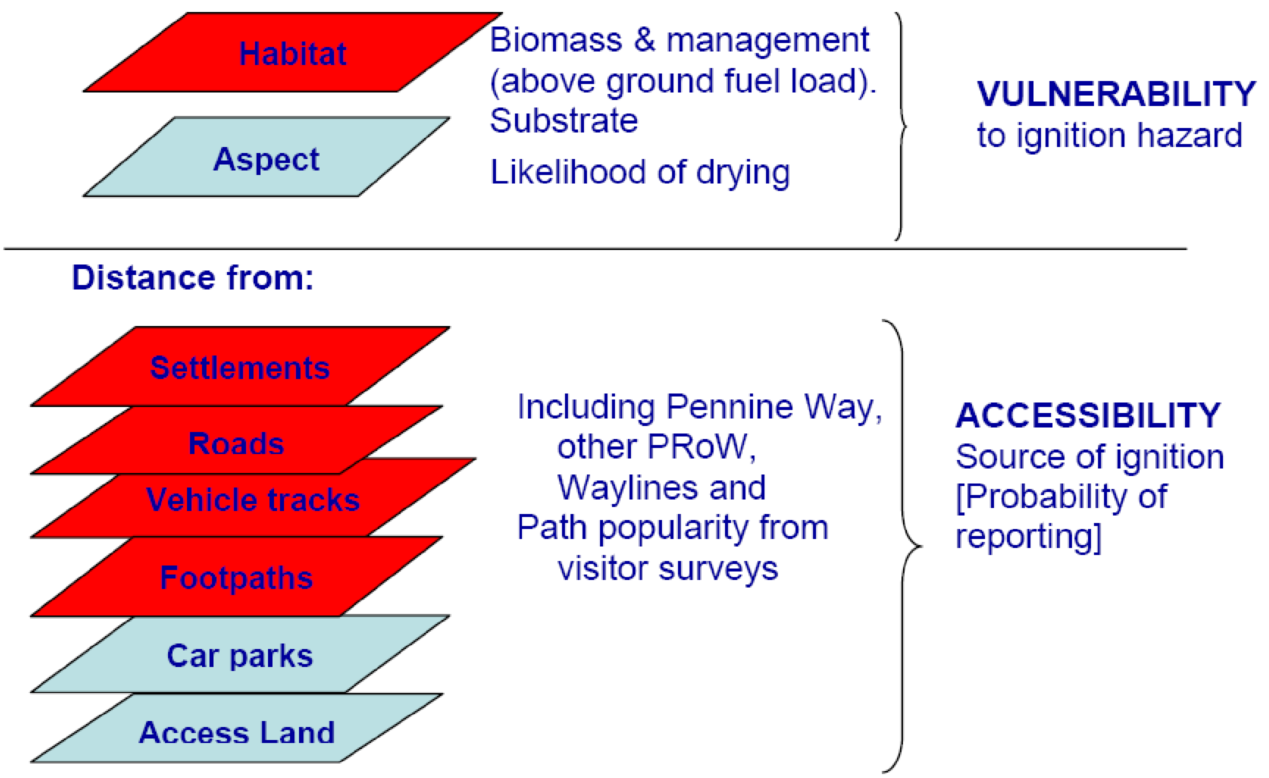


Figure 3. Conceptual model, showing layers in MCE.
Red layers are those used in final models. PRoW (Public Rights of Way). Waylines layer; paths and tracks from digitised aerial photograph interpretation.

1.2.4. Scoring factors

Two types of scoring mechanisms were used, based on the way in which factors were represented as map layers.

(i) *Area-weighting principle*. This was used for factors where map layers were area based, for example habitat

(ii) *Distance decay.* This was used for factors where map layers were based on distances from point or line features, for example, paths

The first part of the process involved generating a distance surface containing distance values from particular features of interest to each 50 m cell in the data layer. Next, distance values were extracted for each cell containing a training fire. Finally, distance values were plotted as frequency distributions with different sized distance classes to assess the most appropriate distance bands and scores in each case. The process of deciding distance bands and scores also referred back to stakeholder input. In some cases, no relationship between distance and wildfire frequency could be established, necessitating the omission of some of the layers.

1.2.5. Weighting

Weighting was required in order to combine individual map layers into a single model to estimate the spatial risk of wildfire. The primary source of information concerning model weights was taken from stakeholder input. Weights were used to generate a formula to apply within the ArcGIS Spatial Analyst Raster Calculator to combine the scores associated with individual cells in each layer and create a final risk score as an output. Open water areas were set to zero in the final risk maps.

1.2.6. Mapping

There are numerous different methods for presenting the results of the data in map form and each method will influence the apparent distribution of high and low risk zones. There are also practical considerations, such as the number of categories which should be used when mapped output is to be used in operational contexts. Opinions were gathered using the online survey with further discussion at the June workshop. The use of three categories for mapped results received broad approval.

Wildfire distribution on South Pennine moorlands

1.2.7. Results

The spatial distribution of wildfires is not random. Wildfires were mostly found on statutory Section 3 moorland. This is not surprising given that the fire database was compiled by PDNP rangers. Spatial bias may exist because wildfires close to access routes are seen more easily and are more likely to be reported; however, it probably also reflects the true distribution according to participants at the CCVE risk workshop (CCVE, 2005). The study was only concerned with section 3 moorland and within this, wildfires are more common in the west of the Park, especially in the Dark Peak on blanket peat, and where the long-distance footpath, the Pennine Way, is located. Few wildfires are found on managed heather moor in the east; this is likely to be because prescribed burning successfully manages fuel load. In the Dark Peak, it appears to be the combination of peat, especially exposed peat, and major footpaths which favour high fire risk.

1.3. Use, application and benefits of wildfire risk maps

This project was initiated as part of the establishment of a South Pennine Fire Operations Group (FOG). The motivation being to reduce wildfire risk and increase the efficiency and effectiveness of the any fire fighting response, for example through improved resourcing and planning. Fire risk maps have the potential to provide a scientific evidence base for Fire and Rescue Services to spatially assess (and visualise) the fire risk on their 'territory' and consequently information for informed spatial fire-fighting resourcing or lobbying for additional resources to mitigate the risk. They can inform fire plans by aiding selection of rendezvous points, access and available water resources (or need for provision of additional water resources for fire fighting, e.g. fire ponds) for / to areas most likely to suffer wildfires. Risk maps might also inform the location of wildfire watches; these act as early detection systems to identify and enable rapid response to any wildfires, thus mitigating the risk of any fire becoming major incidents and in the case of the PDNP, often without the need for FRS attendance. For West Yorkshire FRS, in relation to the South Pennines, fire risk maps are described as what they need at present for informed planning to the risk of wildfire as, at present, WYFRS are at the responsive, rather than the preventative stage in how they tackle their wildfire issue (Andy Newman, WYFRS).

1.4. Aim of this project

The aim of the project was to deliver a fire risk map for the South Pennine Moors based on the methodology used to develop a fire risk map of the moorlands within The Peak District National Park (McMorrow *et al*., 2006). The Peak District wildfire risk map was based on a spatially accurate data on moorland fire incidents collected by the National Park ranger service; however, no such service or data set exists for the South Pennines. The only available fire incident data available being that of the Fire and Rescue Services (FRSs). A significant proportion of the work within this project was to determine and overcome issues related to the spatial accuracy of these data and the quality of the supporting information provided on these incidents. As a result of these issues the focus in this project was to work with the available fire incident data for the region, to produce as spatially accurate fire incident dataset as possible. Using this dataset we then produced fire density mapping for the region and provide discussion of this.

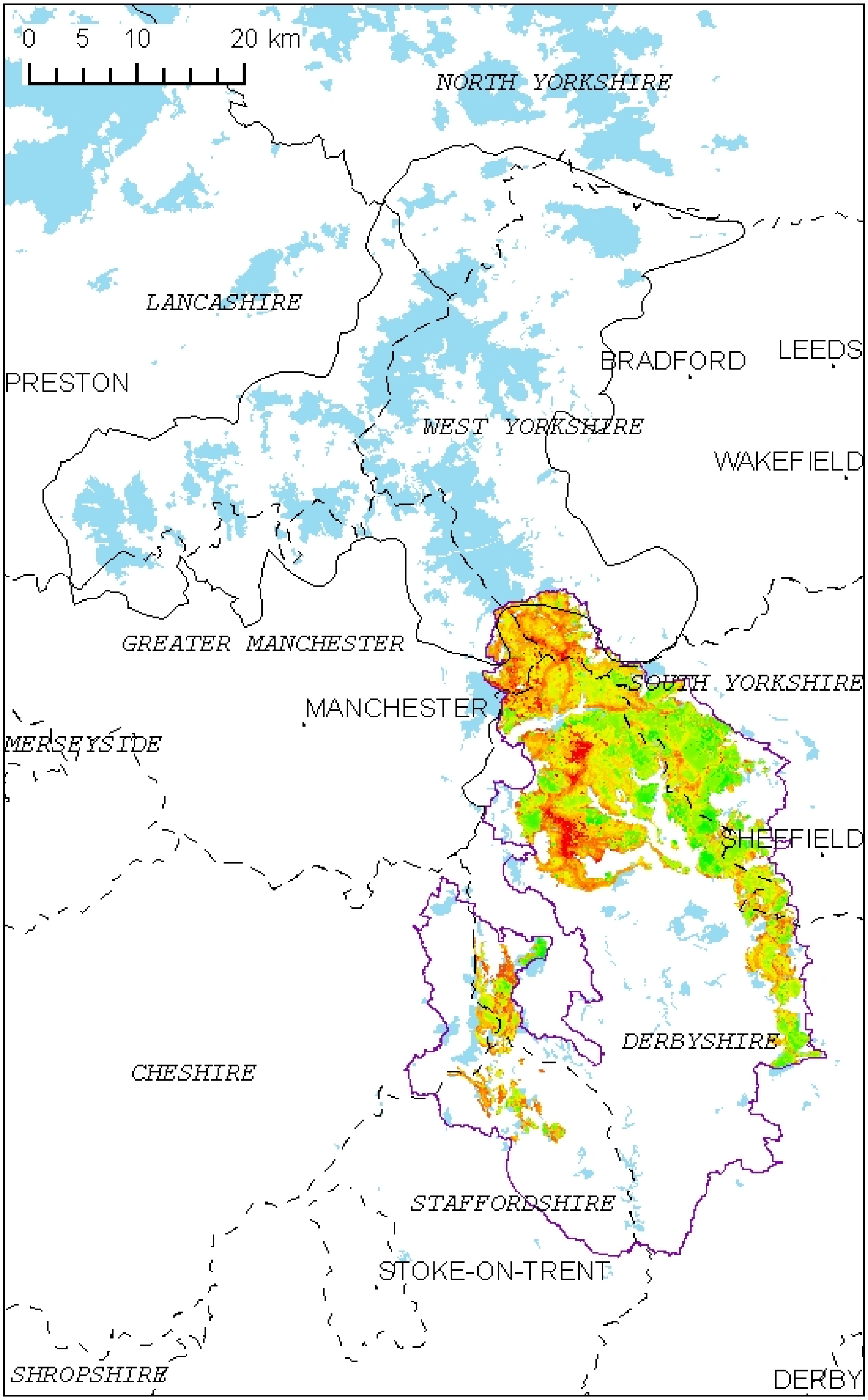


Figure 4. Extent of the South Pennine Moors SAC.
Presented on this are the South Pennines boundary adopted by Pennine Prospects (black solid), the Peak District National Park boundary (purple solid), and county boundaries (hashed). The fire risk map (model 1c) is presented for the moorlands of the Peak District National Park as a 'traffic light' index of wildfire risk (McMorrow *et al*., 2006).

2. Study area

2.1. Location and spatial coverage

The South Pennine moorlands (detailed in Figures 4 and 5) are defined as an upland area in the north of England, roughly matching Natural England's BAP bog habitat classification, situated between Preston to the west and Bradford to the East. Its northern limits extend towards the North Yorkshire Moors and the Lancashire Fells, whilst the south of the region adjoins the Peak District National Park. The moorlands themselves lie in close proximity to a large number of towns and villages, generally sited in valleys adjacent to the higher upland plateaus. In this study we define the South Pennines by the boundary adopted by Pennine Prospects (Figure 4) but exclude the overlap with the Peak District National part as this area. The South Pennines cover an area of 1560 km^2 of which ~10% are classified as urban areas and 434 km², or 28% or the region, are moorlands.

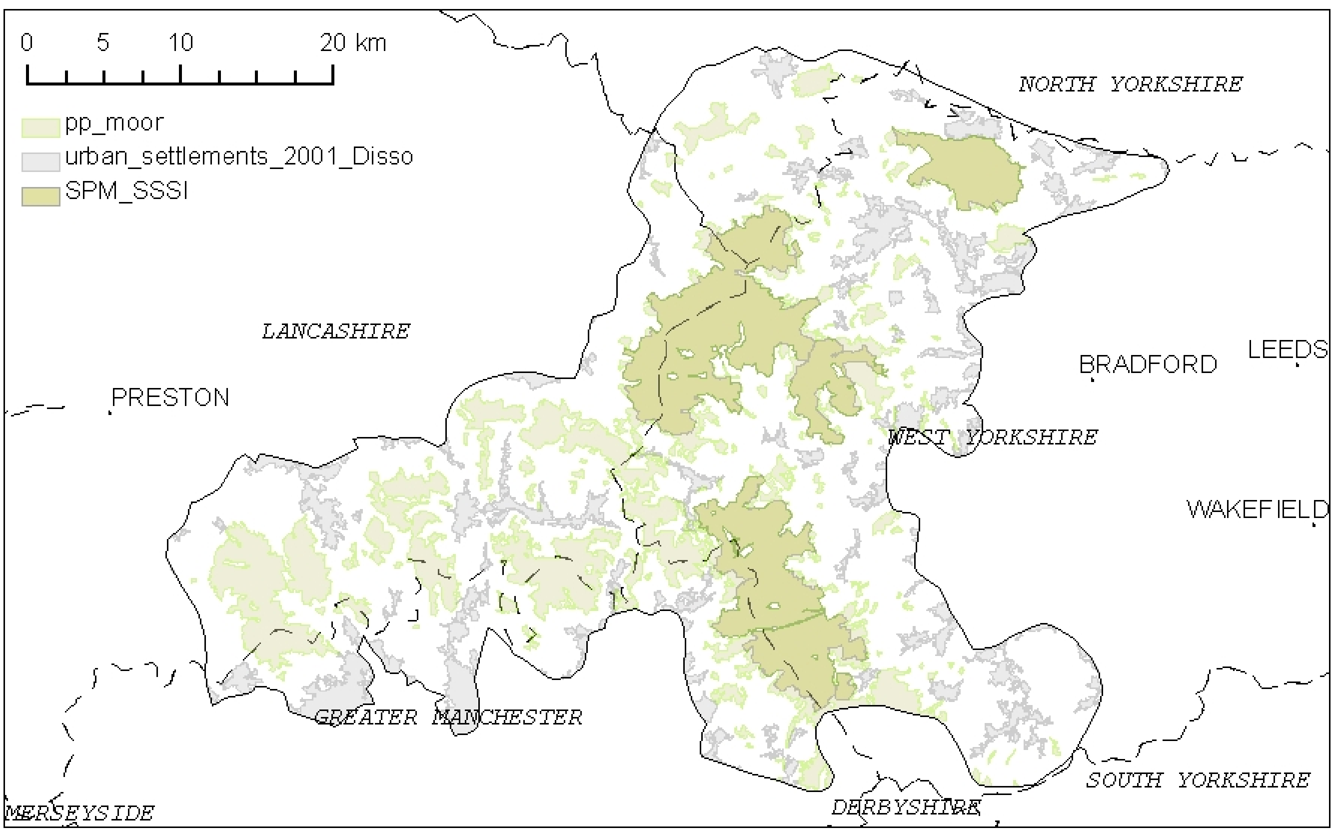


Figure 5. South Pennines study area.
Pennine Prospects boundary is the solid black line (excluding overlap with PDNP), county boundaries are the dashed lines. Grey area denotes urban settlements as defined by the Natural England 2001 dataset, while moorland regions appear in green, the darker green areas represents moorlands within the South Pennine Moors SAC. The moorland boundary is extracted from the Natural England moorland line – see text for further details.

Four counties are represented within the South Pennines (Table 1; Figure 5). Therefore four Fire and Rescue Services (FRSs) are responsible for covering fires on the region's moorlands. By far the greatest responsibility for moorland fire coverage, with over half, is within West Yorkshire.

Table 1. Areal representation of the four counties that in the South Pennines.
Counties are ordered from left to right in terms of moorland area within the South Pennines (for which they are primarily responsible for providing cover).

