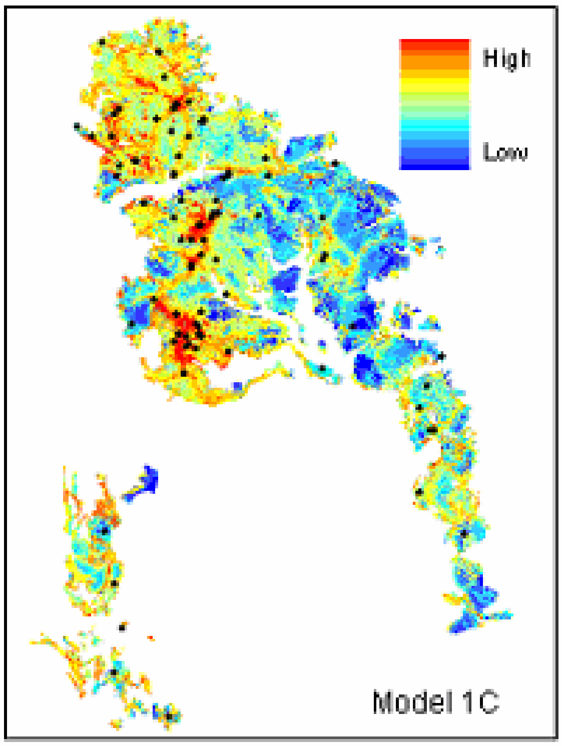
Modelling the spatial risk of Moorland wildfire



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Final report, Moors for the Future small grant A79419_spg17. 31 Dec 2006

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1. *Introduction*

1.1 Wildfires

Prescribed burning between 1st October and 15th April is a well-established moorland management tool (MFF, 2005). Wildfires are man-made accidental fires (such as those caused by cigarettes or litter acting as lenses) or natural fires due to lightning strikes. They also include fires started maliciously, and any managed burns which accidentally get out of control. Wildfires have been recorded in the Peak District National Park (PDNP) Rangers fire log since 1976. It is this database of 353 wildfires which forms the basis of the spatial fire risk assessment presented here.

1.2 Impacts of wildfires

Five thousand acres of the Peak District were accidentally burnt in Spring 2003 alone. Such wildfires have direct and indirect environmental, social and economic costs. They present a threat to habitats, nesting birds and other fauna. The UK holds 75% of the world's resource of open heather moorland. Two percent of this went up in flames in a two-week period in April 2003 (Baynes and Bostock, 2003), including a major fire on Bleaklow.

Fire has been reported to increase water discoloration in peatland environments (Yallop, 2006) and wildfire adversely impacts on peatland carbon budget (Worall and Evans, 2006). Northern peatlands are the largest soil carbon store in the world, holding 30% of the world's terrestrial carbon, of which the UK has 8%. Carbon stored in UK peatlands is equivalent to up to 3 years of national CO_2 emissions (Worall and Evans, 2006). Burning releases carbon from vegetation and, if it back-burns into the peat substrate can permanently destroy this important carbon store. It has other, longer-term effects on the carbon budget; carbon-sequestering vegetation is lost and the exposed peat dries out more easily to release further carbon gradually by aerobic decomposition. Fire scars of exposed peat are persistent in the landscape (Mckay & Tallis, 1996; Anderson *et al.*, 1997). Much of the two million pounds invested by MFF in moorland restoration has been spend on revegetating fire scars.

Figure 1.1: Fighting peatland fire

Other economic and social costs of wildfires include fire control and management (Figure 1.1) (Palutikof *et al*., 1997), loss of capital value and revenue from grouse moors and sheep grazing (Baynes and Bostock, 2003). Transport can also be disrupted due to smoke. Previous wildfires have necessitated the closure of the M62 and even Manchester airport (Trotter, 2003).

1.3 CCVE

This report builds on spatial and temporal modelling carried out for the Climate Change and the Visitor Economy (CCVE) project. CCVE used spatial modelling to identify *where* risk of fire was highest in the Dark Peak part of the PDNP (northern part of the PDNP), based on past reported wildfires. Multi-criteria evaluation (MCE) was used to spatially model the risk of reported wildfires using the 28-year record of wildfires from the PDNP rangers' fire log. Fire risk was investigated using habitat maps to represent vulnerability to ignition, and distance from access features as a proxy for the likelihood of anthropogenic ignition sources. The current report develops this spatial analysis further and for a wider area of the PDNP.

CCVE also used temporal analysis to predict *when* wildfire risk was likely to be highest, based on preceding weather. The temporal model established a non-linear statistical relationship between past weather and wildfires. The model successfully predicted the most fire-prone months and days, especially April-May and July-August and spring bank holidays, reflecting the interplay between visitor numbers and the changing flammability of moorland vegetation (Fig 1.1). A typical British bank holiday is almost five times more perilous than seven days of dry weather (McMorrow *et al.,* in review).

1.4 Climate change and wildfires

Wildfire risk will increase under climate change scenarios (Conway. 1998). A gradual rise in mean temperature will have only a slight effect, but it is changes in climate variability and weather extremes which will generate most of the extra fire risk (McMorrow et al., 2006a). Nearly one third of all wildfires in the database took place during just four months: the very hot, dry summer of July and August 1976, and the dry spring of March and April 2003. A small change in the weather can alter the chance of wildfire occurrence from a rare event to a commonplace but severe nuisance. The probability of a fire was found to rise non-linearly from daily odds of 3% at 8^{o}C to a 26% chance at 25^{o}C (Aylen *et al*., 2005; McMorrow *et al*., in review).

The UKCIP02 high emissions scenario for the 2080s predicts summer maximum temperature will increase by 3.0°C to 5.5ºC over the Peak District, with an average daily maximum of 20.5°C to 23°C. Although little change in annual precipitation is predicted, marked changes in the seasonality and spatial distribution of rainfall are likely. By the 2080s, a decrease of between 23-45% in summer average rainfall is expected for the Peak District (McEvoy *et al*., 2006). These changes in rainfall patterns will have significant consequences for the management of moorland habitats which require a high number of rain days and total rainfall, especially those at their southern limit as in the PDNP.

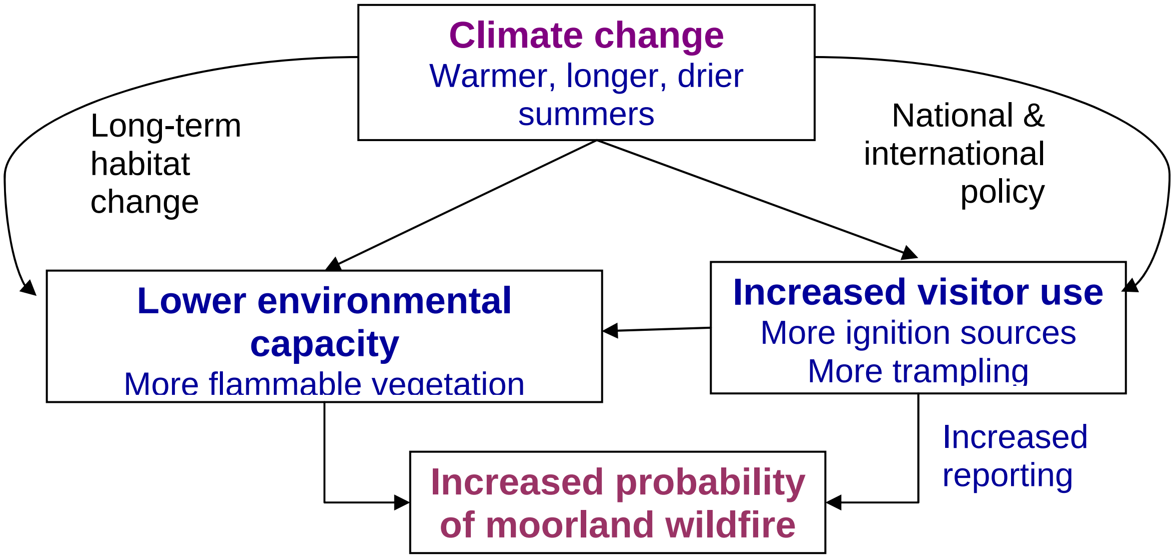


Figure 1.1: Relationship between climate change, environmental capacity and visitor numbers

To understand moorland fire risk, both physical and social elements must be considered (Anderson, 1990) (Fig 1.1). Longer, drier spells will lower environmental capacity as 'curing' from green to brown biomass makes vegetation more flammable (unless fuel load is managed by careful prescribed burning). The new Met Office Fire Severity Index allows only for this first, physical part of the fire risk equation (Met Office, 2005). Yet it is also possible that the number of visitors will increase as summers warm and with it ignition sources and fire risk. In turn, increased visitors further lower environmental capacity by trampling.

Longer-term changes in habitat may result from climate change to make the PDNP overall more vulnerable to fire. The wider context of national and international policies will impact on fire risk. The legitimate goal of achieving a low carbon economy will help to offset future rates of warming and associated climate change, therefore minimizing increases in future wildfire risk. However, increases in UK-based holidays may lead to a higher number of visitors to the moors and therefore result in more potential sources of ignition.

Any national policies will also affect fire risk if they cause a change in habitat (such as changes in agricultural subsidies) or visitor numbers (such as provision of transport infrastructure).

1.5 Significance of PDNP fire risk studies

Present-day fire risk in the PDNP is not only of local importance. The Park lies at the southern boundary of blanket bog, so it is very vulnerable to climate change, and is also the most visited national park. It could, therefore, be seen as an analogue for future fire risk in more northerly peatlands as they experience increased drying and visitor pressure from climate change. In other words, the risk exemplified by the 28 year record for the PDNP may be what can be expected in the future for currently less fire-prone, more northerly peat moorlands. The methods developed here, therefore, have relevance for mapping future fire risk in other areas.

1.6 Aims of the study

(i) To further refine and test the CCVE spatial model for wildfire risk assessment
(ii) To extend the CCVE model to other parts of the Peak District National Park
(iii) To produce a stakeholder-informed version of model and the final risk map

1.7 Objectives

(i) To expand the existing CCVE database over as much as possible of the PDNP and incorporate additional digital spatial datasets, particularly visitor patterns, vehicle tracks and additional car parks.
(ii) To carry out sensitivity analysis on key input datasets notably, locational precision of fire reporting and generalization of habitat classes.
(iii) To hold a stakeholder workshop to determine preferred factor scoring systems and appropriate ranking and weighting schemes.
(iv) To evaluate resultant models using non-parametric statistical techniques
(v) To make recommendations for use of the spatial model and suggest ways to improve it, including identification of further research needs and strategic actions.

2. Overview of data and research methods

2.1 Approaches to fire risk modelling

The approach adopted here is archival, that is, based on reported historical wildfires, in this case the PDNP Rangers fire log from 1976 to 2004. Alternatives include archives of active wildfires (Chuvieco and Congalton, 1989) or biophysical modeling of fuel loading, both using satellite remote sensing (e.g. Chuvieco et al., 2004). This may be used in conjunction with physical modelling based on weather records and forecasting, as for MOFSI. The latter is at a coarse spatial scale (10km) and neither includes the essential trigger of people.