	West Yorkshire	Lancashire	Greater Manchester	North Yorkshire
Area within SP region (km^2)	751 km^2	442 km^2	240 km^2	127 km^2
Proportion of SP region (%)	48 %	28 %	15 %	8 %
Moor area (km^2)	224 km^2	128 km^2	60 km^2	22 km^2
Proportion of moor area (%)	52 %	29 %	14 %	5 %
No. of moorland fragments	87	41	22	11

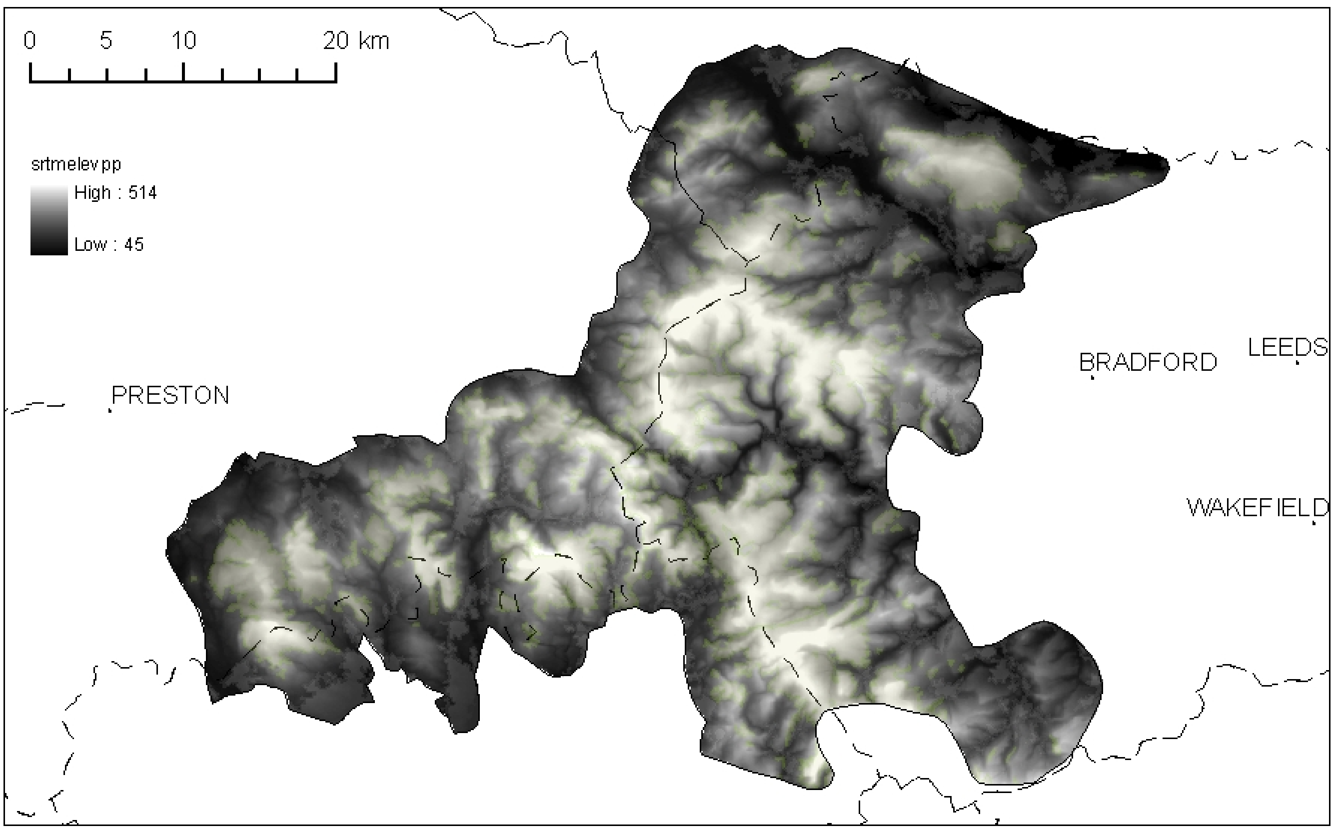


Figure 6. Elevation for the region.
The upland plateaus denoted as moorland by the Natural England moorland boundary. Elevation data shown is 90m SRTM data, with the legend indicating height above sea level in metres (Jarvis et al., 2008).

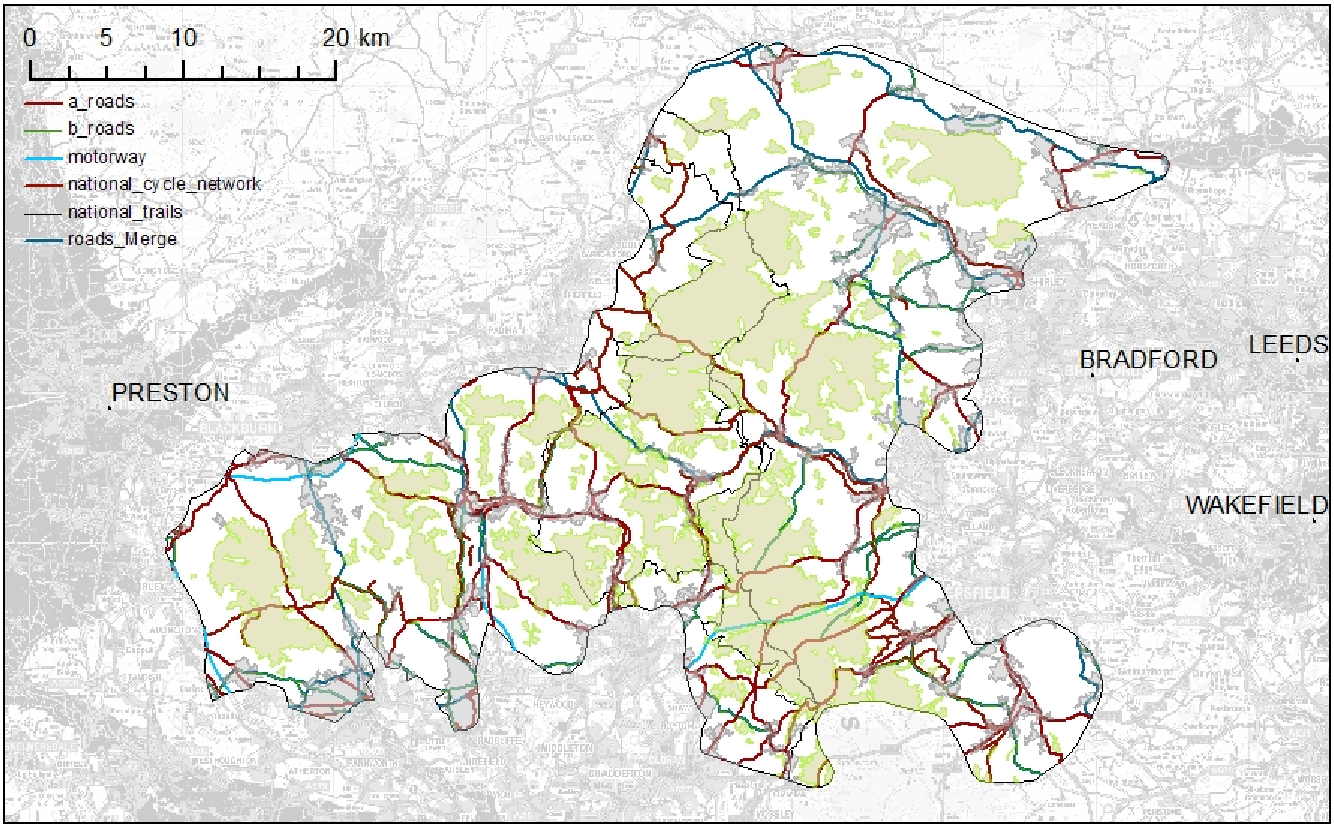


Figure 7. Spatial configuration of the South Pennine moorlands and access urban areas.
The extensiveness of road network and location of urban areas, as identified from OS Mastermap 2008 data. © Crown Copyright. All Rights Reserved. License 1000005734. 2009.

2.2. The moorland of the South Pennines[4]

2.2.1 Spatial configuration and status

The 434 km^2 of moorlands within the South Pennines are composed from a high number of small moorland fragments (Figure 8). There are 142 fragments of moorland ranging from 0.01 km^2 (1 ha) to 131.88 km^2, with an average (median) size of 0.14 km^2 (~1.5 ha) in size. 121 (85 %) are less than 1 km^2 in size; 134 (94 %) smaller than 10 km^2 with just nine bigger than 10 km^2. One very large area of moorland of 132 km^2 dominates the South Pennines and occurs across three of the four represented counties. This moorland has a combined perimeter of some 1270 km not including dissection by roads.

The South Pennine Moors SSSI (Site no. 1006648) covers the 209.4 km^2 or 48% of the moorlands located within the South Pennines. The majority of the site is within West Yorkshire but it also covers

[4] see methods section for details of the moorland boundary used in this study

areas of Lancashire, Greater Manchester and North Yorkshire. Only half of the area of this SSSI is in favourable condition (Table 2).

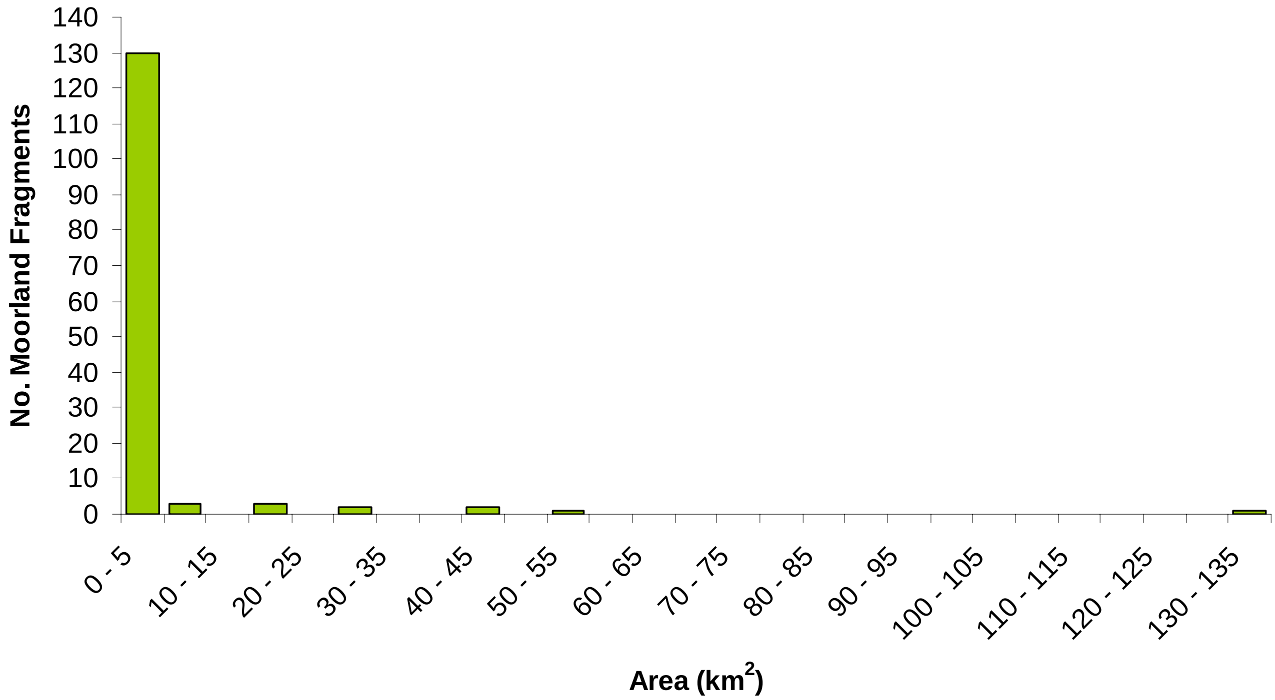


Figure 8. Size distribution of the 142 fragments of moorland within the South Pennines.
92% of fragments are located within the first 'bin', the 0 – 5 km^2 category.

Table 2. Condition of the South Pennine Moors SSSI

Condition category	% of SSSI area
Area meeting PSA target	50.0
Area favourable	0.4
Area unfavourable recovering	49.6
Area unfavourable no change	47.4
Area unfavourable declining	2.6
Area destroyed / part destroyed	0.0

Natural England SSSI information: SSSI name: South Pennine Moors.
http://www.sssi.naturalengland.org.uk/citation/citation_photo/1007196.pdf

2.2.2. Biodiversity Action Plan habitats

Total area covered by BAP priority habitats in the Pennine Prospects region is 287.4 km^2 or 66% of the moorlands within the South Pennines. These are, by far, best represented by blanket bog, which covers 88.4%, or 254.2 km^2 of BAP habitat area in the region (Figure 9). Upland heathland represents the only other notable BAP habitat area cover with 7.3%, or 21 km^2 of the area in the region. Other relevant BAP habitat types and their areas are shown in Table 3.

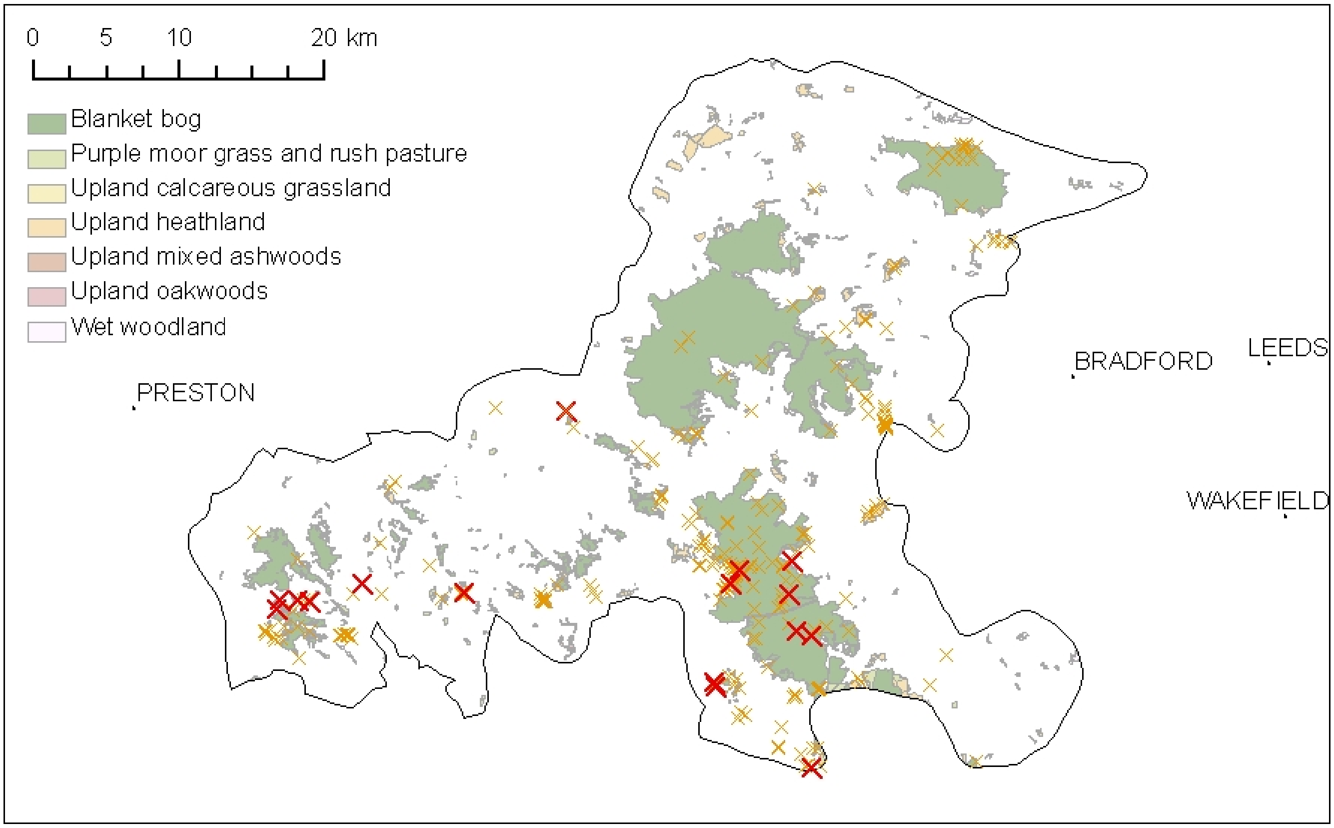


Figure 9. Overview of BAP habitats in Pennine Prospects region, with fires plotted.
Areas are presented in Table 3.

Table 3. Area of BAP listed habitats within the South Pennines.

Bap proportions	Area (km²)	Area (%)
Blanket bog	254.2	88.5
Purple moor grass/ rush pasture	5.8	2.0
Upland calcareous grassland	1.5	0.5
Wet woodland	4.6	1.6
Upland oak woods	0.4	0.1
Upland heathland	21.0	7.3

The blanket bogs of the South Pennine Moorlands are dominated by cotton-grass *Eriophorum* spp., and heather *Calluna vulgaris*. Crowberry *Empetrum nigrum* is abundant on the eroding margins of the blanket bogs of the South Pennine Moors. This crowberry dominant moor is restricted to the South Pennines and is particularly extensive on Ilkley Moor. Areas of wet heath have developed on the blanket mires. The lower slopes are dominated by heather moorland with large areas of acid grassland. Some parts of the heather moors are burnt for red grouse *Lagopus lagopus* and sheep management. The large areas of acid grassland on former heathland reflect patterns of heavy grazing and burning. On wet slopes purple moor grass *Molinia caerulea* is dominant with the wettest areas supporting heath rush *Juncus squarrosus*. The most species rich and diverse habitats are the acidic flushes, mires and seepage lines. This mosaic of habitats supports moorland breeding bird assemblage which, because of the range of species and number of breeding birds it contains, is of regional and national importance. The large numbers of breeding merlin *Falco columbarius*, golden plover *Pluvialis apricaria* and twite *Carduelis flavirostris* are of international importance. (SPM SSSI citation).

3. Methodology

3.1. Fire incident data collation

We identified available fire incident data together with an overview of how these data are recorded and processed (Table 4). Four Fire and Rescue Services are represented within the South Pennine boundary adopted for this project; Lancashire, Greater Manchester, West Yorkshire and North Yorkshire. The latter service is not formally a member of the South Pennine FOG group and has such a small area within the boundary that we did not collect data for this area. We held meetings with West Yorkshire, Lancashire and Greater Manchester FRSs to discuss data availability and how spatial information on 'moorland' wildfires are collected, managed and utilised. We also tried to identify any caveats with the 'quality' of the data, how and whether these data are of value to the FRSs, and whether the recording system is to be updated.

Table 4. Details of meetings held with the FRSs within the South Pennines.

Greater Manchester FRS	Lancashire FRS	West Yorkshire FRS
19.09.2008	05.11.2008	23.09.2008
Steve Yearsley Mike Baines	Ian Potter Robert Shaw	Andrew Newman Hilary Charlton
Jonathan Walker	Jonathan Walker Will Hewson	Jonathan Walker Julia McMorrow

3.2. Overview of moorland wildfire incidents and how they are spatially recorded

How FRS crews are mobilised, how fires are classified and consequently how and what data are recorded on wildfires have a significant effect on how the positions of moorland / wildfire incidents are spatially mapped and the amount of other data recorded.

3.2.1. Mobilisation

The first process in identifying the location of a (potential) moorland fire comes from the mobilisation team. Mobilisation is responsible for taking the 'call' informing the FRS about a fire, collecting information on this fire and deploying appliances to tackle incidents. This marks the initial spatial record of when a fire takes place.

Wildfire distribution on South Pennine moorlands

This system is of great use for the vast majority of fires attended as they are concerned with residential and industrial incidents; however, its application to mapping moorland wildfire is less useful, given the lack of clear features with which to append post code information to on the moorland. With this in mind, it is thought the bulk of moorland fire incidents are reported in relation to the nearest building or roadside – as was often found with fire data for what were undoubtedly moorland fires, the nearest point of reference was usually a locally well known car park, or pub.

The objective of providing this address is to ensure that the appliance(s) are deployed to as spatially accurate position as possible, or alternatively, an address from which fire crews are able to visually locate the fire. For moorland fires this often reflects the 'address' form which the fire was 'called-in', the nearest access road to the fire, or a known and readily accessible 'vantage point' on a given moorland (e.g. communications mast). This location will be the recorded address for a fire incident unless updated by the incident commander. The initial locations are only corrected to a more accurate location if there are significant discrepancies in 'street' address and positions are translated into grid references, often of a landscape feature such as a monument, TV mast, reservoir etc. If the incident requires an additional attendance of extra appliances, a rendezvous point will be identified by the incident commander which will generally provide a more accurate location.

3.2.2. Fire categories

Historically, moorland fires have not been specifically or uniquely identified as such. Therefore, to identify moorland fires we had to interrogate the fire incident databases of the FRSs under a number of fire categories:

- Grassland / heathland / railway embankment
- Trees / fences etc.

FRSs have a number of different categories of fire incident, two of which are relevant to moorland 'wild' fires. The category of fire reflects it's 'importance' and as a result the amount and resolution of data recorded for any given incident.

Primary Fire (FDR1)

Dwellings including mobile homes, caravans, trailers etc, vehicles and other methods of transport, outdoor storage, plant and machinery, other outdoor structures including post-boxes, tunnels, bridges etc, and all fires that involve casualties, rescues or escapes or if five or more fire engines were employed in fighting the fire. (When moorland fires are classified as Primary fires it is mostly because there have been five or more appliances in attendance or there was some monetary value to the land, for example a sporting estate or plantation).

Secondary Fire (FDR3)

Single derelict building, grassland, intentional straw/stubble burning, outdoor structure, refuse and single derelict vehicle.

Full fire reports are completed for Primary fires but only the most basic information available for Secondary fires. Depending on the fire category being attended (Primary / Secondary) this postcode level of resolution could then be upgraded by the incident commander with more spatially accurate grid references (or if a postcode was unavailable, a grid reference would be needed for the FDR1). This spatial updating was generally only performed on the larger category Primary fires for which an incident report is compulsory regardless of size, potentially leaving many (Secondary) incidents inaccurately mapped. Lancashire FRS, for example, uses a six figure grid reference for Primary fires, but a four figure grid reference for Secondary fires.

3.2.3. Fire logs

Fire logs contain a record of every instance of communication between incident control and attending fire crews. Whilst much of this data is understood only by the receiving computer, consisting of unintelligible codes and commands; spatial references can be found through careful inspection of the logs (although such information is not always guaranteed). The inspection of fire logs is a time consuming process. Until April 2009 fire reports were not completed for secondary fires unless there were casualties, and/ or an insurance claim (damage to property/ assets). Despite this initial lack of detailed spatial information, from analysing individual fire logs, some improvement on historic fire locations of Secondary fires might be made (see Appendix 1). A stop code finalises an incident in the fire log. Stop codes are issued when an incident is deemed ‘under control’ (no further resources required) and in the fire log a brief description of the incident is made, for example, size, location, vegetation type. Incidents are sent to the Home Office within three months for ‘finalisation’ after which the incident is closed (Table 5).

Table 5. FRS fire service data.
The text presented inferred possible moorland fire for incidents within the South Pennines.

Fire and Rescue service			Suitable identifiers	Total incidents/
West Yorkshire	1996	2008	Grassland/Heathland/Railway embankment	32687/ 4074
Lancashire	1998	2008	SUB_TYPE: !, Grass/Heath/Railway, Int. Straw/Stubble, Refuse/Container, Standby at Hazard, Tree/FenceLamp LOCATION: Agric, Forestry, Garden, Agriculture and Business, Fence, Fixed Outdoor, Forest, Grassland, Heath, Non Mobile Outdoor, Open Land, Other agr/forst/gdn, Peatland, Plantation, Road Verge, Standing Crops, Stooked Bales, Stooked Stack, Wood	9397/ 2383
Greater Manchester	2000	2008	LOCATIONTY: Elsewhere, Grassland, Heath, Moorland, Open Land, Unspecified. INCSUBTYPE: Grass/Heath/Moor/Railway, Int. Straw/Stubble, Tree/Fence/Lamp	469/ 469
			South Pennines total	42568, 6928

3.2.4. Data management / storage

In April 2009 a standardised national fire reporting database and protocol will be compulsory across all FRSs. This is called the Incident Report System (IRS). West Yorkshire FRS adopted and has been using the IRS since January 2007, Greater Manchester and Lancashire will introduce the system in April 2009. Before the adoption of the IRS all FRS used information management systems; however this was not standardised across FRSs. West Yorkshire, for example, used a database called Sophtlogic. The IRS provides a standard ‘minimum’ reporting form and protocol that can be extended by FRSs. West Yorkshire are working to add additional fields to the standard IRS in conjunction with 11 other FRSs. With regards to the spatial mapping of fires, it is important that there is the option to update the location of the fire from the initial mobilisation location. This is done, on screen, by dragging a pointer on an OS street view map. In a demonstration of this system at West Yorkshire FRS we identified that while simple; this has the limitation that topographical features are not displayed on the OS street map which makes it difficult for the incident commander to accurately locate the position of the fire without local knowledge. This map also has the limitation that once ‘zoomed in’ the user cannot then zoom out again. When an address is updated no record is kept of the original call address. Another issue is that officers are forced to make selections, even if they do not know the answer. There is not any option to select ‘not known’ or ‘unrecorded’ hence officers are ‘forced’ to fit ‘best case’ answers to incidents even if they are not sure.

3.3. Defining the moorland boundary

As the project is focused on moorland fires, the Moorland Line, obtained from the government's MAGIC GIS repository (http://www.magic.gov.uk/datadoc/metadata.asp?dataset=37&x=16&y=11) supplied the demarcation of the study area. The Moorland Line encloses land within England which has been defined as predominantly semi-natural upland vegetation, or predominantly of rock outcrops and semi-natural vegetation, used primarily for rough grazing. This boundary has been cropped to the South Pennines (Pennine Prospects definition; see Figure 4). Additional extents considered relevant to the upland theme included the data provided by Natural England on Biodiversity Action Plan area – in this instance, the "bog" category (Figure 9).

4. Analysis

Data arrived from the fire and rescue services as Microsoft Excel spreadsheets, with all service's incident records providing the core information for analysis – incident number, date, the incident's fire type (FDR1/ FDR3) and geographical reference. The incident records also contained ancillary information, some of which was of use to the investigation (e.g. date, time), alongside fields which were later discarded (e.g. postal addresses) in order to reduce file size and so speed processing of the data. Aside from grid reference co-ordinates, of primary importance from all datasets is the fire type identifier field (see Appendix 2), used by the FRS IT teams in processing the original data request.

To maintain temporal consistency between fire service's datasets, we selected a time period for which we held data for all three FRSs, with the nine year period between the beginning of 2000 and the end of 2008 used. West Yorkshire introduced the IRS in January 2007 so more accurate spatial data is likely to be recorded for this period in this county.

4.1. Identification of moorland fires

We identified moorland fires based on their geographic location in relation to the moorland boundary as defined by the Natural England moorland boundary line dataset provided. Points falling on or within the moorland polygons in the GIS were deemed to be moorland fires, whilst points outside were discarded from further in-depth analysis. Whilst we consider this method to be robust at capturing the vast majority of moorland fires, we acknowledged that many moorland fires located (or recorded) just off the moorland are likely to slip through the net. We mitigated this issue by extending a 250 m buffer around the moorland boundary. This buffer was selected as visual inspection of maps indicated that, across the region, the nearest road to the perimeter of the South Pennine moors were usually located within this distance – therefore capturing fire incidents for which the spatial location was recorded as the nearest road address to the moorland. Additionally, we searched detailed fire incident logs, records of the communications between the fire incident commander and the control station, with a string search for the term "moor" to identify moorland fires. This yielded a broad estimate of fires occurring on moorlands.

4.2. Spatial accuracy of the location of moorland wildfires

Following the initial work to identify moorland wildfires, we then examined the fire logs for information the spatial location of incidents to test whether we able to more accurately determine their spatial locations. Due to differences in methods of accessing the data the ease of this varied between services, with some databases allowing wholesale export of logs into convenient MS Excel format, whereas others required manual sorting and extraction of logs. These fire logs were then read and searched for information on the spatial location of the fire. It is important to note that while a fire log may contain information enabling us to improve the spatial accuracy of a moorland fire's recorded position, concurrently it may not provide enough information to say the fires are in an incorrect position. Additionally, a lack of information in a fire log does not mean that an incident is accurately mapped; it simply means that no information was recorded and that therefore we are less certain of the spatial accuracy of the incident.

Through this process we identified wildfire within the moorland boundary (MO fires), as well as those lying within 250m of the boundary (excluding those lying within urban boundaries). Complete incident logs detailing each individual fire's crew communications were obtained (377 + 136 + 4 = 517 in total). Interrogating the fire logs in conjunction with Ordnance Survey's 1:25,000 digital map of the region we aimed to increase the spatial accuracy of fires place markers as they appeared in the GIS database. As this was a particularly time consuming process, within the scope of this project we were only able to analyse the fire logs for West Yorkshire. We also carried this out for fires within the 250 m buffer within West Yorkshire (excluding those in urban areas). Results of this exercise are detailed in Table 6 (Section 5.2). Of the West Yorkshire wildfires that we examined in further detail, 129 incidents lay beyond the extent of digital maps available at the time of reporting, although this covered two-thirds of incidents within the buffers of West Yorkshire. We also discarded fires in the immediate vicinity to the town of Illingworth for reasons listed later in Section 5.5.1.

4.3. Expert Workshop to inform preliminary maps

We ran a workshop on the 17 March 2009 at the headquarters of the Peak District National Park Authority in which stakeholders were invited to provide feedback and expert comments on preliminary fire density maps (see Appendix 3 for agenda). The outcomes of these discussions are incorporated into the discussion of this report. In attendance at this meeting were:

Andy Valentine	Peak District National park Authority (Ranger Service)
Steve Yearsley	Greater Manchester Fire and Rescue Service
Ian Potter	Lancashire Fire and Rescue Service
Andy Newman	West Yorkshire Fire and Rescue Service
Julia McMorrow	University of Manchester
Danny Jackson	Bradford Council / Pennine Prospects
Will Hewson	Moors for the Future Partnership
Jonathan Walker	Moors for the Future Partnership

5. Results

5.1. Overview of moorland fires in the South Pennines

The spatial distribution of wildfire incidents as recorded in our GIS database show a highly clustered nature, often occurring in close proximity to settlements (Figures 10 and 11). Whilst clustering around urban areas, the spatial distributions of fires also show a strong tendency to occur along moorland perimeter fringes. Examining the situation for those fires occurring only on moorland as defined by the NE moorland boundary (Figure 10), we found the majority of fires are seen to occur in the more densely populated southern area of the study region – particularly in the regions surrounding Greater Manchester, and to the south west of the West Yorkshire county boundary. This also closely correlated with a number of major transport arteries for the north of England – namely the M62 running directly through this region, cutting between Saddleworth and Rishworth Moors.

5.2. Summary of moorland fire incidents in the South Pennines 2000-2008

Overall, for the South Pennines, we identified 388 fires in FRS datasets as spatially occurring on moorlands (Figure 10) and, for the geographical area we have data, 671 incidents within a 250 m buffer of moorlands (but excluding those within urban areas; Figure 11). From the West Yorkshire case study it would appear that FDR1 moorland incidents are reliably mapped / classified as moorland fires (Table 6). FDR3 incidents are less reliably mapped. We found evidence in fire logs that 12 fires, or 3 %, of FDR3 incidents in the 250 m of the moorland boundary were actually moorland fires (Table 6; NB: we were unable to check the location of 129 fires as digital mapping was unavailable for the region in question). Generally the major vegetation/ habitat type was recorded within fire logs and therefore was identifiable. However, as a fire might have started on, for example, grassland around a car park within the moorland boundary, some fires might be missed. We do not know the scale of the issue of missing or incorrect data.