The approach adopted in this report produces a retrospective, spatially distributed assessment of wildfire risk at a fine scale (50m) using multi-criteria evaluation (MCE). The choice of scale was determined by the resolution of the original CCVE data layers. The approach therefore differs from the physical and biophysical models, in the currency of the data sources used (archival data) and the fine spatial scale of the analysis. It also has the advantage that it includes human factors.

The maps produced show the risk of *reported* fire, which is an approximation to the risk of *ignition*, or fire ‘hatching’. Spatial bias may exist because wildfires close to access routes are seen more easily and are more likely to be reported (as shown in the ‘increased reporting’ link in Figure 1.1). However, fire officers and rangers report that the database captures most of the wildfires, since few wildfires extinguish themselves so would eventually be reported no matter how remote (CCVE, 2005). The 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 because the database population was not large enough to produce and test separate maps for spring and summer fire risk.

The MCE GIS technique used here has been employed by others for fire risk mapping (Chuvieco and Salas, 1996; Martín, 2005; Vakalis *et al*., 2004). The MCE technique is explained below (Fig 2.2).

2.2 Fire distribution

The spatial distribution of wildfires is not random and as can be seen in Fig 2.1, wildfires are mostly found on statutory section 3 moorland. This is not surprising given that the fire database was compiled by PDNP rangers. However, it probably also reflects the true distribution according to participants at the CCVE risk workshop (CCVE, 2005). Here we are only concerned with section 3 moorland (see section 2.5). 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 favours high fire risk. This observation was explored in the first stakeholder workshop for CCVE in January 2005 (CCVE, 2005). The list of initial causal factors which emerged was used to produce the first risk maps in the CCVE technical report (CCVE 2005b). They have been refined in the work reported here.

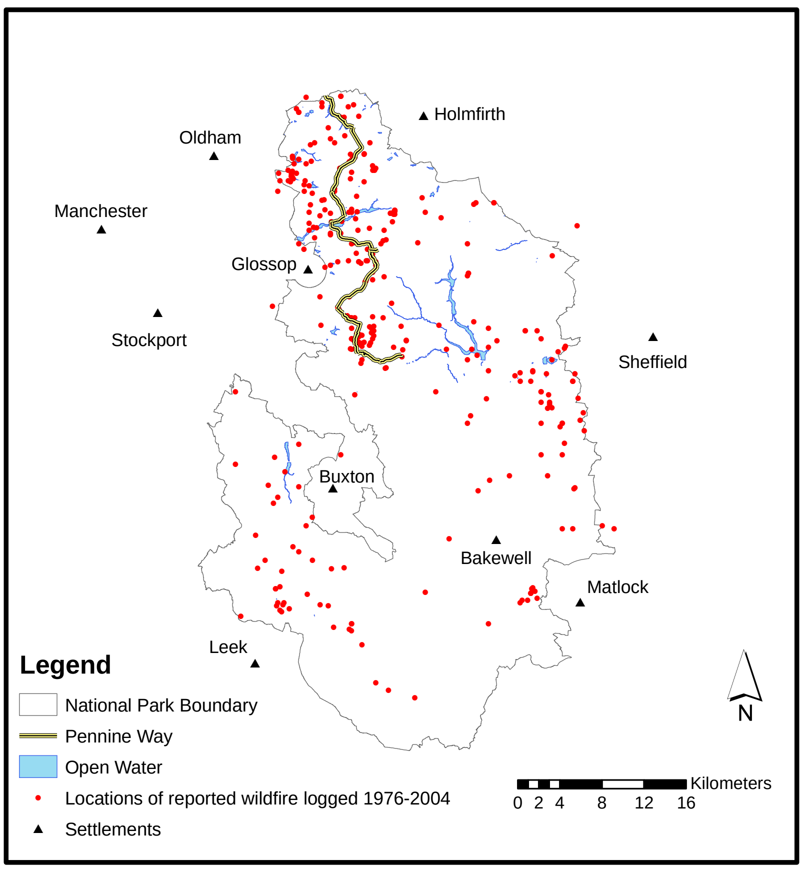


Figure 2.1 Non-random distribution of wildfires in PDNP 1976-2004, showing park boundary, major settlements and the Pennine Way

2.3 Building the model: MCE

There are four stages to building the multi-criteria evaluation (MCE) model (Figure 2.2)

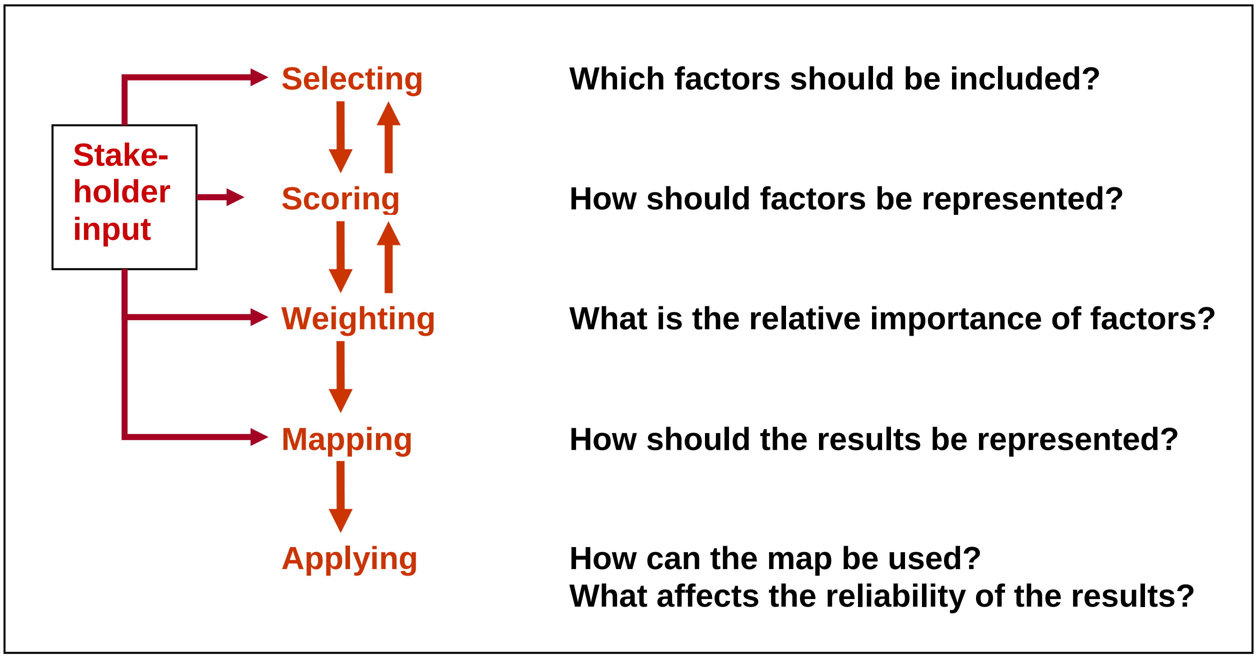


Figure 2.2 Stages in the production of a risk map using multi-criteria evaluation, showing input from stakeholders and feedback into revised selecting, scoring and weighting.

Selecting layers

Initial consultation with stakeholders identified a set of potential factors affecting wildfire distribution.

Figure 2.3 shows the factors considered for the MCE model; which were each represented as individual map layers. There were two groups of factors: vulnerability to ignition hazard (physical factors) and accessibility (human factors).

Vulnerability to ignition hazard can be expressed as flammability, itself a function of degree of drying and species -related differences in fuel loading. Hot, dry weather 'cures' green biomass to brown biomass, so increasing fuel loading. Vulnerability could therefore be seen as a function of *habitat* working via species-dependent variations in biomass, substrate type and wetness (such as depth of peat) and, importantly, the degree of management.

Aspect was incorporated in the initial CCVE model as a surrogate for spatially distributed variation in propensity to drying. A fuller discussion of the rationale for the model is given in the CCVE report, section 2.3 (McMorrow *et al.,* 2006a). Each of the layers in the model will be discussed in more detail in sections 3, 4 and 5.

Selection of the final set of layers to include in the model runs was made following consideration of stakeholder input and the results of empirical analysis (see sections 3-6). 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.

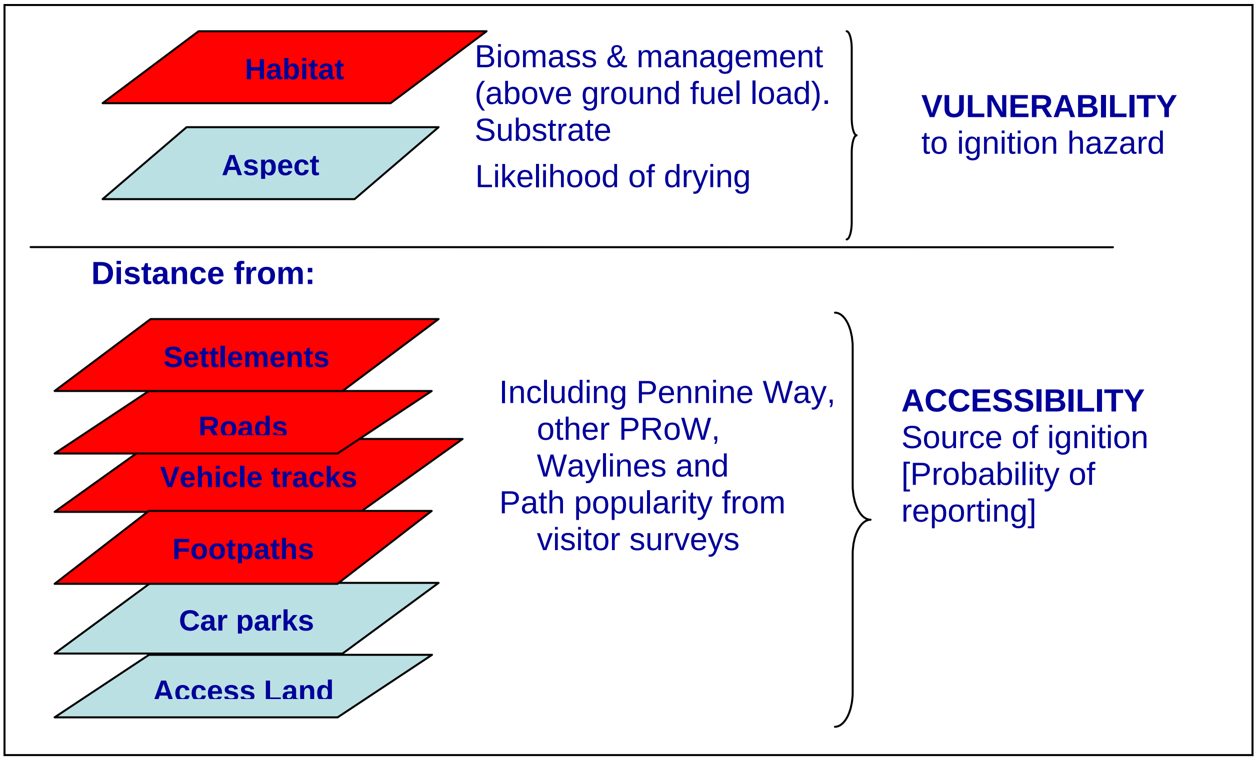


Figure 2.3: Conceptual model, showing layers in MCE. Red layers are those used in final models. PRoW, Public rights of way. Waylines layer; paths and tracks from digitised aerial photograph interpretation.