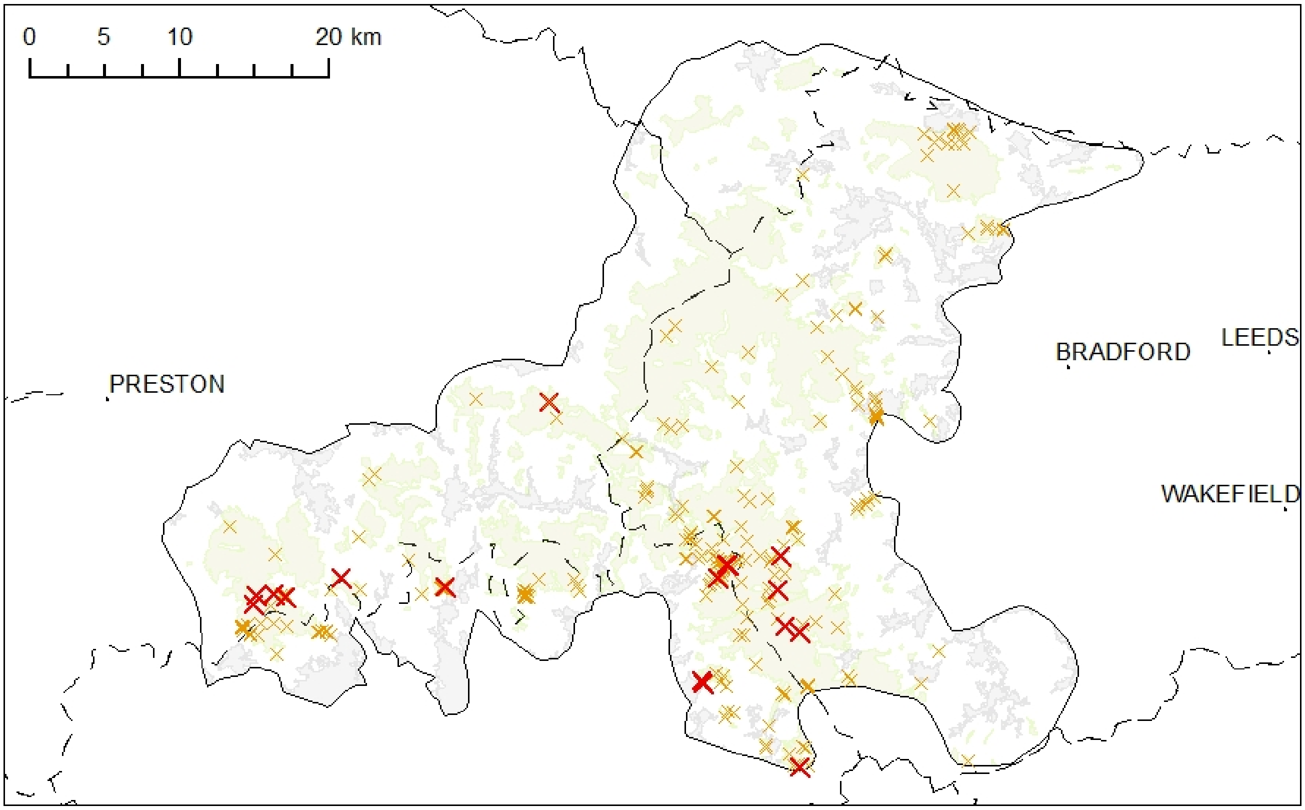


Figure 10. Map showing location of only those fires spatially recorded as occurring on moorland. 388 fires are as occurring on moorland. Apparent is the tendency for fires to occur at the moorland perimeter.

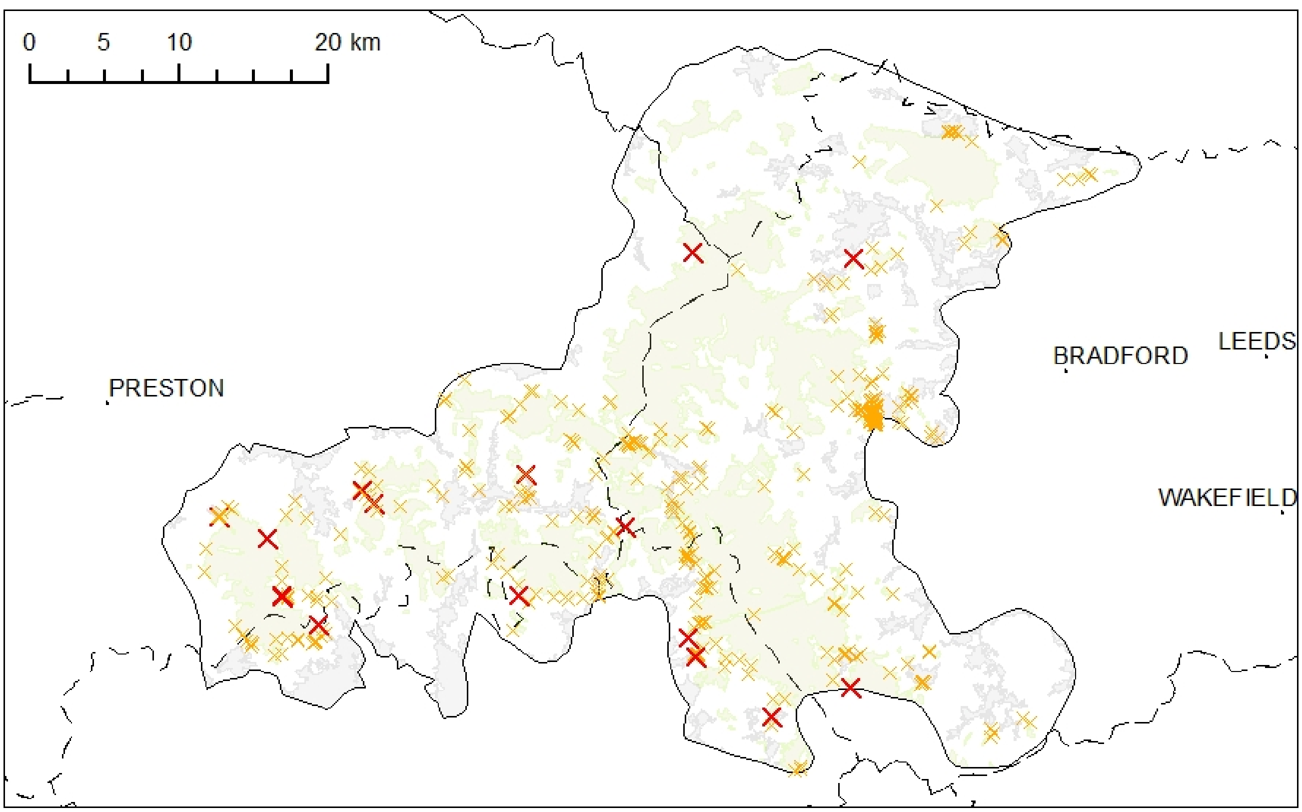


Figure 11. Fires within a 250 m buffer from the moorland boundary. 671 fires are shown excluding incidents contained within the urban areas.

Table 6. Summary of fire incidents on the South Pennine moorland 2000-2008
Results represent a string search of West Yorkshire FRS fire logs for information on whether an incident occurred on moorland**.** Includes all incidents within 250 m buffer (excluding urban areas). Useful spatial Info = information on the spatial location of fire included within the fire log; Unique moor identifier = “moor” identifier included in ‘stop code’ of fire log indicating the incident was potentially a moorland fire; No. fires ‘moved’ = number of fire incidents for which there was information to reliably update the spatial location of the incident.

	Moorland Only Fires		250 m buffer fires	
	FDR1	FDR3	FDR1	FDR3
Total logs	4	171	1	377*
Useful spatial Info.	4	130	1	256
Unique moor identifier	4	91	1	26
No. fires ‘moved’	0	3	0	12

* There were 383 FDR3 incidents within the 250 m buffer; however, six logs could not be interrogated as the West Yorkshire database disregarded the incident numbers.

Unfortunately, interrogating the fire logs for Greater Manchester and Lancashire was beyond the scope of this project as a result of issues related to exportation of the logs into a format that we could investigate. Extrapolating the proportion identified in West Yorkshire across Lancashire and Greater Manchester we produced a broad estimate that the number of moorland fire incidents attended by each FRS (Table 7). As the updating of the spatial accuracy was conducted by the same operator over a short period of time, the human error introduced into the spatial database can be considered both minimal and systematic.

Table 7. Number of fire incidents attended by FRSs on moorland and the 250 m buffer.
Extrapolated moorland fire values give an estimation of the total fires occurring on moorland if the updating of spatial accuracy for West Yorkshire fires is extrapolated across the South Pennines region (e.g. original fire counts + 3%)

	West Yorkshire		Greater Manchester		Lancashire	
	FDR1	FDR3	FDR1*	FDR3*	FDR1	FDR3
Moorland Only Fires	4	162	11	176	3	36
No. fires within 250 m buffer	1	383	6	128	9	144
Moorland buffer fires	0	12	0^	4^	0^	4^
Total No. fires by category	5	174	11	180	3	40
Total number of fires attended	179		191		43	

* GMC fires were received spatially pre-cropped to the Pennine Prospects South Pennine boundary.
^ These values are extrapolated for the proportion derived from the West Yorkshire data set.

Looking at the number of moorland only fire incidents attended by West Yorkshire, Lancashire and Greater Manchester FRSs relative to the areas of moorland within each county in the South Pennines, we found that of the 412 km^2 of moorland within these three counties 54% lies within West Yorkshire, 31% within Lancashire and 15% within Greater Manchester. Greater Manchester attended significantly more incidents that expected, while West Yorkshire and particularly Lancashire attended fewer incidents than expected (G_{adj} = 271.67, df = 2, P<0.001). Relative to moorland area, West Yorkshire FRS would have been expected to have attended 224 of the fires within the South Pennines during this period but attended 166 incidents; Lancashire would have been expected to attend 128 but attended 39 incidents; and Greater Manchester would have been expected to attend 60 fires but in fact attended three times this number, 187 incidents.

5.3. Extra-county attendance

We checked for FRS attendance at fires outside their county boundary, including those with multiple FRS attendance. This was done manually by checking those incidents falling outside their parent FRS county boundary and investigating for the presence of other FRSs attending an incident on the same day (Table 8). Greater Manchester FRS attended the most moorland incidents in another FRS area with 24 of the 27 extra-county incidents (89%); by far the majority of these were in Lancashire (22; 92%; Figure 12). Lancashire and West Yorkshire both attended incidents outside their county boundaries – both in Greater Manchester.

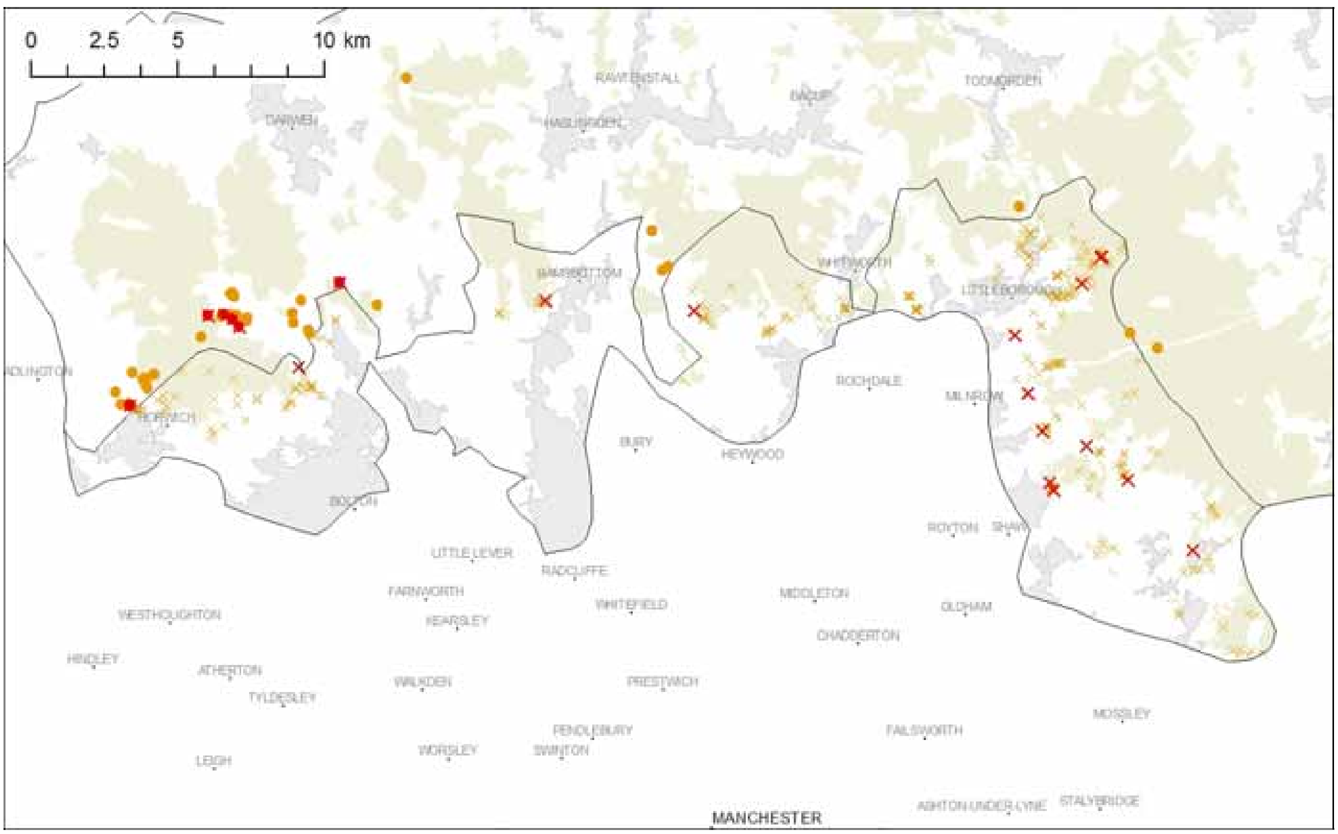


Figure 12. Greater Manchester FRS attendance to South Pennine moorland fires 2000-2008.
Circles = incidents outside GM county boundary; yellow incidents = FRD3s, red incidents = FDR1s.

Table 8. Extra-county attendance for moorland fires (excludes buffers).
WY = West Yorkshire; Lancs = Lancashire; GMC = Greater Manchester. Multiple attendence is where more than one FRS attended an incident. Incident = (unique) fire incident number.

County	Service attending	FDR	~Distance over boundary (m)	Multiple attendance	Incident	Date
WY	GMC	3	55	No	25470042	08/08/2004
WY	GMC	3	430	No	3131081	04/04/2008
GMC	Lancs.	3	110	No	39303766	29/03/2002
GMC	Lancs.	3	125	No	42001871	14/04/2004
GMC	WY	3	730	GMC (12553072)	11761072	07/04/2007
Lancs.	GMC	1	1100	No	2137700	22/03/2000
Lancs.	GMC	1	1100	No	2145600	22/03/2000
Lancs.	GMC	1	200	No	14264061	26/04/2006
Lancs.	GMC	1	1150	Lancs. (45902501)	15139072	14/04/2007
Lancs.	GMC	3	1100	No	2760900	10/04/2000
Lancs.	GMC	3	1200	No	20150021	06/04/2002
Lancs.	GMC	3	310	No	7790031	10/03/2003
Lancs.	GMC	3	500	No	8556032	14/03/2003
Lancs.	GMC	3	1000	No	15716032	28/03/2003
Lancs.	GMC	3	420	Lancs. (40604897)	16019032	29/03/2003
Lancs.	GMC	3	490	No	20092032	06/04/2003
Lancs.	GMC	3	500	No	28692032	18/04/2003
Lancs.	GMC	3	500	No	32828031	05/08/2003
Lancs.	GMC	3	500	No	17395052	01/04/2005
Lancs.	GMC	3	450	No	10920061	14/04/2006
Lancs.	GMC	3	500	No	41789061	27/07/2006
Lancs.	GMC	3	500	No	41904061	27/07/2006
Lancs.	GMC	3	500	No	43390061	29/07/2006
Lancs.	GMC	3	500	No	12239072	06/04/2007
Lancs.	GMC	3	4800	Lancs. (13052072)	13052072	08/04/2007
Lancs.	GMC	3	1100	No	20213071	30/04/2007
Lancs.	GMC	3	400	No	44496071	10/08/2007

5.4. Spatial accuracy of fire incidents

Our attempts to upgrade the spatial accuracy of fire incidents using fire log data only enabled us to update to location of 15 fires from the entire West Yorkshire region (Table 9, see also Appendix 1). The incidents that we did move all showed some degree of spatial correlation, for example, several occurred on Ilkley Moor, or close to Junction 22 of the M62. Overall, we were unable to place the locations of fires with any higher spatial accuracy using the incident logs that appear straight from supplied grid references.

Table 9. Corrected incidents within the West Yorkshire region.
Corrections are based on information from the incident report logs. Distance moved should be considered the most conservative estimates of incident adjustment – with the majority of fires moved the minimum distance possible in order to qualify as a moorland fire from the 250 m buffer. MO refers to fires located within the moorland boundary; the 250 column heading refers to fires originally within the 250 m buffer fire incident dataset.

Incident Number	Distance Moved (km^2)	Moorland Only	250 m buffer	Year	Locale
29110012	0.5	x		2001	Castleshaw Moor
21859022	0.5		x	2002	Moss Moor/ M62
22019022	0.5		x	2002	Moss Moor/ M62
27944022	0.5		x	2002	Rishworth Moor
21797022	1		x	2002	Moss Moor/ M62
4547032	1	x		2003	Warley Moor wind turbines
32350031	0.5		x	2003	Hade Edge
40756031	0.5		x	2003	Rishworth Moor
32382032	1		x	2003	Hade Edge
2799032	2		x	2003	Ilkley Moor
36988052	2		x	2003	Ilkley Moor
51715061	3	x		2006	Ilkley Moor
19133061	0.5		x	2006	Rishworth Booth Wood
27461061	0.5		x	2006	Greetland
9742082	0.5		x	2008	Warley Moor wind turbines

5.5. Illustrative case studies from West Yorkshire

In this section we focus on three case studies to highlight important factors included or excluded in this study. We focus on West Yorkshire as an example as we were able to collate the most comprehensive data of the three counties and therefore undertake the most thorough analyses as achievable within the scope of this project. These three case studies were discussed at the expert workshop and discussion about these examples and the factors, issues they highlight form the discussion of this report.

The three case studies we looked at are:

4) Illingworth ‘moor’ – an example of the implications of the data sets and spatial definitions selected to investigate moorland wildfire density in the South Pennines.
5) Baildon Moor - an example of the value of consultation of other spatial data sources to interpret and understand wildfire locations (both the position mapped and ‘true’ positions).
6) Ilkley Moor – an example of the correction of fire incident locations using information contained in fire logs to update the recorded location which was either the call-out location or closest feature, vantage point address.

5.5.1. Illingworth 'moor'

Using the West Yorkshire data as the basis for detailed investigation into the urban/ moorland interface provided us with a clear indication of the problems faced by not only FRSs in the area, but also issues surrounding the classification and naming of moorland areas, especially when taken within the West Yorkshire context, where moorland is typically highly fragmented due to bio-geographical constraints, but probably more importantly, the extent of urban encroachment and land use type by surrounding communities. Illingworth provides a good example, with two small strips of land classified as moorland sited on a slope between two densely populated areas on the outskirts of Halifax – which at 0.15 km² represent just 0.007% of moorland in West Yorkshire, whilst accounting for 14.2% of all recorded grass/ moor type incidents (Figure 13). Visual inspection of the map suggests that the two strips of land of interest are not 'moorland' but are rather two small thickets of scrub. This raises the question as to the accuracy of the moorland line data in defining the 'true' moorland boundary; however, operationally, this area is a key wildfire 'hotspot'. It is prone to arson and other related incidents potentially as a result of the proximity and accessibility to inhabitants of the neighbouring residential areas. The number of incidents on this site, unfortunately heavily skew results for the county and entire South Pennine region and does pose the question whether such 'moorland' areas should be included in our analyses of moorland wildfire risk, particularly our spatial analysis such as the generation of density mapping.

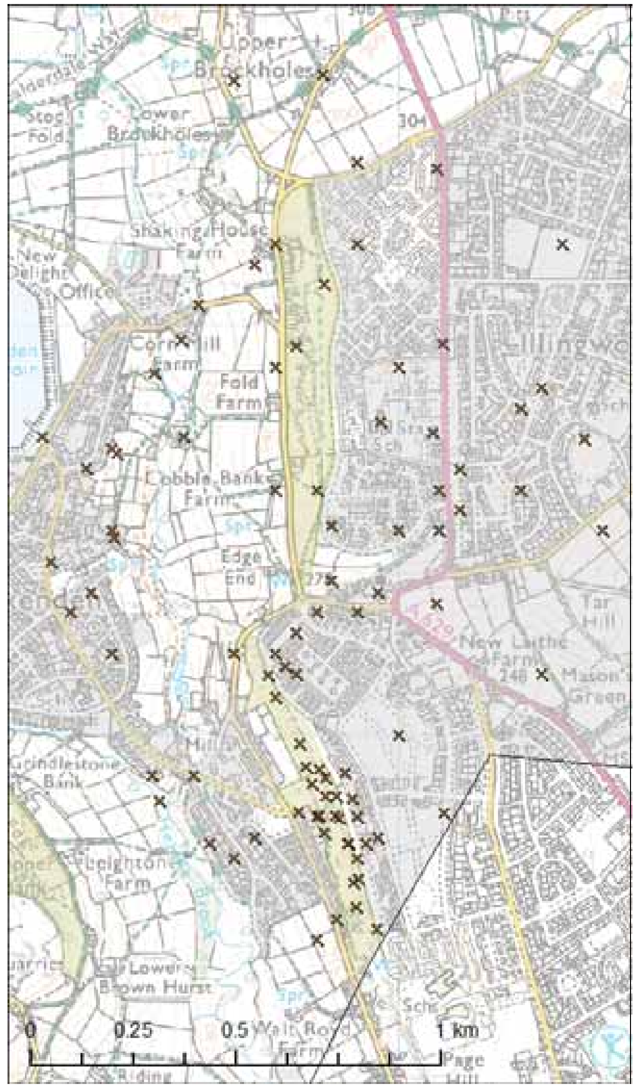


Figure 13. Illingworth 'moors'
OS 1:25,000 mapping with fires overlain, showing the highly residential/ urban nature of the Illingworth site.

5.5.2. Baildon Moor

Baildon Moor provides an excellent example of the necessity of referring to other datasets to interpret the spatial patterns of moorland wildfire incidents. With a perimeter of 10.6 km and an area of 2.8 km², and lying in such close proximity to the town of Baildon, we investigated the location of the 12 fires on this moor during the study period to gain insight into the moorland (wildland) – urban interface (W-UI). When we underlay the OS data to the GIS record of fire incidents (Figure 14) we could see that this moorland was heavily modified, with three paved roads running directly over the top of the moor, as well as a golf club being located within the northern area of the moor. Further investigation using aerial imagery in Google Earth (Figure 15) revealed the true nature of Baildon Moor; with the golf course, marked on the OS map as only a point feature, covering the entire northern half of the moor, as well as a sizable caravan park in the south western corner of the region. The only area on the moor which could be described as "true moorland" is criss-crossed by a tightly interconnected network of footpaths – indicating the moors proximity to the town, and some of its likely uses by the residents – dog walking and small scale recreation.

5.5.3. Ilkley Moor

Situated in the far north eastern corner of the Pennine Prospects study region, Ilkley Moor is considered a good example of "true" moorland, albeit in very close proximity to an urban area, with the houses of Ilkley backing directly onto the moor itself (Figure 16). This is reflected strongly in the spatial configuration of the wildfire distribution for this 26.87 km² site, with 20 out of 26 total fires on the moor occurring within 1km of the urban boundary. We identified fires that were situated directly on the moor itself to be registered to the same point of mobilisation – the single green fire point seen in the middle of the moor in Figure 16 actually representing four incidents (red) which coincided with a key landscape feature along an access track, with a radio mast located there. Interrogation of the fire logs for these incidents enabled us to more accurately position these incidents, with one incident's position being adjusted almost 3 km to the south west, directly over moorland. Further examples of the problems surrounding semantics of fire recording, as well as the accuracy and resolution of NE's moorland boundary set comes from several of the fires in the northern portion of this moor which we found to be spatially referenced to a café built on the moor. This reflects the strikingly different land use patterns found on the South Pennine moors compared with the Peak District National Park.

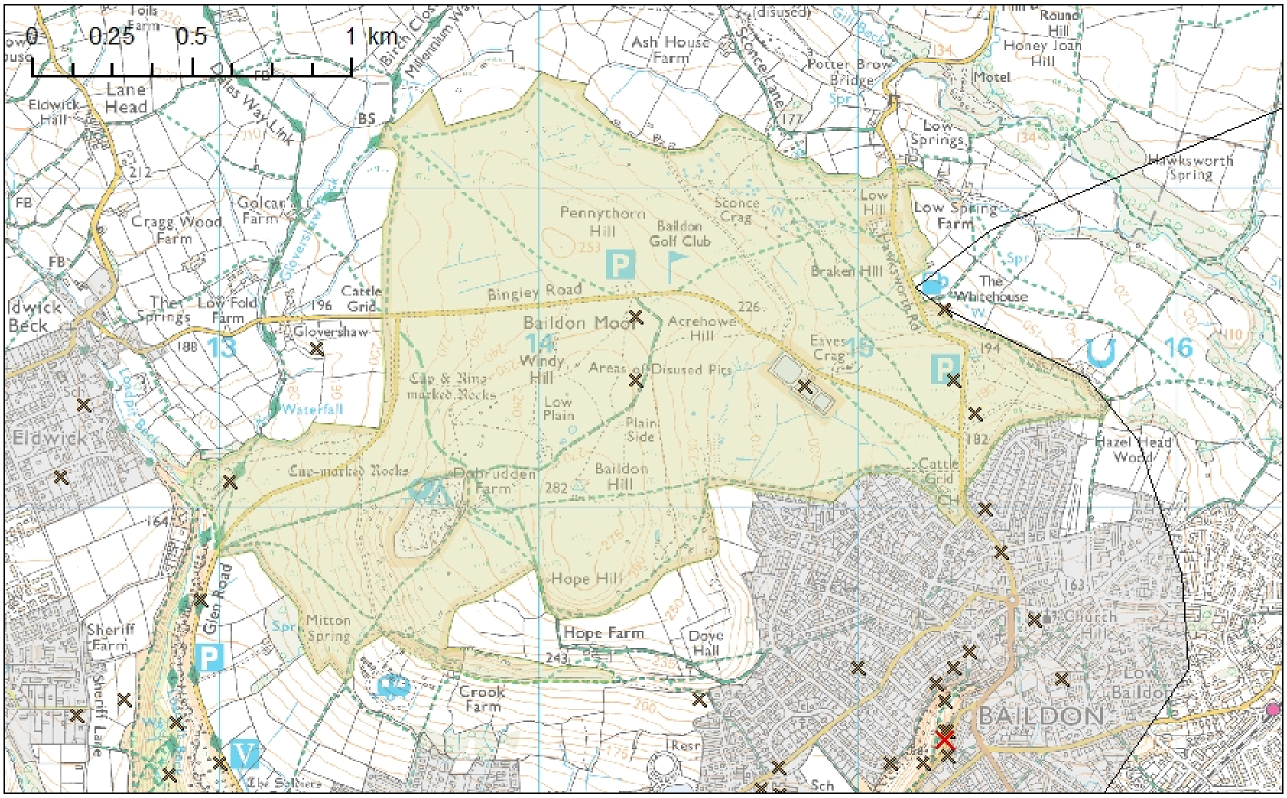


Figure 14. Fire incidents on Baildon Moor overlaid on an OS 1:25,000 map.
The fire located in the reservoir is an example of a moorland fire recorded at a 'feature' address.

Figure 15. Satellite imagery of Baildon Moor (© Google Earth (14.04.2009).
Using aerial imagery, the true extent the path network plus spatial location extent of other, potentially influential features can be seen (golf course)

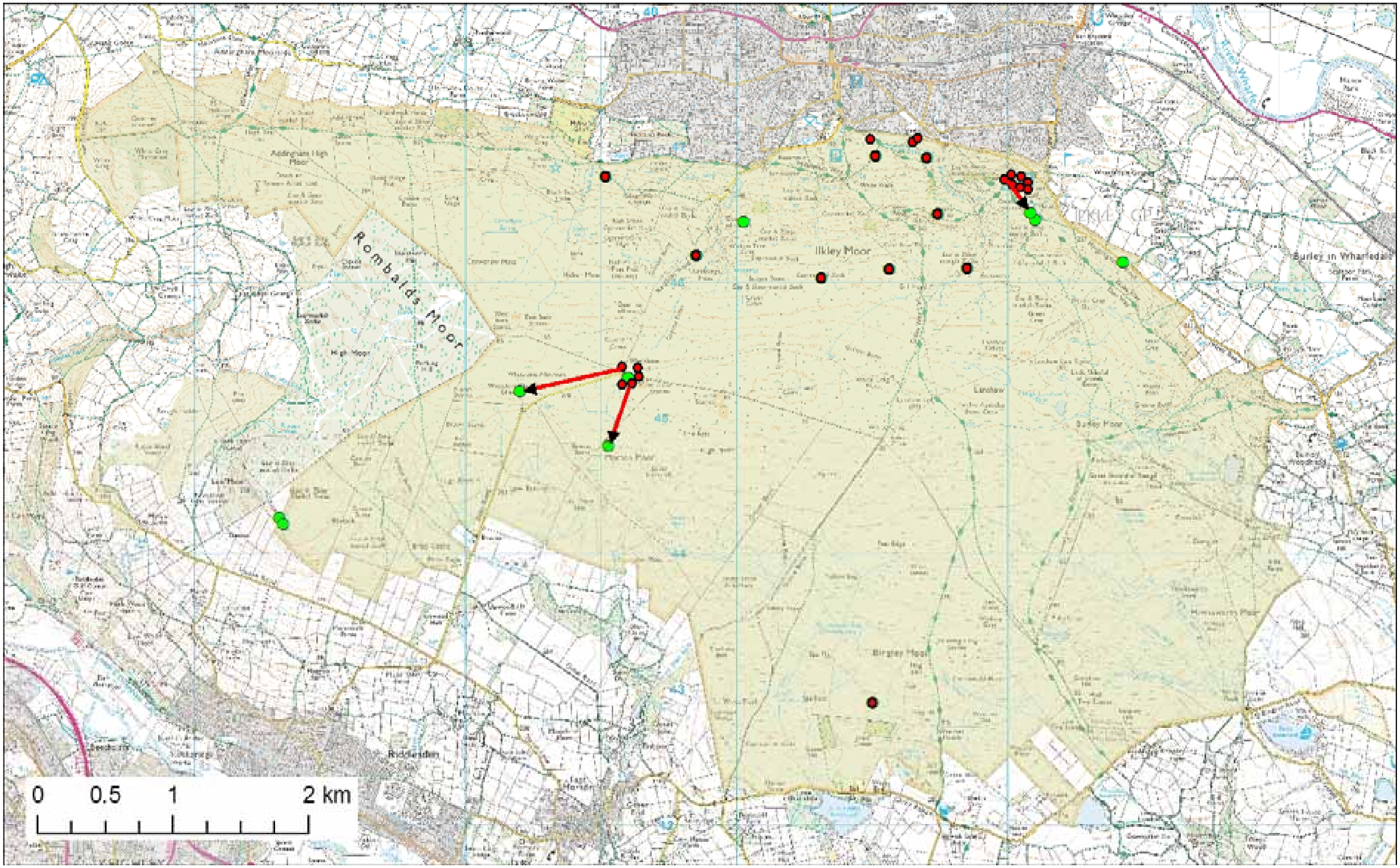


Figure 16. Location of fire incidents on Ilkley Moor.
Shaded in grey are the urban areas of Ilkley itself directly abutting the moor to the north, and the interface between Keighley and Bingley to the south. Colouring of moorland areas has been enhanced according to the Natural England moorland boundary line dataset described earlier. Incidents in bright green show those which were moved, with the original incidents in red. Arrows indicate the extent and direction of movement.

5.6. Other factors

5.6.1. Habitat

Of the 126 fires occurring on the BAP priority habitat, in close correlation with the areal extents of habitat type, 84.92% of fires occur on 88.45% of the land (blanket bog), this trend continues throughout the results, with only heathland fire amounts suggesting a discrepancy between areal extent and fire counts – although with the sample size available it has been difficult to draw reliable conclusions from this dataset (Table 10).

We found no significant difference in the numbers of fires that have occurred on the five different BAP habitats relative to the expected number given their area coverage (G = 3.85, df = 4, P = 0.427). This indicates that no single habitat is more prone or at risk of experiencing a wildfire incident.

Table 10. Numbers of fire attended by each FRS by BAP habitat types.

BAP Priority Habitats	**Area**		**West Yorkshire**		**GMC**		**Lancashire**		**BAP fire totals**	**% Fires**
	km²	**%**	**FDR1**	**FDR3**	**FDR1**	**FDR3**	**FDR1**	**FDR3**		
Blanket bog	254.2	88.4	3	78	0	25	0	1	107	84.9
purple moor grass / Rush pasture	5.8	2.0	0	0	0	0	0	1	1	0.8
Upland calcareous grassland	1.5	0.5	0	1	0	0	0	0	1	0.8
Wet woodland	4.6	1.6	0	3	0	0	0	1	4	3.2
Upland heathland	21.0	7-4	0	12	0	1	0	0	13	0.0
Regional total	287.4	100.0	3	94	0	26	0	3	126	10.3

5.6.2. Influence of the Pennine Way

Bisecting the study region, the Pennine Way travels 50 km through the boundaries of West Yorkshire, North Yorkshire and Greater Manchester (Figure 17). There appears a clustering of fire occurrence near the path in its southern extent on Blackstone Edge Moor. In this area (~2 km east of Littleborough) the Pennine Way crosses A58 at the location of two car parks, a public house and Blackstone Edge reservoir. This 'black spot' along the Pennine Way in this region is; however, not continued for the larger remainder of the route northwards and here may not be directly attributable to the effects of the 'Pennine Way' traffic itself.