Scoring

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 (polygon) based, for example habitat (see section 2.6)
>
> *(ii) Distance decay.* This was used for factors where map layers were based on distances from point or line features, for example, paths (see section 3). The first part of the process was to generate a distance surface containing distance values from particular features of interest to each 50m cell in the data layer. Next, distance values were extracted for each cell containing a training fire (section 2.6). Finally, distance values were plotted as frequency distributions with different sized bins (or 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 (see section 2.4). In some cases, no relationship between distance and wildfire frequency could be established, necessitating the omission of some of the layers.

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. However, a number of different versions were generated from the original stakeholder weights in order to test the relative reliability of model outputs (section 6). 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. All formulae were of the form shown in Equation 1:

Risk score = (layer 1 * layer 1 weight) + (layer 2 * layer 2 weight)
+ (layer 3 * layer 3 weight) + (layer n * layer n weight) [Equation 1]

Open water areas were set to zero in the final risk maps. Full metadata for the datasets used in the MCE model and for the resulting layer(s) will be supplied separately.

2.4 Incorporating expert opinion

FOG consultation

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. It was decided that stakeholder involvement should be organised in two stages; first, through an online questionnaire open to a wide number of stakeholders and other experts, followed by a dedicated one-day workshop where the issues could be explored in more detail.

Online survey

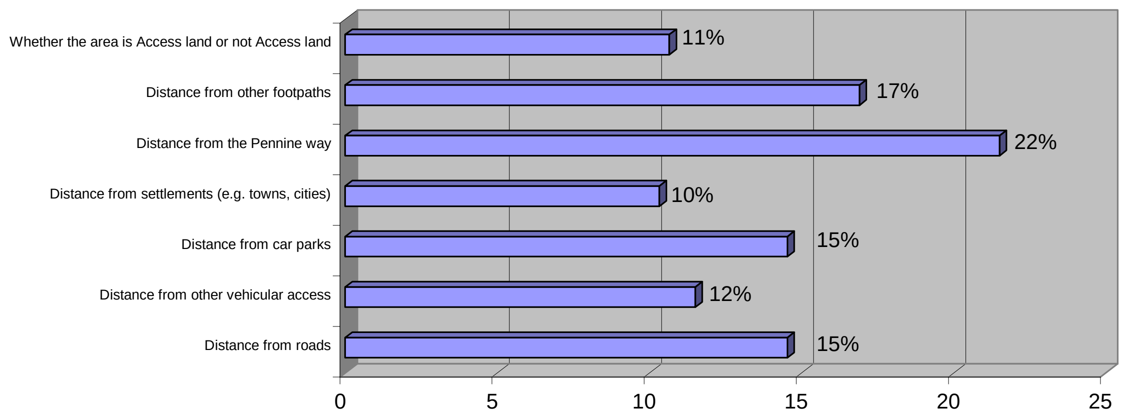
Drawing on the findings of the CCVE project and discussions at the initial FOG meeting, an online survey was developed. It was piloted by selected members of FOG prior to wider distribution in order to identify any ambiguous or otherwise problematic questions. The aims of the survey were:

- To introduce the project and identify potential contributors to a follow-on workshop – responders were asked whether they would be prepared to contribute to a follow on workshop.
- To canvass opinions in relation to the perceived relationships between wildfire occurrence and individual causal factors and/or causal factor groups, and to identify an initial set of weights based on opinions on the relative importance of factors. This was established through a set of questions asking responders to rate and rank the importance of specific factors.
- To canvass opinions in relation to preferred methods for communicating project results. This focussed on determining the format of the final risk map to be produced and the number of categories to be used to present the results.

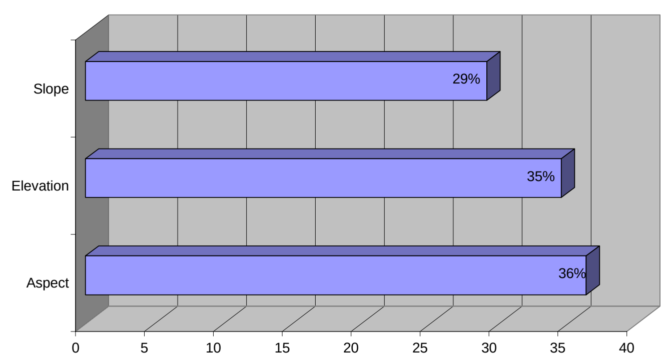
The survey was circulated to FOG representatives and a limited number of outside experts in Spring 2006. Sixteen responses were returned from a range of stakeholder groups (Figure 2.4). Some examples of screen shots from the online questionnaire survey are shown in Appendix 1. Examples of the results format are shown in Appendix 2.

As indicated above, an important goal of the online survey was to provide an improved starting point for generating a weighting scheme for the MCE model compared to the original CCVE work which used estimates generated by the research team. There are several different ways of generating weights for MCE exercises, each with different benefits and drawbacks (Thill, 1999). Rating and ranking were used as two alternative means of generating weights, since these were judged to be the most appropriate for an online survey due to their simplicity.

The results of the rating and ranking questions are shown in Figures 2.4 and 2.5, respectively. Comparison of the two methods used to generate weightings shows that there were some inconsistencies, such as the perceived importance of slope and elevation, but there were also clear agreements about the importance of some of the factors, such as the perceived influence of the Pennine Way.

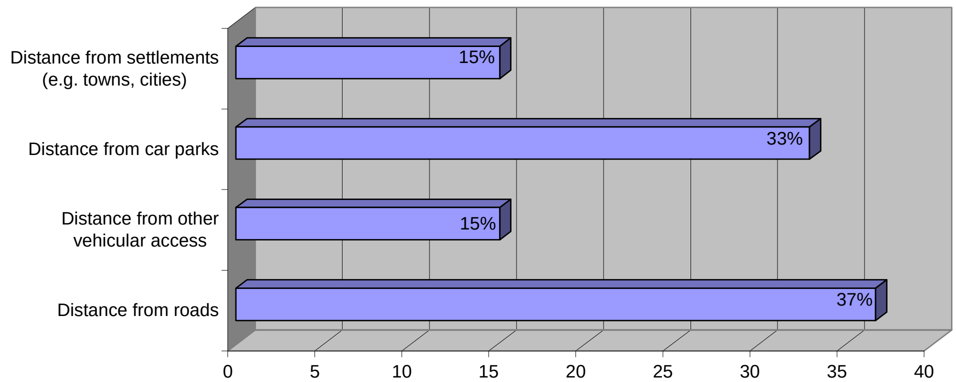


(a)

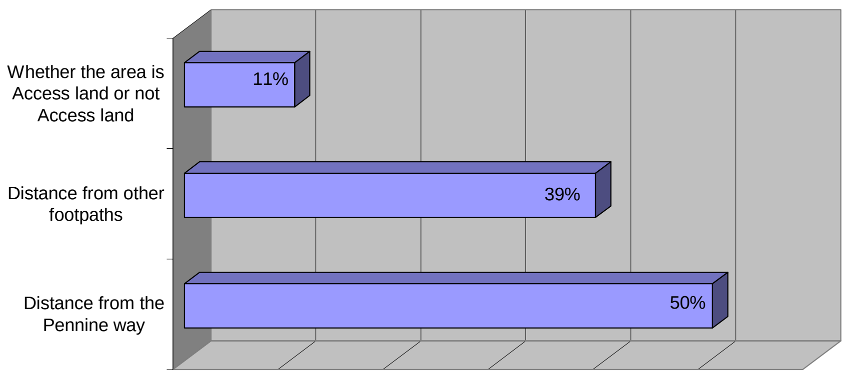


(b)

Figure 2.4: Rating of the relative importance of (a) human and (b) topographic factors in the online survey



(a)



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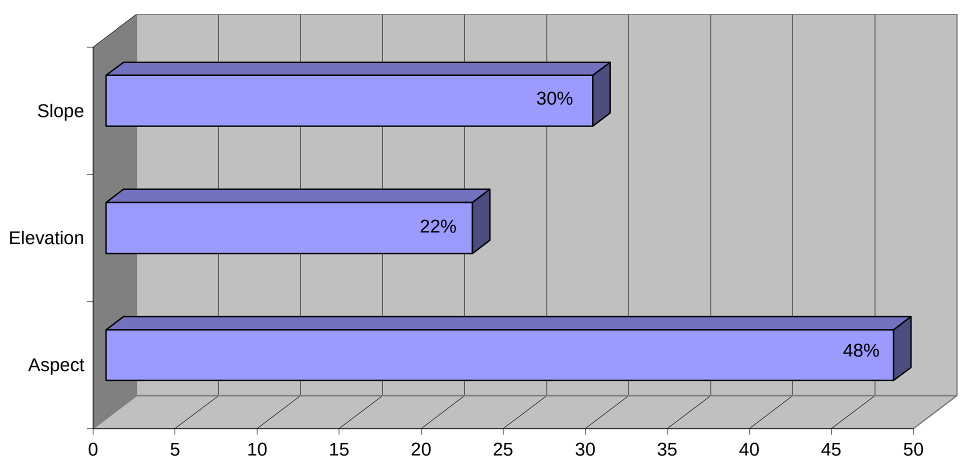


(c)

Figure 2.5: Ranking of the relative importance of (a) human (car access) (b) human (foot access) and (c) topographic factors in the online survey

Stakeholder workshops

A dedicated workshop had been held in January 2005 as part of the CCVE project (CCVE, 2005). A second workshop was held in June 2006 for the current project (see Appendix 3 for the attendance list). The workshop was structured to address the following questions and related aims as part of the process towards generating a stakeholder-informed spatial wildfire risk map:

- Which factors should be included? To build on the CCVE report and survey findings
- How should factors be represented? To decide if map layer scores should be based on data (empirical) or opinion
- What is the relative importance of factors? To resolve differences in weightings suggested by the survey results and agree a basis for combining layers into a single moorland wildfire risk map.
- How should be results be represented? To develop an agreed mapping basis for the final results.
- What affects the reliability of the results? To consider other issues affecting the reliability of the results.

Which factors should be included?

Figure 2.6 shows the factors included in the online survey for consideration by the workshop group.