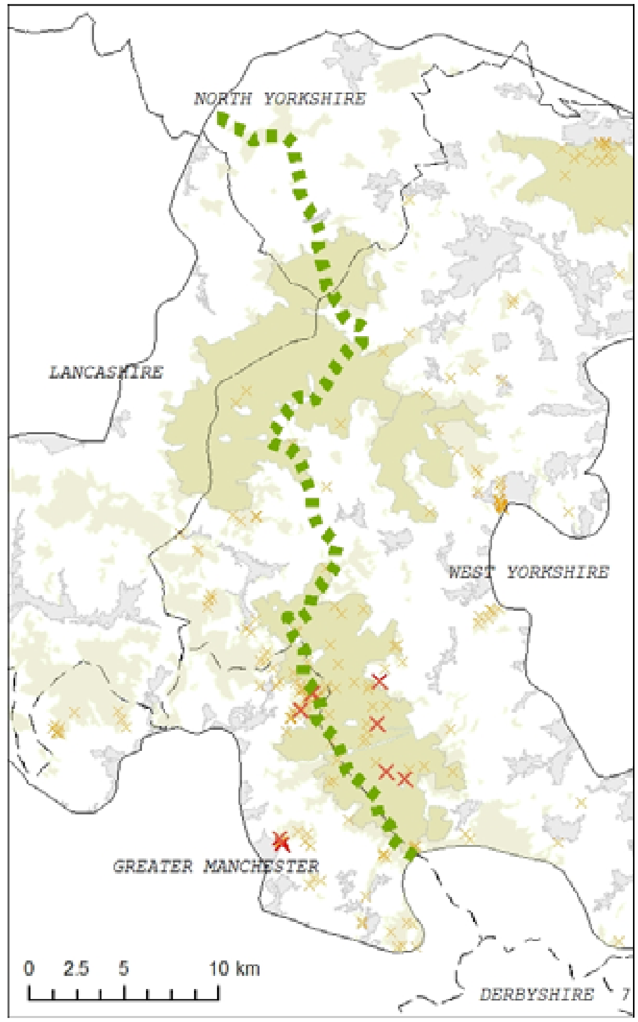


Figure 17. Fire incidents in the proximity of the Pennine Way (thick green dash).
Moorland and 250 m buffer fire are presented. This shows little spatial pattern between the location of the path and fire occurrence. Fire incident data was not available, and therefore not presented for North Yorkshire.

5.7. Fire density map across the South Pennine Moorlands

5.7.1. A fire density map for the moorlands of the South Pennines

Density mapping shows the broad scale spatial configuration of wildfire in the South Pennine region, with the areas in red, or hot spots, appearing in close proximity to the urban areas in the region. Overall, during the period 2000-2008 the majority of the moorlands in the South Pennines have experienced no, or very few wildfires (the size, environmental or economic impact of the fires is not factored into this report), see Figure 18 (maps focusing on each county are presented in Appendices 4-6). Visual inspection of this map suggests that areas with higher fire density occur at moorland edges, commonly near the urban fringe.

Three 'red' hotspots stand out from the rest of the density map:

1) Rishworth, Soyland and Blackstone Edge Moors, *Greater Manchester, West Yorkshire*
   Blackstone Edge Moor lies 2 km east of Littleborough along the A58. Two car parks and a public house are located at this site. Blackstone Edge reservoir is also located here and the Pennine Way runs through (Figure 17). The wider 2x2 km tile includes Rishworth and Soyland Moors.

2) Crompton Moor, *Greater Manchester*
   Crompton Moor adjoins the northeast boundary of Shaw in Greater Manchester this site is dissected by a network of paths (including the Oldham Way) and vehicle tracks.

3) Illingworth, *West Yorkshire*
   An area defined within the moorland line but essentially comprising two small strips of land that contain development within Illingworth. To the west of the site, some two miles distant lie Ovendon and Warley Moors. See case study in section 5.4.1.

Other areas of medium (orange) density are:

1) Ilkley Moor, *West Yorkshire*
   See case study in section 5.4.3

2) Baildon Moor, *West Yorkshire*
   See case study in section 5.4.2

3) Anglezarke Moor, Rivington Moor, *Greater Manchester, Lancashire*
   Anglezarke Moor lies close to the town of Chorley, just north of Rivington Country Park and is finely dissected by a network of paths and tracks. On the south-western edge of Anglezarke Moor lies Anglezarke reservoir which provides picnic and car parking facilities, therefore harbouring significant source of anthropogenic ignition risk.

4) Ashworth Moor, *Greater Manchester*
   Ashworth Moor lies on the outskirts of two large urban areas, Rochdale and Ramsbottom, and is heavily dissected by a path and road network.

5.7.2. Fire density and biodiversity conservation

In Figure 19 we present the fire density map with the location of twite (*Carduelis flavirostris*) breeding pairs overlaid. The twite is a Red-listed bird species of conservation concern as a result of it experiencing a severe decline in the UK between 1800 and 1995, without substantial recent recovery and having suffered a severe decline in the UK breeding population size of more than 50%, over 25 years. The South Pennine moorlands are a key breeding area for the species with this population vital to maintaining the present world distribution of the species. We use this species as a proxy for an assessment of biodiversity conservation and wildfire risk. In the southern moors of the region there is some cause for concern that the high density of breeding pairs are in this area overlap with relatively high levels of wildfire. We are not aware of any relationship between breeding twite density and wildfire history. Further north, breeding pairs on the moorlands between Burnley and Hebdon Bridge (Worsthorne Moor area) are in an area of comparatively reduced fire risk.

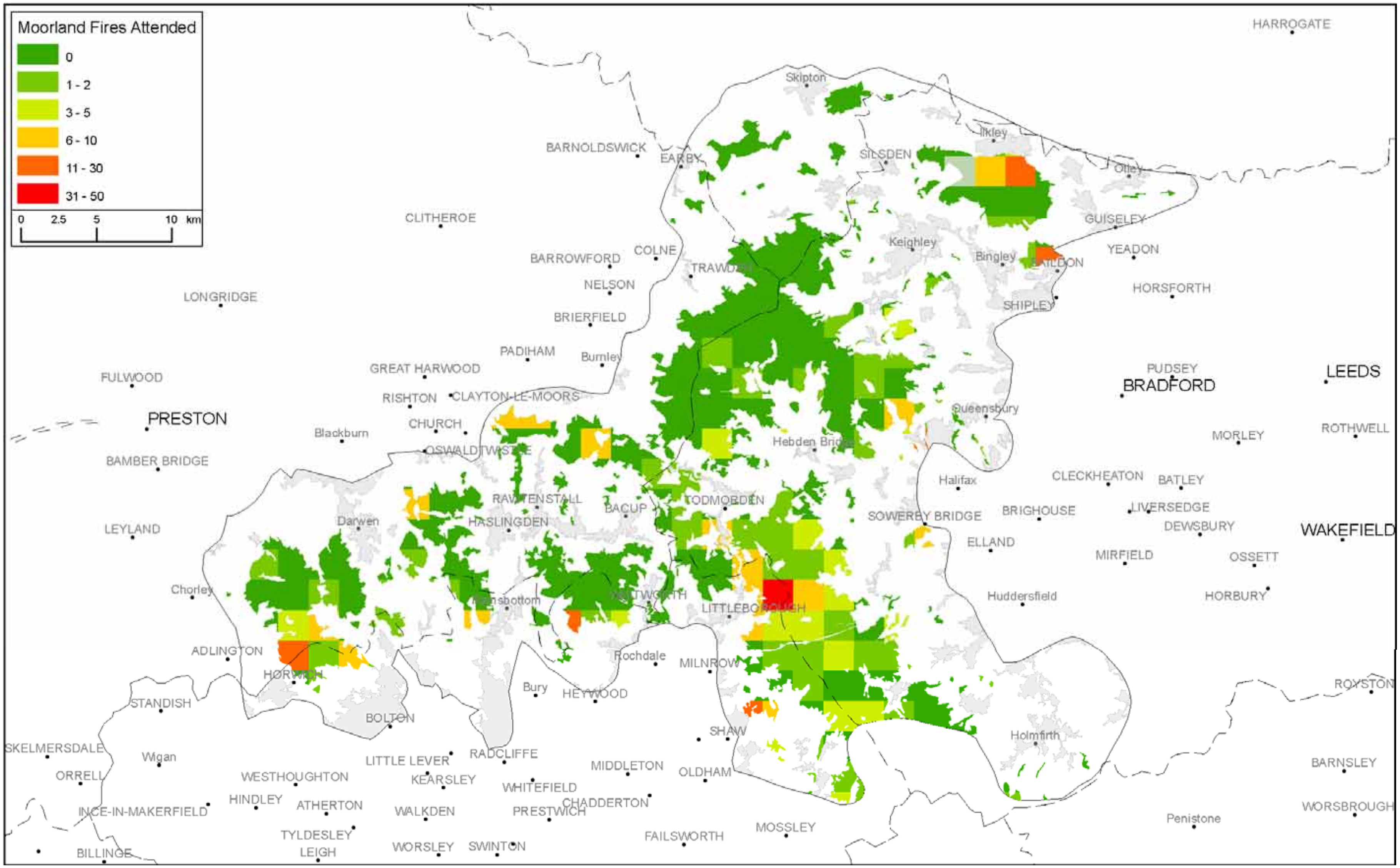


Figure 18. Moorland fire density map of incidents attended between 2000-2008 at 2x2 km cell resolution.
Green indicates few to no fire occurrences, whilst red indicates fire hot spots. Based on analysis of West Yorkshire incident logs it can be assumed only a small proportion of fires are missing from the initial datasets (~3%). Moorland within North Yorkshire is depicted as green; however, no fire data were analysed for this county in this project.

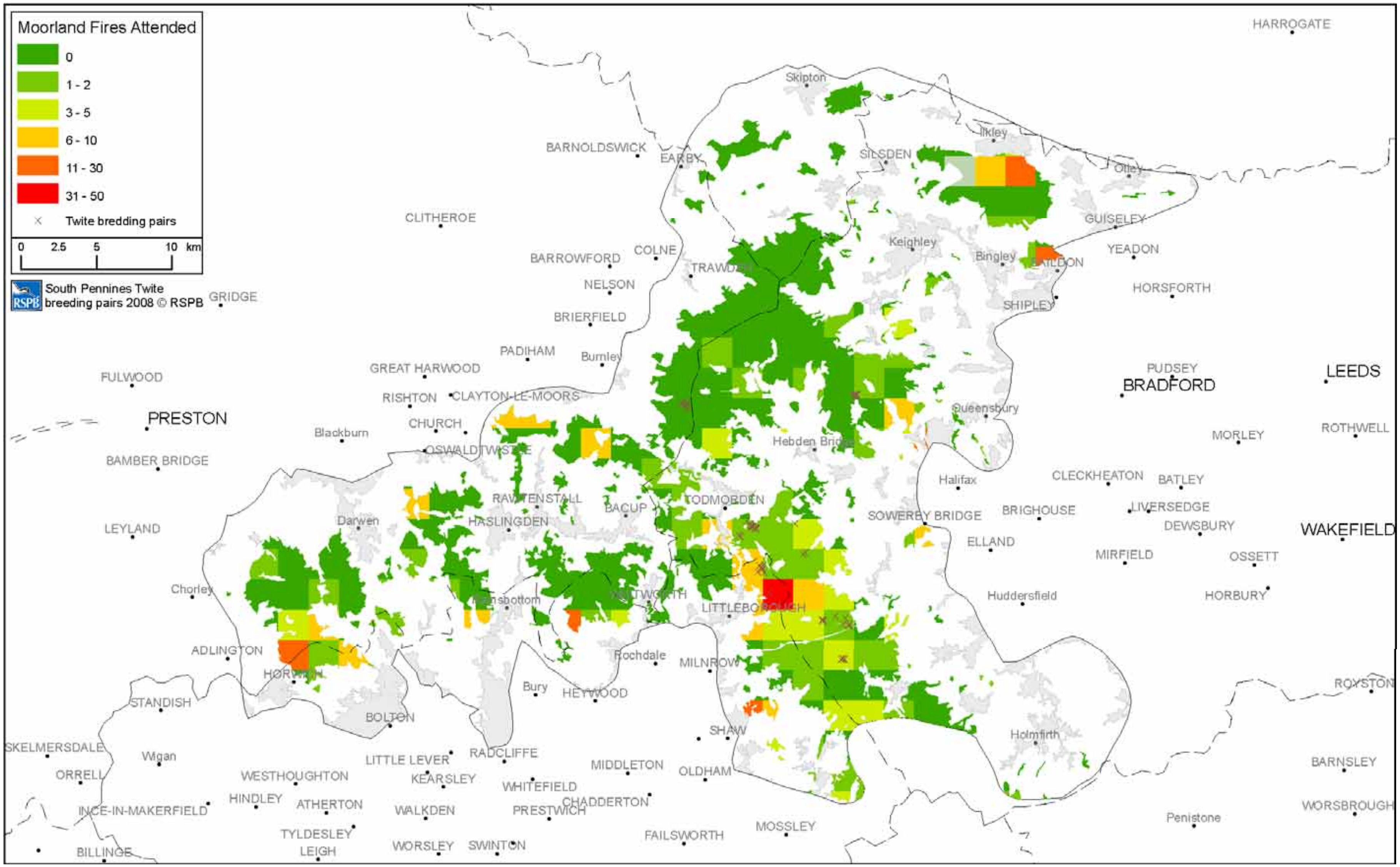


Figure 19. Fire density map and locations of twite (*Carduelis flavirostris*) breeding pairs.
Breeding locations marked with brown crosses.

6. Discussion

The original scope of the project had to be revised to reflect the spatial quality of the available data on wildfire incidents for the South Pennine Moorland area and the level of data processing required in order to produce a high quality database of fire incident records for the South Pennines. With stakeholder input, we have presented these data as a set of maps of wildfire occurrence and density that provide an evidence base of spatial wildfire risk in the region. Using these, we identified and here discuss the wildfire ‘hotspots’ in the region and compare the general findings of wildfire risk on the moorlands of the South Pennines with that of moorlands of the Peak District National Park.

6.1. Moorland wildfire incident data

The key data set required to produce a reliable wildfire risk map based on a spatial data set of historic wildfires from 2000 to 2008 for the project was the locations of historic wildfires. We obtained these datasets from the West Yorkshire, Lancashire and Greater Manchester FRSs. Although these datasets display essentially similar information, between services the data exhibited marked variation in terms of what data was presented, and to what level of detail. This is a result of all services operating on different software packages performing the same task - that of fire incidence logging. To a certain extent this lack of homogeneity is expected to be addressed with the introduction of the centralised IRS system, which will also, hopefully, provide greater geographical accuracy in recording fire incidents (see below). This system however, will not overcome the quality of the data collected at the fire incident and therefore the quality of the data imputed into the new IRS system. For example, West Yorkshire FRS supplied us with data field on whether fires were accidental or deliberate. This is potentially very useful data in assessing the issue and spatial distribution of wildfires as a result of arson. However, these data are not reliable as it is very difficult to identify the cause of moorland wildfires, unless ignition has been witnessed. Adding to this is the lack of post fire investigations on moorland wildfires (Andy Newman, West Yorkshire FRS, personal communication). While a proportion of the classifications within this data field may be accurate, the potential value of these data are lost as we don’t know the reliability of data overall, resulting in the omission of these important data from analyses. Information on the number and distribution of fires started deliberately (arson) as opposed to those started accidentally would be of tremendous value - not only in the development of fire risk models, but also in targeting preventative actions (e.g. educational programmes) and planning the fire-fighting response.

6.2. The location of moorland wildfires

Fire and Rescue Service fire incident data were of value and interest for mapping the approximate location of wildfires but cannot be considered a spatially accurate map of wildfire location. The recording of the spatial location of wildfires has not been accurate, particularly for FDR3 (secondary) fires. This is a factor of the historic importance for wildfires in comparison to property and vehicle fires, which comprise the majority of incidents attended by FRSs. As a result the fire recording and mobilisation system is based on a system specifically designed to fulfil the requirements of house, commercial property and vehicle fires in which locations are recorded using postal and street addresses.

To identify moorland fires we had to make a number of key decisions and 'work-arounds' in this project. We adopted the Moorland line boundary as our working definition of the moorland within this project as it was an easily obtained data set. This boundary represents a practical, working boundary that includes fires on moorland fringes that, while not necessarily occurring on distinct moorland habitats, had the potential as a result of their proximity to 'moorlands' to develop into moorland fires. Examples would include grass fires on picnic sites or campsites within the moorland boundary, or fires recorded as occurring within a reservoir (see Figure 14 for an example of this), or any other non-'moorland' habitat that occurs within the 'moorland boundary'. The definition of 'moorland' is a key decision that has a major influence on fire density results. The definition used in this study defined some areas as moorland that in a stricter ecological sense (or study) might not be classified as moorland. In this project, not only do we capture incidents on the margins of moorland vegetation communities, but also classify discrete areas as moorland that does not necessarily support vegetation communities (e.g. Illingworth). Depending on the aims of the study this definition is an important and influential decision that has significant effects on results.