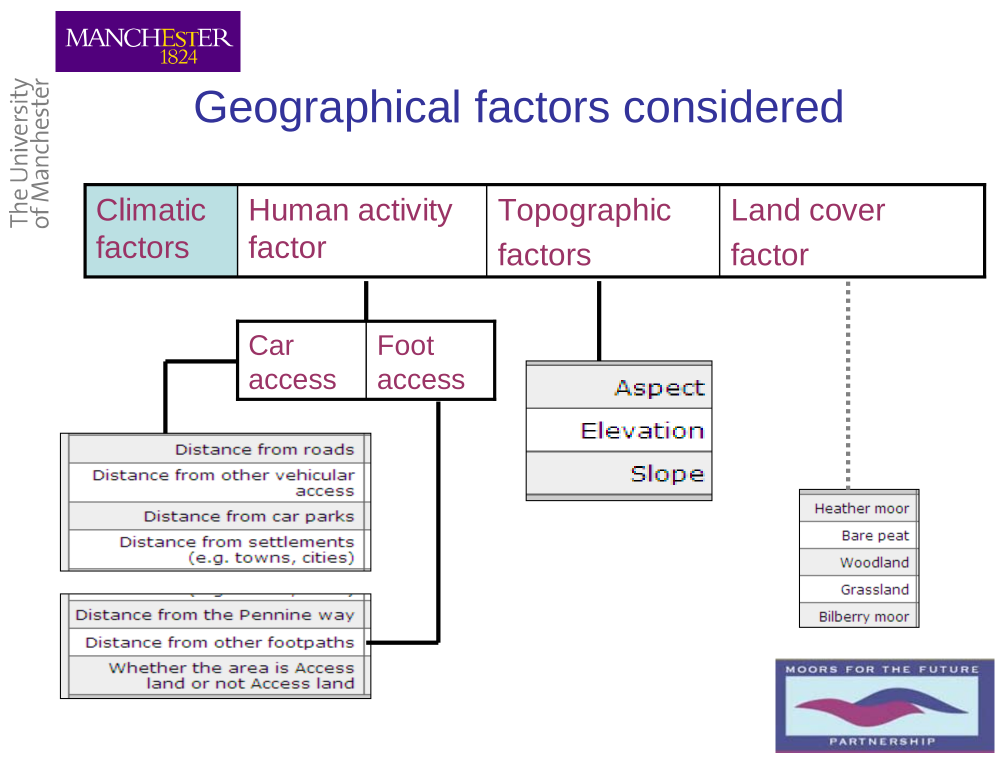


Figure 2.6: Factors used as the basis for discussion at the June workshop

A number of sub-questions informed the discussion:

- Were any geographical factors missed out?
- Should all existing factors be included?
- Should factors be grouped differently?
- Are there any other human activity factors?
- Are there any other environmental factors

There was some discussion of the differences between wildfires caused by arson and those caused accidentally, in particular, to establish whether each tends to occur in different places and whether one is more important than another. This could help to establish areas where the final risk map may be less reliable. It was noted that there are specific geographical areas, for instance, Cannock Chase in Staffordshire and Dovestones which are associated with arson. These areas are believed to be associated with stolen cars being taken to car parks or minor roads in remote areas (often the nearest car park to where the car was stolen) and then set alight. A similar pattern of activity has been seen in South Yorkshire, making the sites for wildfires from arson-related events often rather predictable for local fire crews. In this case, there is a definite perceived relationship between wildfire and proximity to settlements, with areas having good accessibility near to high crime areas believed to be particularly important. This suggests that, ideally, separate spatial models are needed for accidental and malicious fires. However, the model developed here is for all fires because cause is generally not known and/or recorded.

Another suggestion was that rough campers may be a cause of wildfires, this time through accidental causes, and as a result of access largely on foot. Although rough camping is not permitted in the National Park, Rangers are aware that this still takes place. There was some disagreement about the distances away from footpaths that rough camping could be expected, but most agreed that campers would prioritise areas out of sight. Campsites could also be important (a lack of campsites may also encourage rough camping if existing sites are full), but this is clearly a seasonal influence on fires.

Some felt that rough campers would have a relatively small effect compared to fires started through other types of foot access; for instance. people driving out to car parks and walking short distances to areas to stop for barbeques. One of the issues discussed was the role of path popularity, given that it would be expected that wildfire likelihood would be directly proportional to number of people using footpaths. However, this is not always a straightforward relationship, since some very popular paths are not associated with many wildfires, for example, Derwent Edge. It was suggested that this might be due to the path being a relatively difficult walk and therefore not as physically accessible. One would expect difficult terrain to result in lower popularity and fewer fires, unless difficult paths are popular with walkers who are more aware of fire risk. The relationships between terrain, popularity, fire awareness and fire occurrence would be worth investigating, given more time and collection of suggested additional data in the visitor surveys. The distance of footpaths from car parks can also be important, as well as footpath conditions.

Given this evidence, it was confirmed that human (socio-economic) factors are important and should be considered for inclusion in the refined model. It was also decided to retain a differentiation between foot and car access, although there was some debate about the usefulness of this grouping. A grouping based on arson and accidental fire factors was suggested as a possible alternative but is not possible since fire cause is not known (linking to the FRS database may provide this information).

How should factors be represented?

This part of the workshop explored some of the options for representing factors as map layers in the model. In particular, the discussion looked at different scoring options. The results for this part of the workshop are presented in the sections 4 and 5.

What is the relative importance of factors?

One of the most important roles of the workshop was to establish a set of initial weights to use as the basis for combining layers representing individual and/or groups of factors. In order not to bias the discussion, the results from the online survey were not presented at the workshop. Instead, stakeholders were asked to negotiate a set of agreed weights based on their own views. It has been noted that there are a number of different techniques for establishing weighting schemes. A workshop situation enabled the use of a more sophisticated pairwise comparison method, developed by Saaty (1977). The pairwise technique has the added advantage of providing a structure for group discussions and establishing areas of divergent opinions (Eastman 2003). The pairwise comparison method is based on assessment of factors using a scaling system, shown below. Using this scale, pairs of factors are compared and a judgement made to indicate the degree to which one factor is more or less important than the other, or whether they are equally important. Another way of thinking about this is that different pairs of factors are traded-off against one another (Table 2.1).

Table 2.1: Pairwise weighting system

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	V. strongly	Strongly	Moder ately	Equally	Mode rately	Strongly	V. strongly	Extremely
Less important					More important			

The scaling system can be used to construct a matrix (table) of values which records all the relative scores for each pair of factors in the table. An example is shown below for car access factors (Table 2.2). For the first column in the table, the scores can be read as follows:

- distance to roads is equally important (1) as distance to roads
- distance to other car access is very strongly more important (7) than distance to roads
- distance to car parks is moderately more important (5) than distance to roads
- distance to settlements is extremely more important (9) than distance to roads.

Table 2.2: Pairwise weighting for car access factors

	Dist to roads	*Dist to other car access*	*Dist to car parks*	*Dist to settlements*
Distance to roads	1.0	0.1 (1/7)	0.2 (1/5)	0.1 (1/7)
Distance to other car access	7.0	1.0	0.1 (1/7)	0.1 (1/7)
Distance to car parks	5.0	7.0	1.0	0.2 (1/5)
Distance to settlements	9.0	7.0	5.0	1.0

Note the decimalisation of the scores shown above for the “less important” scores where 1/7 is converted to 0.1 and 1/5 is converted to 0.2. The process of calculating approximate weights from these scores involves:

- summing the scores for each of the factors listed left to right (*i.e.* producing column totals)
- determining the proportion of each column total which is represented by each of the factors listed in the rows (*i.e.* the relative contribution provided by each of the four cells in the column to the column total)
- estimating the final weights by averaging the values for each of the factors listed in the rows (*i.e.* producing row averages)

The scores allocated formed the basis for establishing a set of initial weights for the car-related human factors. The same process was used for other factors and factor groups. The results are shown in section 2.9.

How should be results be represented?

Building on the results of the online survey, this part of the workshop involved a more in-depth consideration of the influence of mapping techniques and map classification schemes on the communicability of the final risk map. This is discussed in more detail in section 6.1 (Table 6.1)

What affects the reliability of the results?

The day ended with a general discussion about the factors that are likely to affect the reliability of the results, including issues such as the accuracy of reporting of fire locations. It was felt that the reporting of locations for wildfire were reasonably reliable and would be suitable for the analysis to be carried out in this project.

2.5 Defining the study area

The study area for the analysis covered the widest possible area of the PDNP. The main limitation was the spatial extents of the key input datasets, in particular habitat and wayline data. Since Wayline data[1] were only consistently available for areas of section 3 moorland, the study area was generated as the spatial coincidence of section 3 moorland, habitat data (for which consistent habitat classes were available) and the Park boundary. The final study area covers some 480 km^2 and is shown in Figure 2.7.

A lack of metadata describing the contents of the MFF database made the process of determining a study area for which all data were available a time-consuming task. It is recommended that metadata records are created using UK geospatial metadata standards[2] to make the process of data management more efficient for future research tasks.

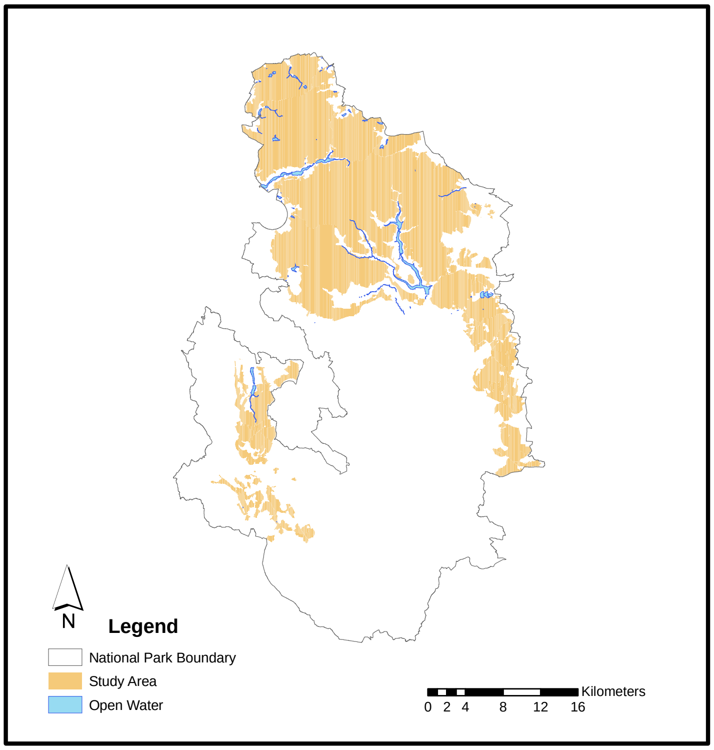


Figure 2.7: Study area

2.6 Fire database

The fire database gives fire location to varying degrees of precision, ranging from GPS 12 figure grid references (1 m) to the centres of 1 km grid-squares (500 m). It is not known whether the location recorded is the estimated point of ignition, the approximate centre of the burning area or the point at which the recorder was standing. It is recommended that the point is standardised, and is ideally the estimated point of

[1] Wayline data are a dataset held by MFF. They were produced by digitising access lines interpreted from aerial photographs. They include: vehicle tracks (double lines); eroded paths (lines, exposed mineral or peat soil); trampled paths (lines, vegetated); and sheep tracks (polygons, small vegetated tracks).
[2] See gigatewayhttp://www.gigateway.org.uk

ignition. It is also recommended that GPS is used to map the boundary of all wildfire (as is now the case) and that a cross-reference to the GPS file name is recorded.

All records have the date of the fire. Other fields are incomplete, especially for older entries. They include the area of fire in various units, duration of burn, vegetation type and, for 19% of the record, the suspected cause of the fire, which is largely cited as cigarettes (McMorrow *et al.,* 2006b). It is recommended that the Fire and Rescue Service (FRS) incident number is recorded where FRS attended, as this will provide surrogate information on fire severity from the number of tenders and duration of deployment. Despite its limitations, the database is a good resource. Similar fire incident records are available for few other areas, such as the Dorset heaths, maintained by Dorset county council (Dorset heaths, 2006), and some areas of Scotland, maintained by the Firebeaters group (Firebeaters, 2006). It is recommended that a national wildfire incident database be set up using the PDNP fire record sheets as good practice.

The fire records had already been entered into Excel by MFF. Considerable effort had had also been expended to prepare the database for the CCVE project, including standardising units, joining to the weather and habitat databases and adding other fields for the temporal analysis. For the current project, fires outside the study area were excluded and the rest were randomly stratified into a 60% (128) subset used to develop the spatial model (training fires), with 40% (84) retained for testing the models.

2.7 Habitat sensitivity analyses

Two assumptions have to be made about the habitat layer in view of the data and resources available. First, it is assumed that habitat is a causal factor in fire ignition through its role in providing fuel and indicating the type and wetness of substrate. In the absence of data on the location of managed heather moors for all years except 2002, habitat is also taken to indicate managed burning for heather dwarf shrub and heather dry bog habitats.

Second, only one suitable habitat map was available (see discussion below). Habitat maps could have been generated for other dates, but the resources required were beyond the remit of the study. It had to be assumed, therefore, that the 1991 source date for the majority of habitat mapping is representative of habitat over the 28 years of the fire record. This is a fair assumption for post-1991 fires, as fire scars are persistent landscape features and fires tend to recur on or close to other fires scars. Ideally, habitat prior to each fire should be known, especially for pre-1991 fires.

The original PNDP moorland habitat map based on the Dark Peak and Southwest Peak Environmentally Sensitive Area (ESA) habitat maps was used, referred to here as the ‘36 ESA class’ map. An area-weighted risk score was calculated for each of the 36 habitats by, first, extracting the habitat at each fire point. The percentage of the study area covered by each of the 36 classes was then calculated and used to predict the expected number of fires in each class. For instance, since dry heather bog occupies 18% of the area, it would be expected to have 18% (23) of the 128 training fires. The expected number (Exp_Nfire_tr36) was subtracted from the reported number (Pt_Nfire_tr36). Positive residuals indicate more fires than expected by area and were awarded higher empirical fire risk scores. Scores were calculated by allocating a score of ten to the largest positive residual, 1 one to the largest negative residual and scaling the intervening values pro-rata between 10 and 1. For instance, suppose the highest residual was 11, the lowest was -11 and the second highest was five. The score for the second highest would be 7 (Equation 2).

$$\text{Score} = 10 - (\text{residual} / \text{increment}) \qquad \text{[Equation 2]}$$

$$\text{Where, increment} = (\text{max residual} - \text{min residual}) / 9$$

The exception was classes for which no fires occurred in any of the habitat sensitivity analysis tests described below. These classes, such as open water and wet bog, were automatically allocated a score of zero. The exception was the six class variant, where the Other class contained some habitats which had fires and other which did not.

The CEH land cover data 2000 was also evaluated as an alternative to the ESA habitat data because it is a nationally available, consistent scheme, which is due to be updated in 2007. It was expected to be suitable because it uses dominant species. It was, however, rejected because it did not have a bare peat class, which had emerged as the critical fire risk class in the CCVE analysis and again here. Experience suggests that a bare peat class could be mapped from Landsat Thematic Mapper satellite images and added to the CEH layer. Comparable land cover maps could also theoretically be generated for earlier dates back to the mid 1980s when suitable satellite data sources became available, so that habitat closer to the time of earlier fires could be used. Unfortunately, this was beyond the resources available for the project, as indicated above, but should be explored in future work.

Habitat class generalisation

Sensitivity of fire scores and final fire risk to degree of habitat class generalisation was tested to ascertain if simpler classes could be used. This is important if wider stakeholder consultation is required, especially using an online survey. The original 36 PDNP moorland habitat/ESA class scheme uses a combination of dominant species, peat depth (for dry bog and dry dwarf shrub heath), and degree of management (for grassland). The 36 classes were combined into four variants. Class listings for the original 36 classes and the variants are given in Tables 3.2 – 3.6

- ***18 classes***. (Table 3.3) This scheme was unusual in that it combined classes using dominant species regardless of peat depth, so that heather dry dwarf shrub heath was combined with dry bog heather dominant, and the equivalent for the two non-heather categories. It kept broadleaved and coniferous woodland classes separate and reduced grassland to three types.
- ***13 classes*** (Table 3.4) based on a scheme suggested in the stakeholder workshop. It was very similar to the 18 class scheme, but, significantly, retained the distinction between dry bog (on >0.5m depth of peat) and dry heath (<0.5m). It combined dwarf shrub heath classes as either dry bog or dry dwarf shrub heath. It therefore used peat depth regardless of dominant species and did not differentiate between heather and other dwarf shrub species. In practice, as will be seen in the next section, heather has far fewer fires than expected by area compared to bilberry/ crowberry so it is important to use scheme which is based on dominant species.
- ***6 classes***, (Table 3.5) based on the five used in the online survey, plus an 'Other' class. This was a dominant species-physiognomy scheme, which retained critical classes from the previous CCVE analysis yet tried to use

'vegetation types' which would be as meaningful as possible to a mixed audience without assuming too much ecological knowledge.

- ***20 classes*** (Table 3.6) produced by MFF using red-amber-green traffic light coding for relative fire risk of habitats based on local knowledge. It was similar to the 36 and 13 class variants in that it used peat depth instead of dominant species

New habitat layers were made for each of the variants and area-weighted scores were calculated as before ('Point data' column in Table 2.3).

Locational precision

The sensitivity of habitat scores to locational precision of fire records was also tested since older (pre-GPS) fire locations were often recorded only 1 km grid squares, which meant that they were allocated the centre point of the grid square for this analysis. The dominant habitat in buffer zones of 100, 200 and 500 m around each fire point was recorded. This data was then used to re-calculate area-weighted risk scores for the original 36 class scheme and the four variants habitats.

The test schedule is shown in table 2.3, which flags those selected for used in the final models. Note that the 20 class variant was not used in the locational precision analysis and was be evaluated for point data only. Results are shown in Tables 3.2 – 3.6 and discussed in section 3. The scope of the study did not permit the buffer analysis to be extended to other layers, but locational precision will affect all of the layers. Nevertheless, it is considered to be most important for the habitat layer.

Table 2.3: Sensitivity analysis schedule for habitat scores

	Point data	*100m buffer*	*200m buffer*	*500m buffer*
36 ESA classes	√, Model 1	√	√, Model 3	√
20 MFF classes	√			
18 land cover classes	√, Model 2	√, Model 5	√ Model 4	√
13 stakeholder classes	√	√	√	√
6 online survey classes	√, Model 6	√	√	√

2.8 Testing the model

Many models can be produced by MCE, depending on the layers selected, their scoring and relative weighting. The independent 40% test set was used to judge the success of models. Distributions of training sets final fire scores from the combined weighted layers were compared against those for the test set. Distributions were usually skewed to higher scores so a non-parametric test was used, the Mann-Whitney test. A good fit exists when was a training and test distribution as similar as possible and with a high mean. The null hypothesis, H_o, was that the two samples were drawn from the same population, and any difference between them was purely due to chance. Unusually, then, the desired outcome was that H_o, should be accepted, which occurs if the Mann-Whitney significance is larger that 0.05 (for 95% significance). Results of testing are presented and discussed in section 6.

2.9 Presenting the results

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. The influence of mapping techniques and categorisation bands on the interpretation of mapped information can be considerable (Monmonier, 1991; Lindley and Crabbe, 2004). Given that, and the large range of mapping options offered by modern GIS packages, it is important to consider mapping issues for presenting the final results, especially where results are to form the basis of ongoing planning and management decision-making. Additionally, 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. To help MFF establish an appropriate means of mapping the results of the spatial risk assessment, 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 (Figure 2.8).

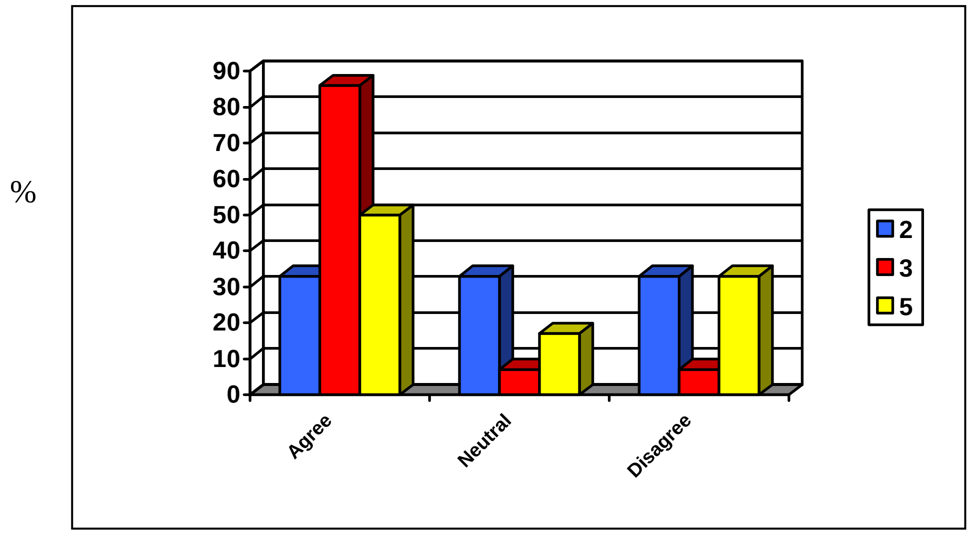


Figure 2.8: Stakeholder views on the preferred number of categories to be used for the final risk map.

The online survey also suggested that colour output was also preferred with 84% of respondents approving or strongly approving colour output compared to only 16% approving or strongly approving of black and white output. However, 54% felt black and white and colour output would be useful.