Identification of fires on these moorlands for the most part was reliant on two pieces of evidence 1) mapping the locations of wildfires and identifying those that occurred within the moorland boundary (which relied on the spatial data on wildfires being relatively spatially accurate), and 2) unequivocal evidence within the fire logs, the record of communications between the incident commander and FRS control, that the incident was a 'moorland' fire and, where available, information on the spatial location of the fire. We also established a 250 m buffer around the moorland boundary and for West Yorkshire only, searched fire logs for information that incidents spatially recorded as occurring within this buffer should actually have been located on the moorland, and therefore classified as moorland fires.

6.3. Interrogation of fire logs for spatial evidence of the accurate location of fires

Performing the string search within detailed fire incident logs provided an extremely useful indicator of the problems faced by fire crews and the recording system, with regards to the nomenclature applied in the system, and how a fires spatial definition may not necessarily match its real world counterpart. As can be seen with the West Yorkshire fire incidents, filtering the logs spatially within the GIS, and subsequently applying a text filter, the amount of fires listed as being on moorland spatially, are approximately twice as many as those fires featuring the text string “moor” in the incident log. Of the total 171 FDR3 fires occurring on moorland (as defined by the moorland boundary), only 130 were found to possess any useful spatial information at all – usually in the form of an incident call out address. Filtering these 130 fire incident logs further for only those featuring the word “moor”, reduces the number of incidents with a unique moorland identifier to 91. This figure may be artificially high as an indicator of the real number of FDR3 fires occurring on moorland due to the inclusion of addresses and street names featuring moor in the title. However, when compared to the fires identified spatially in the GIS database, this figure likely represents a more realistic count due to the more detailed refinement of the filter as opposed to the spatial method – often recording incidents in or near to car parks, public houses, golf courses, and roads.

Further proof of the utility of the string filter method to identify moorland fires comes when considering those fires near to the moorland boundary (within the 250 m buffer). Of the 377 occurring within this buffer (whilst excluding those occurring in urban areas), 256 could be seen to contain useful spatial information, whilst from these, only 26 possessed a unique text moorland identifier. However in comparison to the fires spatially located on moorland (described in the previous paragraph), this information proved key in assisting in the upgrading of 12 incidents spatial accuracy, shifting fires from near moorland – be they at a roadside or car park, onto the moorland itself.

6.4. The scale of the wildfire problem on the South Pennine Moors

We identified ~400 fires occurring on the moorlands of the South Pennines in the eight year period between 2000 and 2008 (excluding North Yorkshire). This is a similar number to those recorded over the last 32 years on the moorlands of the Peak District National Park (PDNPA ranger service data, unpublished). The data sets used in this study suggest moorland wildfires are four times more common on the moorlands of the South Pennines than the Peak Park. This is despite the analysis for both regions covering similar areas. However there are areas of moorland included within the PDNP model that are included within the Moorland Line that are not classified as Section 3 moorland (the area included in the risk mapping exercise within the PDNP). It should be noted that as the moorland criteria selected for the South Pennines was 'more relaxed' than that used in the Peak District risk map, the SPM map may include more fire incidents on the fringes of moorland, which may potentially experience a higher threat of wildfire ignition.

6.5. Spatial distribution of wildfires on the South Pennine Moors

Based on a 2x2 km grid of wildfire occurrence we identified three areas of high wildfire density and four areas of medium wildfire density, shown in Table 11. In this study we focused on three case studies within West Yorkshire, all that we later identified as being among the seven areas at highest wildfire risk within the South Pennine Moors. For these sites we visually inspected the location of incidents in relation to aerial imagery and Ordnance Survey maps, with these data sources providing significant insights into firstly the reliability of the recorded wildfire incidents, and secondly into the factors associated with their distribution. These sites were all sites of recreational use, dissected by path networks and with visitor or landscape features, namely, reservoirs, radio masts, golf courses, car parks, cafes and public houses. There were also moorland areas close to, if not adjoining developed areas.

Table 11. The seven moorland areas within the South Pennines with the greatest wildfire densities.

High fire density areas:		
1	Rishworth, Soyland and Blackstone Edge Moors	Greater Manchester, West Yorkshire
2	Crompton Moor	Greater Manchester
3	Illingworth	West Yorkshire
Medium fire density areas:		
4	Ilkley Moor	West Yorkshire
5	Baildon Moor	West Yorkshire
6	Anglezarke and Rivington Moor	Greater Manchester, Lancashire
7	Ashworth Moor (Knowl Moor)	Greater Manchester

6.6. The moorland (wildland) – Urban Interface

The majority of the moorland in the South Pennines lies within close proximity of urban/ developed areas, allowing easy access to moorlands from conurbations, called a Wildland (moorland) – Urban Interface (W-UI). The moorland within the South Pennines comprises 142 'fragments,' 121 (85 %) of which are less than 1 km² in size, with just nine bigger than 10 km^2. This means that not only are they likely to be highly accessible by the inhabitants of nearby conurbations, but also that there are likely to be few 'remote' areas on these moors. The South Pennine moorlands exhibit considerable moorland (wildland)-urban interface (W-UI). This contrasts with the situation in the PDNP where the moorland is generally contiguous and by far the majority is rural and remote. There are also potentially significant differences in the demographic status of the population between the two areas and, given the National Park status of the Peak District, management, development pressure and eligibility/ availability funding for conservation purposes.

Wildfire risk in the W-UI is a recognised issue within the European Union, with several co-funded research projects focusing on W-UI fire management in Europe. Key recent European research projects on this topic are the Wildland-Urban Area Fire Risk Management (WARM) Project (Caballero, 2008) which aimed to identify and characterize direct and indirect risks to the human activity due to the forest fire occurrence in the W-UI in Europe) and FIRESTAR, a decision support system for fuel management and fire hazard reduction in Mediterranean wildland-urban interface. However, in the UK moorland context, we do not face the same risk to life and property as experienced at the W-UI in Europe, particularly within forested regions. In fact, while moorland fires within the South Pennines moors have significant socio-economic and environmental consequences, the significance of the W-UI is not so much in the risk to life or (built) property but rather the additional risk of ignition experienced as a direct function of its geographic proximity and therefore accessibility to anthropogenic sources of ignition.

Fires within a W-UI have two main technical/ operational aspects - how best to mitigate and fight fires at such an interface, as well as socio-economic and political aspects. For these, much wildfire research has focused on the biological and physical aspects of fire, but comparatively less attention has been attributed to the importance of socio-economic variables (Romero-Calcerrada *et al*., 2008). Wildfire risk models that consider human variables are becoming increasingly common. In Spain, where more than 95% of wildfires are known to be caused by human activity for example, Romero-Calcerrada *et al*. (2008) consider the inclusion of human activity variables essential to the estimation of ignition risk (Table 12). In wildfire risk models for the forests in the SW of the Madrid region, distance to urban and building areas was found to be the most predictive variable of ignition risk. Spatial patterns of ignition are strongly associated with landscape accessibility; while the presence of goats and sheep has a direct relationship with absence of wildfire ignition - the abandonment of traditional livestock farming and the change to new uses (e.g. recreational) are involved in ignition increases (Romero-Calcerrada *et al*. 2008).

Table 12. Anthropogenic variables included in a study of wildfire risk in Madrid. (after Romero-Calcerrada *et al*., 2008).

Group	Description (Units) Sources
Socio-economic data	Density of Population (Inhabitants/ha of Urban Area)
Socio-economic data	Density of Housing (Housing/ha of Urban Area)
Socio-economic data	Density of Cattle (Cattle/ha of pastures)
Socio-economic data	Density of Sheep (Sheep/ha of pastures)
Spatial relation	Distance to Urban Areas (m)
Spatial relation	Distance to Industrial Areas (m)
Spatial relation	Distance to Roads (Highways etc.) (m)
Spatial relation	Distance to Tracks: rural path etc. (m)
Spatial relation	Distance to Camping (m)
Spatial relation	Distance to Recreational Areas (m)

There is still much work to be done to adequately estimate risk, and predict the occurrence of wildfires in regions where the majority of events are ignited by human activity (Romero-Calcerrada *et al*. 2008). For the South Pennines future wildfire risk models need to incorporate 'human variables'. Much can be learnt from the research and application of the learning experience from continental Europe. There is, however, an ecologically more relevant and practical project from which the South Pennines can learn and develop its wildfire risk models in light of the spatial configuration of its moorland and its proximity to developments, and that is the Urban Heaths Partnership in Dorset (UHP). This project has successfully addressed the issue of wildfire risk on heathlands that are in close proximity to urban areas, highly accessible and heavily utilised by the local population. Strategies developed to address this issue include (adapted from Elliott, 2009):

- *Planning*
  - premise risk assessments,
  - regular visits to heathlands,
  - training in conservation importance of heathlands
  - training for land managers in fire incident command system-fighting
- *Prevention*
  - Site Managers and firefighters identify areas of high fire loading and remove it where possible via the PRP process
  - UHP staff, Police and Firefighters regularly visit schools and youth projects to deliver education packages
  - Media campaigns are used to deliver simple fire safety messages
- *Response*

- Dedicated and specialist fire-fighting equipment
- Firefighters
- UHP staff via pager
- Police – if deliberate

- *Recovery*
  - high quality fire recording and reporting
  - UHP wardens attend to fill in the recording gap. Geographically record and measure the incident, log damage, count wildlife casualties etc.
  - Ranger Staff manage recovery of site
  - All partners deliver education packages to local schools
  - Police attend ALL deliberate incidents and gather evidence to prosecute

6.7. FRS moorland coverage and numbers of incidence attended

By far the most fires occurred within West Yorkshire, which is expected given that this county contains the areal majority of moorland within the South Pennines (although please note no information is analysed on the spread, intensity, remoteness and therefore the efforts required / expended to suppress any of the fires included in this study).

Although unexpected given the relative spatial extent of moorland in the county, Greater Manchester FRS is shown to attend significantly more fire incidents than either West Yorkshire or Lancashire FRSs. The suggested reasons for this are as follows:

1) There are a disproportionate number of moorland fires on the relatively small area of moorlands within the county;
2) GM FRS attends a high number of moorland fires that occur or start in other counties;
3) A combination of the above: a disproportionate number of fires on the relatively, small area of moorland within Greater Manchester <u>and</u> they also attend a high number of fires on moorlands outside their county boundary.

The final option most accurately describes the situation for Greater Manchester FRS. Greater Manchester FRSs have agreements with neighbouring FRSs to attend incidents occurring outside their home boundary. This mutual assistance has been a ‘knock for knock’ basis but is a legally binding contract under the Fire Services Act 1947 and superseded by the Fire and Rescue Services Act 2004. Manchester and Lancashire use the term ‘ceded territory’ for the area where mutual assistance occurs. It essentially represents a logistically informed geographic extension to a FRS’s operational boundary in light of the location of moorlands, fire stations, and the expected speed/ distance of the FRS’s response. Greater Manchester attended 24 wildfire incidents that outside their own county boundary (24 in Lancashire). This still means that, of the 60 fires more than expected that Great Manchester attended, 26 were within their own county boundary, reflecting relatively high numbers of fires starting on the moorlands within Greater Manchester in relation to the area or moorland. This information is of significance to Greater Manchester FRS for their operations and resource requirements within the South Pennines, as it clearly demonstrates the moorland wildfire workload of the service is relatively higher than other FRSs (in terms of number of incidents attended). Great Manchester attended ~21 incidents per year (187 over the 9 year study period) or 0.33 fires per km^2 of moorland in the county per year (excluding incidents within ceded territory). It is important to note that four of the seven areas within the South Pennines with the highest fire density were within Greater Manchester.

West Yorkshire FRS contains the largest area of moorland within the South Pennines, including some of the most remotes areas, as well as four of the seven areas with the highest wildfire density. With ~19 attendances at moorland wildfires per year this is a similar turnout to Greater Manchester FRS, but represents a lower ratio in terms of turnout per km^2 of moorland, 0.08 fires per km^2 of moorland within the county per year. Within Lancashire all but 12 incidents were within ceded territory and attended by Greater Manchester FRS. Lancashire FRS attended ~4 fires per year or 0.03 fires per km^2 of moorland in the county per year. However a proportion of the moorland within this county is ceded territory, and while this is a long established system it seems that Lancashire FRS, at least, do not keep records of incidents on ceded territory within their boundary (Ian Potter, personal communication). Calls to Lancashire FRS arrive at their mobilisation unit where, if the incident occurs on ceded territory, responsibility for the incident is completely transferred to the responding FRS. Unless effort is made to capture information on such incidents or this information is shared between the relevant FRSs, then accurate data on fires within this county and other counties with ceded territories have not been kept.

6.8. Future recording of wildfire incidents

Quickly becoming apparent from discussions are the lack of any fixed definitions for ‘ecological’ variables, and no training provided to fire crews/ incident commanders to accurately, or even consistently (between officers) identify vegetation classes. While the IRS provides detailed options for recording wildfire parameters, unless training is provided in identification of vegetation types, and guidance on selection of certain options there will always be inconsistency in data recording.

From April 2009 compulsory use of the Incident Reporting System was introduced for all Fire and rescue services in the UK. Within this system there is scope to accurately record information on fire incidents including the spatial locations of wildfire incidents; however, from meetings with WYFRS where we received demonstrations of the IRS systems, as well as consulting IRS documentation and actual IRS incident fire reports, we identified limitations to the system. These include the drag and drop fire incident location map using OS street view – a mapping source which by its very nature does not include detailed geographical/ topographical information to help identify the location of a fire away from roads and property. Also, once zoomed in on a feature the user is then unable to return to previous lower zoom levels, which can, and has in West Yorkshire, led to erroneous placements of fire locations. Additionally, fire incident commanders who complete IRS forms are presented with a limited option set, all of which are compulsory (even when the correct option is not present, or the commander is uncertain of the option to select), presumably set up this way in order to avoid gaps in data reporting. For descriptions of vegetation types (and a number of other categories) there is no detailed standard definition of optional categories, and as a result there is considerable scope for personal interpretation of the definitions of different vegetation categories. This will inevitably lead to inconsistent and unreliable data being collected. Experience from using the IRS within the Urban Heath Partnership is that while it is a great improvement on the previous system, it does not go far enough (Elliott 2009).

We suggest that immediate additional and supporting actions to aid and improve data capture on wildfire incidents should include:

- Use of GPS to accurately record the location of fire incidents – recording both the fire centroid, ignition point (if known) and fire perimeter.
- Training fire-fighters or a number of dedicated 'wildfire officers' within each FRS, in the identification of moorland plants/ vegetation types and the conservation value of each.

And if possible:

Adding a confidence/ certainty value to completed data fields, so an indication of the reliability of the data recorded can be calculated, for example a percentage score - Allowing the reliability of data to be estimated. This would enable assessment of areas of data recording for which there may be issues, and as a result offering further training or support as required. This would have the added benefit of filtering unreliable data out of further analysis, enhancing the certainty of conclusions drawn from such data.

6.9. Wildfire prevention

We have identified seven moorland areas showing potential for increased wildfire risk within the South Pennines. As the use of these moors is predominantly for local recreational purposes this information could be utilised to inform an education programme at local schools in these areas focussing on the conservation importance of the moorlands and the risk and impact of wildfire. Additionally given the high moorland - urban interface of these moorlands, education could also be targeted as ‘road shows’ at local urban centres. If the contribution of arson to the problem of wildfire in the South Pennines could be established (and quantified) then this should inform a prevention response. For example, if it is considered a significant issue, then engagement and cooperation with police services to communicate severity, punishment and intolerance to arson should be pursued. Additionally a campaign to identify incidents of arson and real attempts made to identify and prosecute those responsible may assist in this line of prevention. Such measures have been effectively applied as part of the Urban Heaths Project and there has, also recently been a successful prosecution of arsonists within the Peak District National Park. There might be potential to engage with these known arsonists as art of a potential ‘rehabilitation’ package.

6.10. Future wildfire risk

Climate Change will bring changes in wildfire risk through changes in the potential flammability and vulnerability of the landscape (for example as a result of vegetation type, fuel loadings, moisture contents) which alter the risk of ignition and post ignition behaviour (severity and intensity) (Albertson *et al*. 2009). While general climate change patterns are robust (e.g. the climate is getting warmer), finer temporal variations, from month to month and year to year, fluctuate greatly, making it difficult to predict precise climatic and wildfire risk patterns. As well as direct effects on wildfire risk, climate change will likely be a significant indirect factor in future wildfire risk. Changes in land management (for example, as a result of food production or conservation initiatives) and shifts in peoples lifestyle to increased recreation time and activities, and more ‘holidays at home’, may lead to changes (increases) in ignition events and the spatial nature of wildfire risk in the South Pennines.