The discussion at the workshop will have enabled a fuller appreciation of the potential influence of mapping techniques on the final results. Figure 2.9 provides an example of the effect of different techniques based on the CCVE results. Each technique groups the risk scores shown in the frequency distribution graph in the bottom right hand corner differently, so that a varying number of values can be contained within each class. For example, a three category equal interval classification identifies a relatively small number of high risk cells compared to the 'natural' breaks in the frequency distribution calculated using the Jenk's optimisation technique (which produces categories based on the 'natural' peaks and troughs in the frequency distribution data).

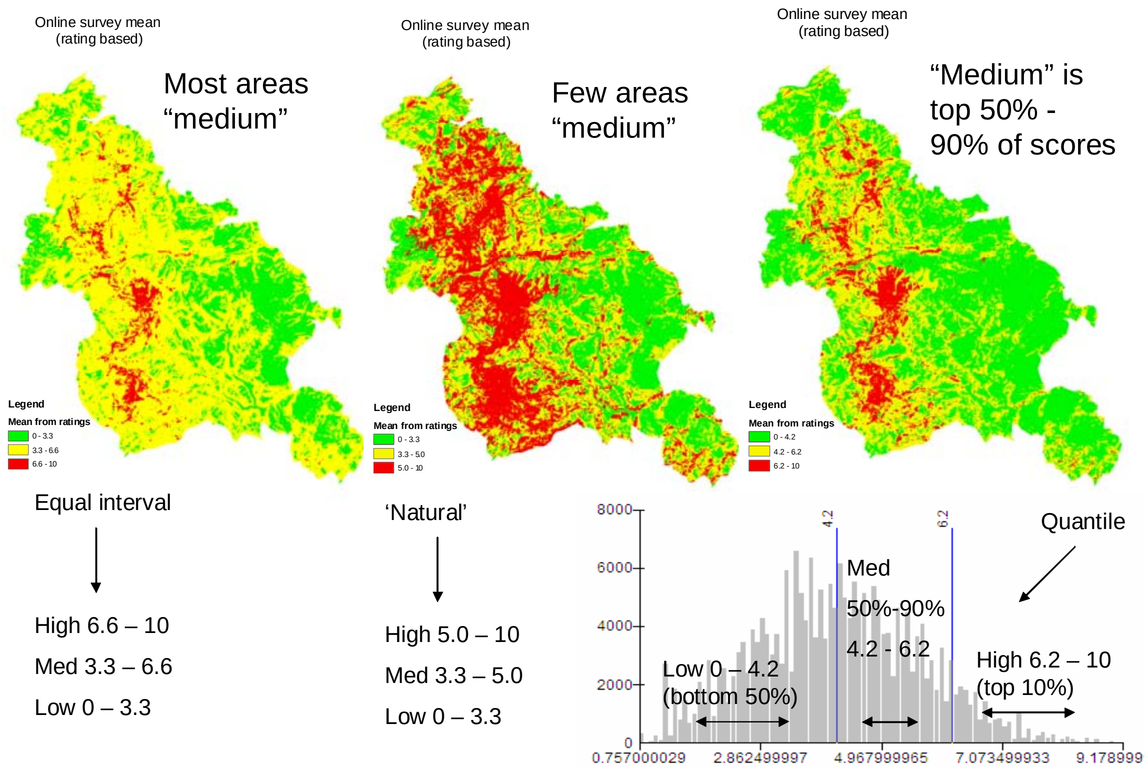


Figure 2.9: Example of the effect of different presentation techniques. Note that this based on CCVE results only

The suggested method in this case would be to use a quantile basis where a known proportion of risk values are contained within each class. For example, the map on the right in Figure 2.9 shows the top 10% of values in the high category, the top 50% (above average as represented by the median value) to 90% of values in the Medium category and the bottom 50% of values (*i.e,* below average as represented by the median value) in the low category. It must be noted that online survey respondents disapproved of the use of 5% and 10% thresholds, but this may have been due the question erroneously suggesting that the associated mapped output would have only two categories.

The results in section 6 of this report have been represented using a continuous scale stretched along a blue to red multi-coloured palette. However, the final decision on the mode of representation and specific category breaks to generate the final version of the mapped results is referred back to MFF and FOG. A digital version of the final model will be provided in an appropriate format so that MFF have full flexibility in producing output. This will also enable FRS areas to be clipped out and rescaled to identify the highest risk areas within their jurisdiction.

It is recommended that the final category breaks are generated with a view to management as well as aesthetic considerations, for example, this may take account of resource considerations for identifying critical risk thresholds.

2.9 Testing the model

Many models can be produced by MCE, depending on the layers selected, their scoring and relative weighting. The independent 40% test set was used to judge the success of models. Distributions of final fire scores from the combined weighted layers for the training sets were compared against those for the test set.

Distributions were usually skewed to higher scores so a non-parametric test was used, the Mann-Whitney test. A good model will have training and test fire score distributions which are as similar as possible. The null hypothesis, H_o, was that the training and test d fire scores were drawn from the same population, so that differences between them were purely due to chance. Usually, we wish to reject H_o, in favour of the alternative hypothesis that the samples really do differ. We usually want the significance value to be less than 0.05; that is, there is a 95% probability that the differences are real and only a 5% one that they have occurred by chance.

Unusually, here the desired outcome is the opposite. We want H_o to be *accepted* and the significance value to be as *large* as possible. For instance, if the significance value is 0.95, then there is only a 5% probability that the differences are real and a 95% one tat they are not. In other words, it could be said with 95% confidence that the two distributions came from the same population, *i.e.*, that the test and training fire scores are very similar. The larger the significance value, the lower the probability that the scores differ so, in statistical terms, the higher the value the better the model. Results of testing are presented and discussed in section 6.

3. Habitat factor

3.1 Comparison of empirical and stakeholder scores

Empirical area-weighted scores for the original 36 ESA classes are shown in the second of the 'traffic light' colour-coded columns, Pt_Score_tr36 Tables 3.1 and 3.2. Red is used for a score of >7, amber for 6-3 and green <3.

Three classes clearly emerge as high risk, having more wildfires than would be expected by virtue of their area; bare peat, eroding moor and bare ground (Fig 3.1, solid black bars). The significance of the bare ground class is surprising, and contrasts strongly with the low risk assigned by stakeholders (Table 3.1). However, the other two confirm findings from the original CCVE study (McMorrow *et al*., 2006a). Wildfires are clearly associated with eroded areas in this analysis, whether caused by trampling, grazing or previous wildfires. The definition of the bare peat ESA class is a mosaic which can include up to 75% vegetation. This means that it could be vegetation which ignites rather than peat, especially since representatives of the FRS reported that peat itself was quite difficult to ignite (CCVE, 2005).

There is an issue of cause and effect here, due to the two assumptions discussed earlier. Does bare peat cause fire, or is it caused by fire? That is, did fire itself create the eroded areas with which post-1991 wildfires are then associated? If so, then, fire seems to beget more fire. A two way feedback link between habitat and fire does seem to exist; fire scars are slow to heal and wildfires do tend to recur on previously burnt sites, notably the cluster of wildfires at Bleaklow and Kinder Scout. More problematically, can we assume that pre-1991 wildfires occurred on areas now mapped as bare peat? A time series of habitat maps are required to answer this.

Fortunately, stakeholders all agreed that bare peat and eroding moor were high risk (Table 3.1, Score_SH), which validates the scores used here. It is important that these eroded classes are retained in building a fire risk model. Habitat maps need to include these classes.

Both heather habitats have low risk scores; the high frequency of wildfires is diluted by the large areal coverage. If we can assume that both are managed by prescribed burning, it suggests that this is effective in reducing wildfire risk. One important conclusion is that prescribed burns or other fuel reduction strategies, such as grazing, may need to be used in high risk eroded habitats where there has been heavy investment in restoration. Under climate change, all such prescribed burns will need to be even more carefully managed.

In stark contrast with empirical scores, stakeholders mostly scored the two heather habitats (dry dwarf shrub heath and dry bog) as high risk (Table 3.1, column Score_SH). For dry bog heather dominated, stakeholders were split but most rated it as high risk. Most importantly, stakeholders did not differentiate between types of dwarf shrub heath and dry bog – all were seen as high risk, regardless of the dominant species. This is in direct contrast to empirical results, which score heather as low risk and non-heather as high risk. That is, in the empirical analysis the dominant species emerges as the key differentiating factor instead of peat depth. This makes ecological sense, as bilberry and crowberry are reported to very flammable, and favour well-drained micro-habitats which dry out more easily (CCVE, 2005).

Broadleaved woodland variants had moderate empirical risk scores, whilst conifers had zero scores. Stakeholders generally agreed that broadleaved semi-natural woodland were medium risk, although not unanimously. They did not agree for conifers; their average risk is high, but some scored it high and others low. It is important, therefore, not to combine woodland into a single class for fire risk modelling.

There was very good agreement between the empirical method and all stakeholders on the low risk of acid flush, cliff and open water, quarry, scree, semi-improved acid grassland, short term ley/arable, and wet bog. Equally, there is good agreement between the two methods on medium risk for cotton grass moorland, *Molinia* grassland and unimproved acid grassland.

Generally, there was much disagreement between stakeholders, depending on personal experience. Often bi-modal or tri-modal results were obtained, where groups of participants held two or three starkly contrasting views. For instance, for coniferous plantation, stakeholder scores were split equally into high medium and low risk, whilst the empirical score was very low.

The MFF 20 class scores (Table 3.6) agreed with empirical scores in the Pt_Score_tr20 column for only nine classes. Strongest disagreement was for dry bog and dry dwarf shrub heath. It is suggested that this is because both these two classes combine dominants with different degrees of fire risk in the same class; flammable bilberry/crowberry and relatively low risk heather (when managed by prescribed burns for grouse).

There are several possible reasons for these differences within the stakeholder group and between methods. Differences of opinion amongst stakeholders are due to differences in experience and standpoint. Those with knowledge of the CCVE results were often closer to empirical scores, whereas those with extensive field experience such as PDNP Rangers differed most from the empirical scores and were, perhaps, guided more by their experience of fire *frequency*. For instance, Figure 3.1 (Pt_Nfire_tr36 red bars) shows that wildfires on dry bog heather are the most frequent. This is followed by bare peat, dry dwarf shrub non-heather (bilberry-crowberry), cotton grass and dry bog non-heather (bilberry-crowberry). The frequencies in Figure 3.1 broadly parallel stakeholders' averaged perception of risk in Table 3.1. Indeed, it is suggested that differences between the methods seem to be mainly attributable to the fact that participants judged risk on the frequency of wildfires rather than allowing for the area covered by a habitat. This suggests that the question may need to be reworded if the survey were to be repeated.

Consultation with larger sample and range of stakeholders is recommended, even though this may introduce other issues where the cause of wildfire differs. Differences in opinion for any of the factors are of interest in their own right, as they of allow maps of *perceived risk* to be constructed. Given the disagreement among the small sample of stakeholders, the final model uses habitat layers based on empirical scores, but incorporates stakeholders' views on class generalisation.