8. References

Albertson, K., Aylen, J., Cavan, G. and McMorrow, J. (2009) Forecasting the outbreak of moorland wildfires in the English Peak District. *Journal of Environmental Management* 90: 2642–2651.

Caballero, D. (2008) Wildland-Urban Interface Fire Risk Management: WARM Project. General Technical Report PSW-GTR-208. Pp 473-484 in González-Cabán, A. (Ed) *Proceedings of the Second International Symposium on Fire Economics, Planning, and Policy: A Global View*. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. http://www.fs.fed.us/psw/publications/documents/psw_gtr208en/psw_gtr208en_473-484_caballero.pdf Accessed 23.04.2009.

Caballero, D., Giroud, F., Picard, C. and Xanthopoulos, G. (2005) Wildland-Urban Interface Management: A State of the Art. D-10-01. Electronically published by the Euro-Mediterranean Wildland Fire Laboratory (EUFIRELAB). http://www.eufirelab.org Accessed 15.03.2009.

Elliott, A. (2009) Fighting UK Wildfires A firefighter's perspective. Presentation at FIRES4: Economic impacts of wildfires and adaptive land management to reduce wildfire risk and impact. Seminar 4 in the Interdisciplinary Research on Ecosystem Services: Fire and Climate Change in UK Moorlands and Heaths. May 13-14, Losehill Hall, Peak District National Park, Derbyshire.

Jarvis A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from: http://srtm.csi.cgiar.org.

Romero-Calcerrada, R., Novillo, C.J., Millington, J.D.A. and Gomez-Jimenez, I. (2008) GIS analysis of spatial patterns of human-caused wildfire ignition risk in the SW of Madrid (Central Spain). *Landscape Ecology* 23: 341–354.

McMorrow, J., Aylen, J., Albertson, K., Cavan, G., Lindley, S., Handley, J. and Karooni, R. (2006) *Moorland Wildfires in the Peak District National Park*, Peak District Case Study, Technical Report 3, Climate Change and the Visitor Economy.

McMorrow, J. and Lindley, S. (2006) Modelling the spatial risk of Moorland wildfire. Final report to Moors for the Future. GeoInformatics Research Group, the University of Manchester: Manchester UK.

Appendix 1. Example of a FRS incident log.

Only the text pertaining to the spatial location of the incident are included in this text log.

Date	Time	Inc ID	Log entry type	User ID	Call sign	Log source ID	Log Text
25/06/2003	19:14:54	20204032	ADDSEL	JW	0	JW	NEAR THE RESERVOIR CAR PARK~CHURCHBANK LANE~MYTHOLMROYD~WEST YORKSHIRE~SE
25/06/2003	19:16:21	20204032	ADDSEL	JW	0	JW	NEAR THE RESERVOIR CAR PARK~WITHENS LANE~WITHENS MOOR~CRAGG VALE~WEST YORKSHIRE~HX7~SD 98800
25/06/2003	20:07:49	20204032	ADDSEL	JW	0	JW	NEAR THE WITHENS RESERVOIR CAR PARK~WITHENS CLOUGH~.~CRAGG VALE~WEST YORKSHIRE~HX7~SD 98000
25/06/2003	19:14:09	20204032	ENTDATA	JW	0	JW	NEAR THE RESERVOIR CAR PARK~CHURCH BANK LANE~PREMISE*STREET~INCIDENT ADDRESS~~
25/06/2003	19:14:52	20204032	ENTDATA	JW	0	JW	NEAR THE RESERVOIR CAR PARK~CHURCHBANK LANE~MYTHHOLMROYD~PREMISE*STREET*TOWN~INCIDENT ADDRESS~~
25/06/2003	19:14:34	20204032	ENTDATA	JW	0	JW	NEAR THE RESERVOIR CAR PARK~CHURCHBANK LANE~PREMISE*STREET~INCIDENT ADDRESS~~
25/06/2003	19:13:51	20204032	ENTDATA	JW	0	JW	NEAR THE RESERVOIR CAR PARK~CRAG VALE~PREMISE*DISTRICT~INCIDENT ADDRESS~~
25/06/2003	19:14:00	20204032	ENTDATA	JW	0	JW	NEAR THE RESERVOIR CAR PARK~CRAGG VALE~PREMISE*DISTRICT~
25/06/2003	19:16:16	20204032	ENTDATA	JW	0	JW	NEAR THE RESERVOIR CAR PARK~WITHENS LANE~MYTHOLMROYD~WEST YORKSHIRE~SE 01181 26052~PREMISE*STREET*TOWN*COUNTY*GRIDREF~INCIDENT ADDRESS~~
25/06/2003	20:07:32	20204032	ENTDATA	JW	0	JW	NEAR THE WITHENS RESERVOIR CAR PARK~WITHENS CLOGH~WITHENS MOOR~CRAGG VALE~PREMISE*STREET*DISTRICT*TOWN~INCIDENT ADDRESS~~
25/06/2003	20:07:38	20204032	ENTDATA	JW	0	JW	NEAR THE WITHENS RESERVOIR CAR PARK~WITHENS CLOUGH~WITHENS MOOR~CRAGG VALE~PREMISE*STREET*DISTRICT*TOWN~INCIDENT ADDRESS~~
25/06/2003	19:16:39	20204032	ENTDATA	JW	0	JW	NEAR THE WITHENS RESERVOIR CAR PARK~WITHENS LANE~WITHENS MOOR~CRAGG VALE~WEST YORKSHIRE~HX7~SD 98800
25/06/2003	19:16:39	20204032	MOBILISE	JW	7001	JW	GD92~70~LFF ~4~-~CB~OS 75 B8~SD 98800 23500~CONTACT METHOD/STATION AREA/OIC/RIDERS/WATCH/STATE/BRIGADE MAPREF/GRIDREF ~~
25/06/2003	19:21:18	20204032	TEXT	AJW	7001	AJW	7001 MI SUBO AND 6 ~~

Appendix 2. Example of wildfire incident data supplied by FRSs (for FDR3)

Year	Inc_No	Date	Month	SG	Use	Cause	No_of_pumps	East	North	Coords	Coord_temp
2003	29509032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	3	424100	423400	Y	Se 24100 23400
2003	29653032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	1	424791	420240	Y	Se 24791 20240
2003	29466032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	2	425586	433633	Y	Se 25586 33633
2003	29461032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	1	425874	432962	Y	Se 25874 32962
2003	29646032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	1	428172	425880	Y	Se 28172 25880
2003	29464032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	1	428798	429742	Y	Se 28798 29742
2003	29444032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	1	430600	434200	Y	Se 30600 34200
2003	29648032	25/09/2003	9	Thursday	Grassland/Heathland/Railway embankment	Deliberate	1	432000	421500	Y	Se 32000 21500

Appendix 3. Discussion agenda for stakeholder meeting dated 17 March 2009

Spatial location of moorland fire incidents
(all F&R Services will be using IRS by April, but we need reliable historic data to build models)

- Capturing moorland incidents – buffers:
- Any trends across the region

Resolution of maps given uncertainty – moor by moor (fragment by fragment)

Access and use:

- In the South Pennines the moorland is highly fragmented with a high moorland perimeter to 'centre' ratio – little 'isolation'
- The moorlands are highly dissected by road footpath network
- Around the moorland perimeter there is significant urban development, much within easy access of the moorlands – are these moorlands used more for local recreation
- Spatial pattern across moors (different demographic of people using moorlands, and the 'core' areas within these, that the Pennine way dissects.

Sources of fires

- Accidental vs. arson
- 'Residents' vs. visitors

Importance of other factors

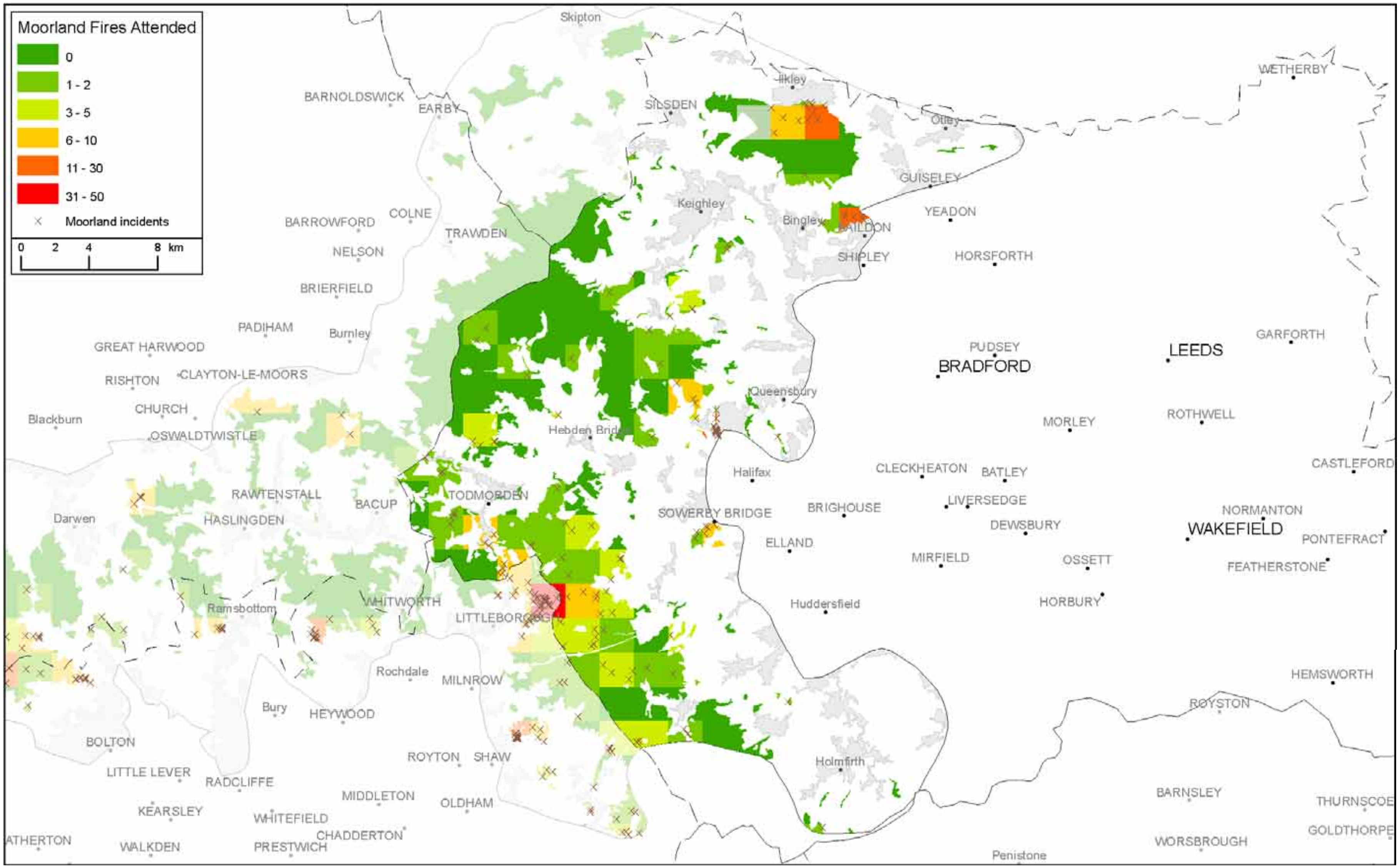
- Land cover (vegetation / land use)
- Topography (elevation, slope, aspect)

Key differences in producing a SPFRM and the PDNPARM?

- Spatial configuration of the moorland (contiguous vs. fragmented)
- Access issues
- F&R access for fire fighting
- Patterns of use: how, when, by whom

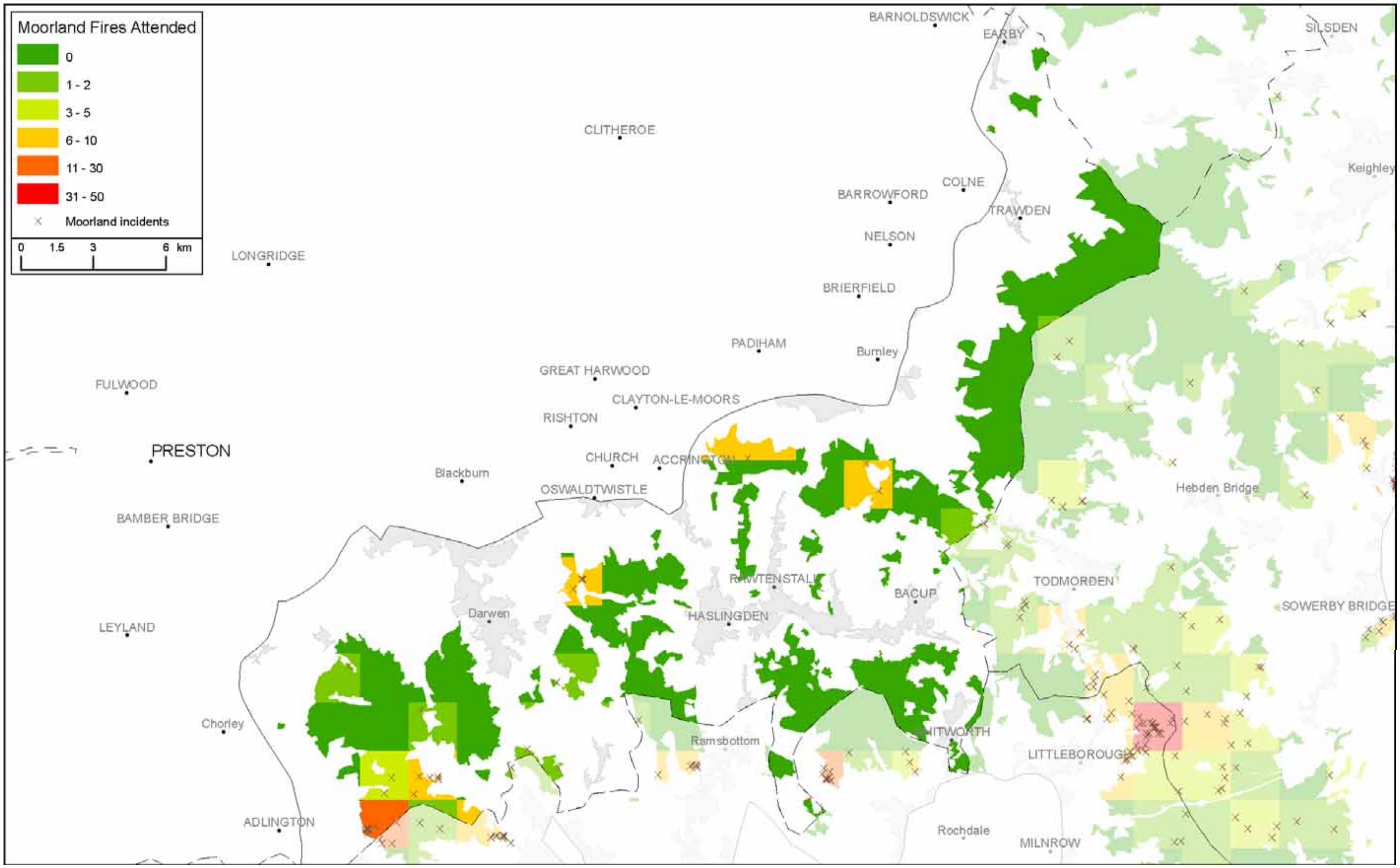
Appendix 4. Density map of moorland fire incidents attended in West Yorkshire between 2000 and 2008.

Fire density is calculated for a 2x2 km cell resolution; green indicates few to no fire occurrences, whilst red indicates fire hot spots. Brown crosses indicates the location of moorland fire incidents as mapped by the FRS; NB – some crosses might represent multiple incidents mapped at the same location.



Appendix 5. Density map of moorland fire incidents attended in Lancashire between 2000 and 2008.

Fire density is calculated for a 2x2 km cell resolution; green indicates few to no fire occurrences, whilst red indicates fire hot spots. Brown crosses indicates the location of moorland fire incidents as mapped by the FRS; NB – some crosses might represent multiple incidents mapped at the same location.



Appendix 6. Density map of moorland fire incidents attended in Greater Manchester between 2000 and 2008.

Fire density is calculated for a 2x2 km cell resolution; green indicates few to no fire occurrences, whilst red indicates fire hot spots. Brown crosses indicates the location of moorland fire incidents as mapped by the FRS; NB – some crosses might represent multiple incidents mapped at the same location.