3.2 Effect of locational precision and class generalisation on habitat scores

The colour-coded columns in Tables 3.2 to 3.6 show how scores for 36, 18, 13, and 6 class variants of the habitat map change as allowance is made for locational precision. The show how habitat fire risk scores change from a single point to 100, 200 and 500 m buffers around the point. Locational error analysis was not conducted for the 20 class variant (Table 3.6).

Figure 3.2 and Table 3.2 show that there is only slight change in score for the 36 classes and no discernible trend. The additional red in Figure 3.3 is due to the unimproved acid grassland score rising from five for the point data to seven when majority habitat for a 200m buffer zone is used. A similar lack of trend exists for 18 classes and the opposite change is observed; because the bilberry score falls from seven to six once the buffer is 100 m or more, there is less high risk red shading in Figure 3.4. Contrary to expectation, precision of fire reporting has relatively little effect on habitat fire scores. Thematic accuracy of the map and locational accuracy of reporting are likely to be more important. It has already been recommended that the latter be standardized to a particular part of the burnt area.

Sensitivity to class generalisation is much higher, as can be seen by comparing the point data maps in Figures 3.3 and 3.4 and the values in the first colour-coded columns of Tables 3.2 to 3.6. When the test wildfires are overlaid on the habitat score layers, visually 36 and 18 classes appear best, probably because both retain the distinction between two key dominant species, high risk bilberry and low risk (managed) heather. The six class variant is reasonably successful for the same reason.

3.3 Habitat layers selected

In conclusion, the 36, 18 and six class variants of the habitat layer were selected for use in modelling with various buffers (Table 2.3). Results of modelling and testing are presented in section 6.

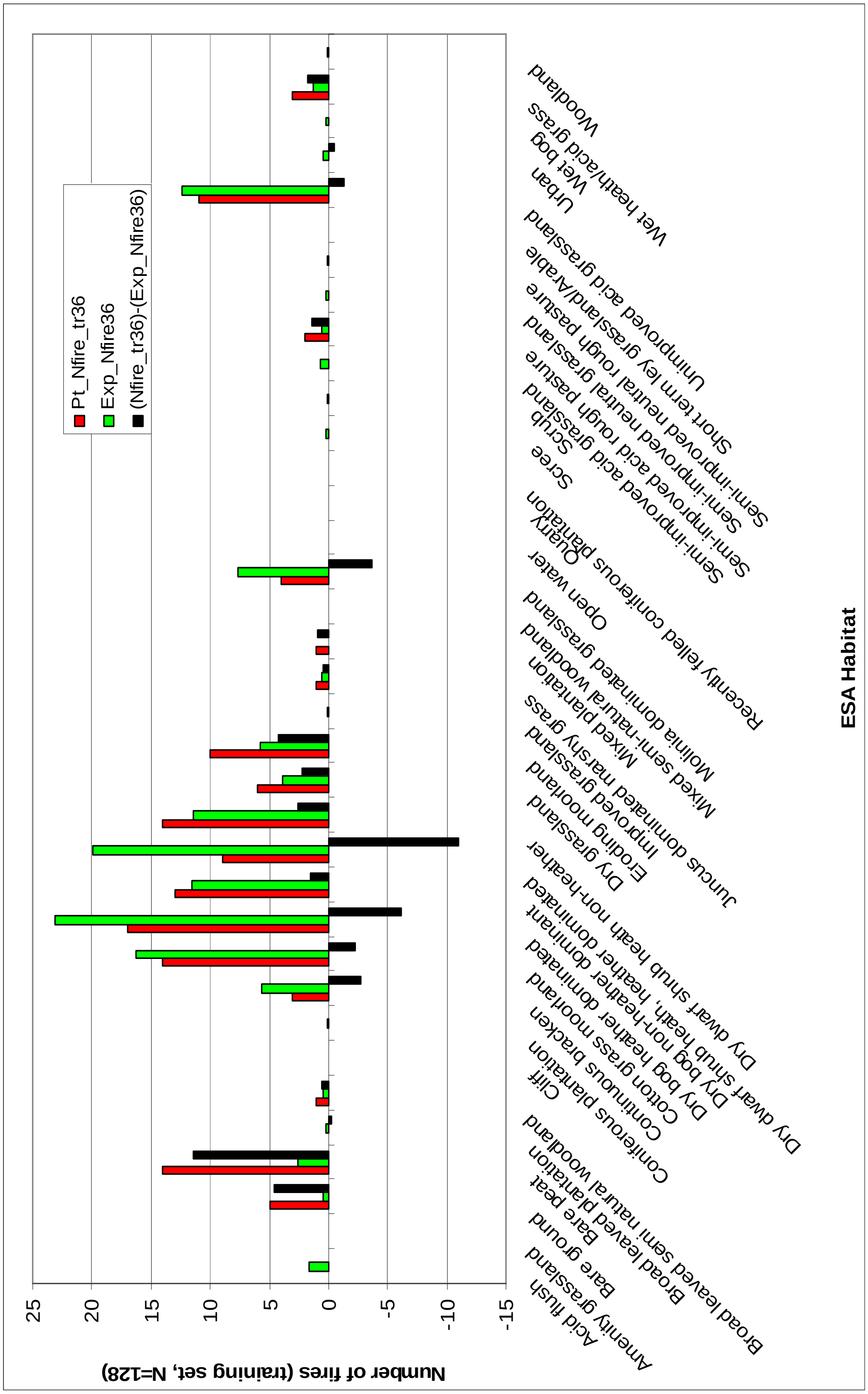


Figure 3.1: Derivation of area-weighted habitat risk scores for 36 classes, point data: Pt_Nfire_tr36, actual training wildfires; Exp_Nfire36, expected wildfires by area; (Nfure_tr36 – Exp_Nfire36), residuals from which risk score is derived

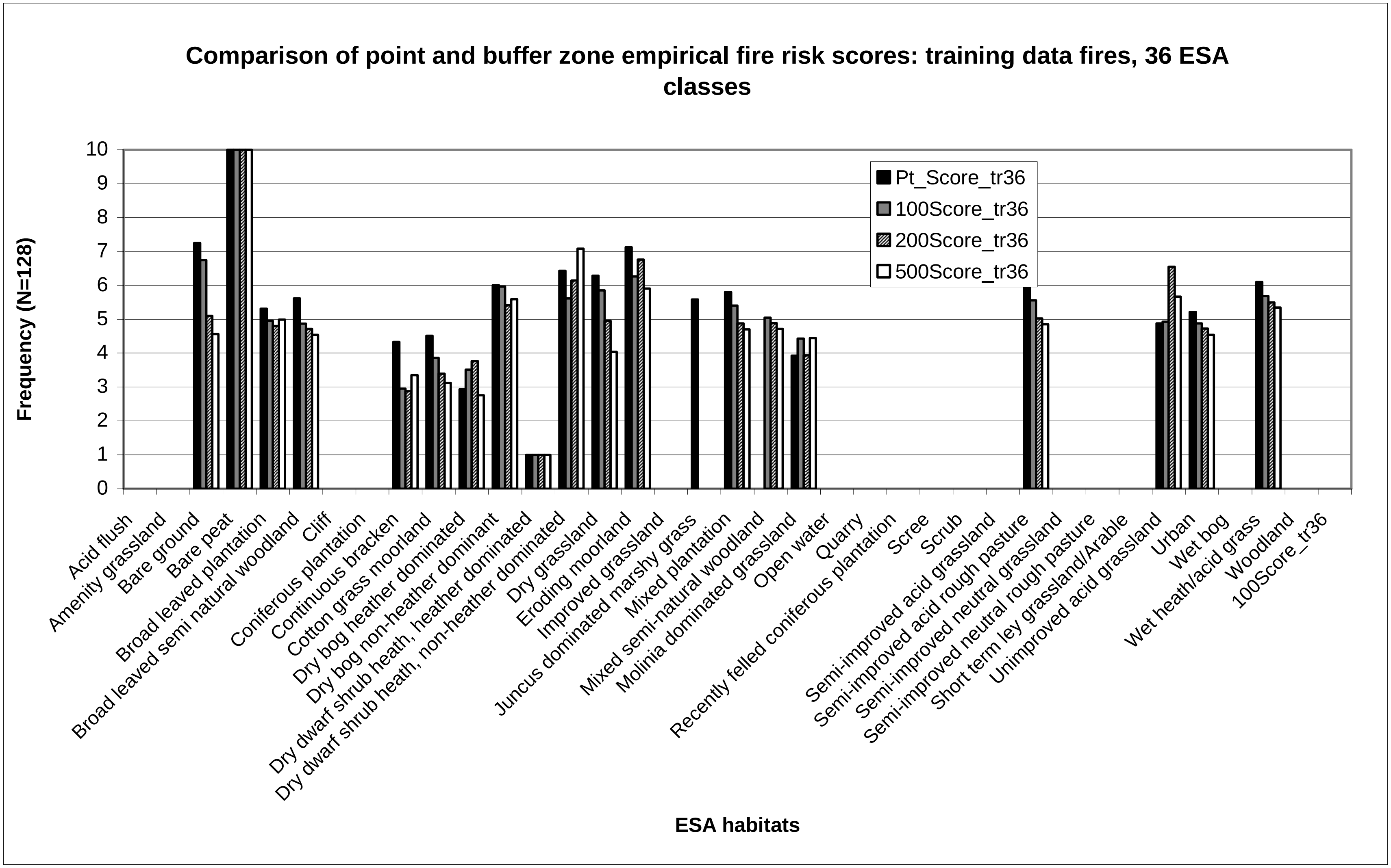


Figure 3.2: Sensitivity of fire score to locational error for 36 classes

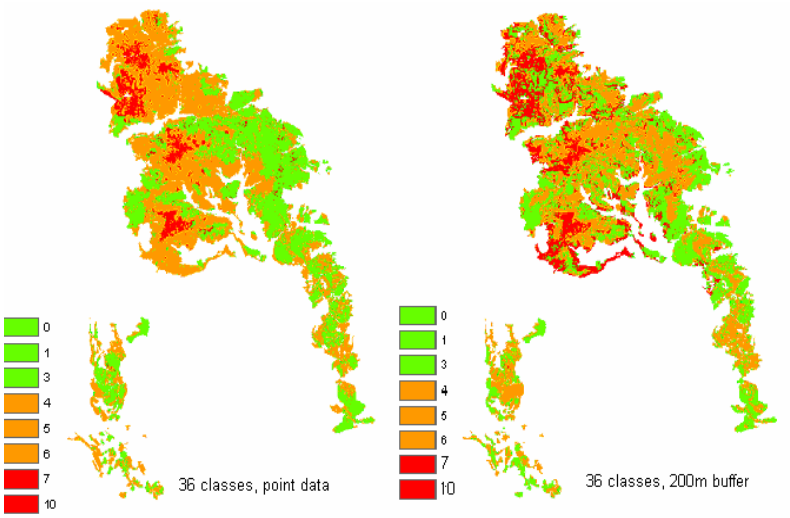


Figure 3.3: Sensitivity of habitat scores to locational precision for 36 classes. The larger area of red for 200m buffer version is due to the fact that the score for unimproved acid grassland increases from 5 to 7 when the majority habitat in a 200m buffer zone is used.

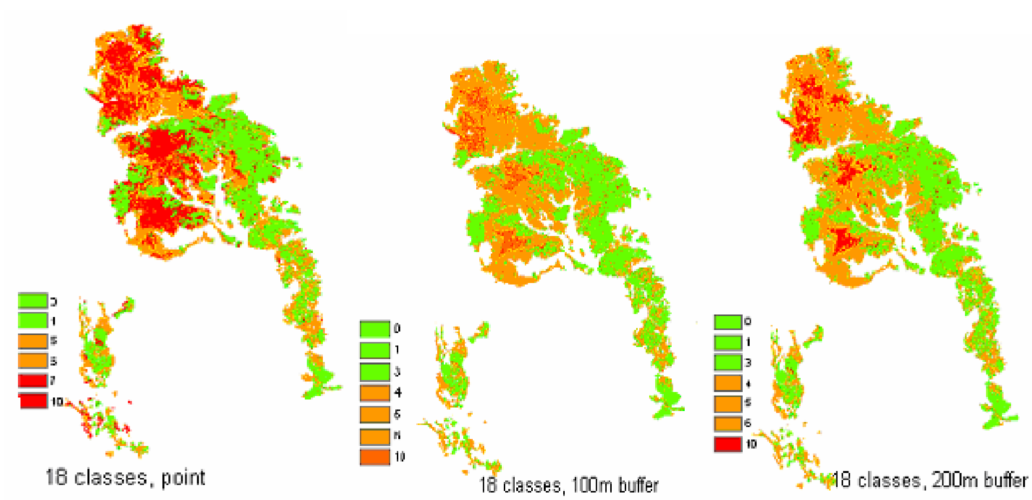


Figure 3.4: Sensitivity of habitat scores to locational precision for 18 classes. The smaller area of red for 100m and 200m buffer is due to the fact that the score for bilberry falls from 7 to 6 when majority habitat in buffer zones is used to calculate the score.

Table 3.1: Comparison of stakeholder and empirical habitat scores, 36 classes

Agreement definitions: V good = Empirical score agrees with stakeholders & all stakeholders concur; Good = Empirical agrees with stakeholders but disagreement within stakeholders; Moderate = Empirical and stakeholders one grade apart, intermediate or good agreement within stakeholders; Poor = Empirical and stakeholders one grade apart, poor agreement within stakeholders; V poor = Two grades apart, poor agreement within stakeholders

	PDNP Moorland habitat (ESA 36 classes)	**Score _SH**	**Agreement within stakeholders**	**Empirical Pt_Score _tr36**	**Agreement between Pt_score & Stake holders**
1	Acid flush	L	Good	0	V. Good
2	*Amenity grassland*	L	Moderate	0	*Good*
3	Bare ground	L	Good	7	V poor
4	Bare peat	H	Good	10	V. Good
5	Broad leaved plantation	L	Poor	0	Good
6	Broad leaved semi-natural woodland	M	Poor, trimodal	6	Good
7	Cliff	L	Good	0	V. Good
8	Coniferous plantation	H	Poor	0	V poor
9	Continuous bracken	H	Poor, bimodal	4	Poor
10	Cotton grass moorland	M	Poor	5	Good
11	Dry bog heather dominated	H	Moderate, bimodal	3	Moderate
12	Dry bog non-heather dominated	H	Poor, bimodal	6	Good
13	Dry dwarf shrub heath, heather dominated	H	Poor, bimodal	1	V poor
14	Dry dwarf shrub heath, non-heather dominated	H	Poor, bimodal	6	Poor
15	Dry grassland	H	Poor, bimodal	6	Poor
16	Eroding moorland	H	Good	7	V. Good
17	Improved Grassland	L	Poor	0	Good
18	Juncus dominated marshy grass	L	Good	6	Moderate
19	Mixed plantation	L	Poor, bimodal	6	Poor
20	Mixed semi-natural woodland	M	Poor, trimodal	0	Poor
21	Molinia dominated grassland	M	Moderate, trimodal	4	Good
22	Open water	L	Good	0	V. Good
23	Quarry	L	Good	0	V. Good
24	Recently felled coniferous plantation	L	Poor	0	Good
25	Scree	L	Good	0	V. Good
26	Scrub	M	Poor, trimodal	0	Poor
27	Semi-improved acid grassland	L	Good	0	V. Good
28	Semi-improved acid rough pasture	L	Moderate	6	Moderate
29	Semi-improved neutral grassland	L	Moderate	0	Good
30	Semi-improved neutral rough pasture	L	Moderate	0	Good
31	Short-term ley grassland/Arable	L	Good	0	V. Good
32	Unimproved acid grassland	M	Moderate	5	Good
33	Urban	L	Good	0	V. Good
34	Wet bog	L	Good	0	V. Good
35	Wet heath/acid grass	L	Poor	6	Poor
36	Woodland	M	Poor, trimodal	0	Poor

Table 3.2: Sensitivity of habitat scores to locational precision: 36 classes

ESA 36 classes	Pt _Score _tr36	Score _100 tr36	Score _200 tr36	Score _500 tr36
1. Acid flush	0	0	0	0
2. Amenity grassland	0	0	0	0
3. Bare ground	7	7	5	5
4. Bare peat	10	10	10	10
5. Broad leaved plantation	5	5	5	5
6. Broad leaved semi natural woodland	6	5	5	5
7. Cliff	0	0	0	0
8. Coniferous plantation	0	0	0	0
9. Continuous bracken	4	3	3	3
10. Cotton grass moorland	5	4	3	3
11. Dry bog heather dominated	3	4	4	3
12. Dry bog non-heather dominant	6	6	5	6
13. Dry dwarf shrub heath, heather dominated	1	1	1	1
14. Dry dwarf shrub heath, non-heather dominated	6	6	6	7
15. Dry grassland	6	6	5	4
16. Eroding moorland	7	6	7	6
17. Improved grassland	0	0	0	0
18. Juncus dominated marshy grass	6	0	0	0
19. Mixed plantation	6	5	5	5
20. Mixed semi-natural woodland	0	5	5	5
21. Molinia dominated grassland	4	4	4	4
22. Open water	0	0	0	0
23. Quarry	0	0	0	0
24. Recently felled coniferous plantation	0	0	0	0
25. Scree	0	0	0	0
26. Scrub	0	0	0	0
27. Semi-improved acid grassland	0	0	0	0
28. Semi-improved acid rough pasture	6	6	5	5
29. Semi-improved neutral grassland	0	0	0	0
30. Semi-improved neutral rough pasture	0	0	0	0
31. Short term ley grassland/Arable	0	0	0	0
32. Unimproved acid grassland	5	5	7	6
33. Urban	5	5	5	5
34. Wet bog	0	0	0	0
35. Wet heath/acid grass	6	6	5	5
36. Woodland	0	0	0	0

Table 3.3: Sensitivity of habitat scores to locational precision: 18 classes

Equivalent 36 ESA	18 classes	Pt_ Score_tr18	Score _100tr18	Score _200tr18	Score _500tr18
3	Bare ground	7	6	5	5
12,14	Bilberry/Crowberry moorland	7	6	6	8
9	Bracken	5	3	3	4
5,6,36	Broadleaved woodland	6	5	5	5
8,24	Coniferous woodland	0	0	0	0
10,34	Cotton grass moorland	5	4	4	4
31	Cultivated land	0	0	0	0
4,16	Eroding moorland	10	10	10	10
15,32	Grass moor	6	6	6	5
11,13	Heather moorland	1	1	1	1
1,18,21,35	Marshy grassland	5	4	4	5
19,20	Mixed woodland	6	5	5	5
2,17,27,29	Permanent grassland	0	0	0	0
7,23,25	Rock exposure and wasteland	7	5	5	5
28,30	Rough pasture	6	5	5	5
26	Scrub	0	0	0	0
33	Urban	6	5	5	5
22	Water	0	0	0	0

Table 3.4: Sensitivity of habitat scores to locational precision: 13 classes

Equivalent 36 ESA class	13 classes	Pt_Score _tr13	Score _100tr13	Score _200tr13	Score _500tr13
3,7,23,25,33	Bare inorganic	6	6	3	3
9	Bracken	3	2	2	2
8,24	Coniferous woodland	0	0	0	0
10,34	Cotton grass moorland	3	3	2	1
11,12	Dry bog	2	4	3	2
15,32	Dry grassland	4	5	5	3
13,14	Dry heath	1	1	1	2
4,16	Eroding peat	10	10	10	10
2,17,31	Improved grassland	0	0	0	0
1,18,21, 35	Marshy grassland	3	4	2	3
27,28,29,30	Semi-improved grassland	4	4	3	3
22	Water	0	0	0	0
5,6,19,20,26,36	Broad-leaved and mixed woodland	5	4	3	3

Table 3.5: Sensitivity of habitat scores to locational precision: 6 classes

Equivalent 36 ESA class	6 classes	Pt _Score _tr6	Score _100tr6	Score _200tr6	Score _500tr6
11,13	Heather moor	1	1	1	1
4,16	Peat	10	10	10	10
1,2,10,15,17,18,21,27,28,29,30,32,34,35	Grassland	4	4	4	3
5,6,8,19,20,24,26,36	Woodland	6	5	4	5
12,14	Bilberry Moor	7	6	6	8
3,7,9,20,22,23,25,33	Other	6	5	3	4

Table 3.6: Habitat fire risk scores for 20 class variant

Equivalent 36 ESA	MFF 20 Classes	Pt_Score _tr20	MFF score	Agreement with Pt_Score_tr20
3,7,23,25	Bare ground	6	L	Disagree
4,16	Bare peat & eroding moorland	10	H	Agree
9	Continuous bracken	3	H	Disagree
10	Cotton grass moorland	3	L	Disagree
11,12	Dry bog	2	H	Disagree
13,14	Dry dwarf shrub heath	1	H	Disagree
18	Juncus-dominated marshy grassland	4	L	Disagree
21	Molinia dominated grassland	3	M	Agree
27,28,29,30	Semi-improved pasture/grassland	4	L	Disagree
15,32	Unimproved acid grassland	4	L	Disagree
35	Wet heath/acid grassland	5	L	Disagree
5,6,8,19,20,24,36	Woodland & plantation	5	M	Agree
1	Acid flush	0	L	Agree
2	Amenity grassland	0	L	Agree
17	Improved grassland	0	L	Agree
26	Scrub	0	M	Disagree
31	Short-term ley grassland/Arable	0	L	Agree
33	Urban	4	L	Disagree
34	Wet bog	0	L	Agree
22	(Water)	0	N/A	Agree

4. Human factors

4.1 Human factors selected

Based on data availability and the time and resources available for this project, the final set of human factors to be considered were taken as:

- distance to settlements;
- distance to car parks;
- distance to roads (including major and minor roads and vehicle tracks); and
- Distance to different path types (Pennine Way, Public Rights of Way and Waylines, including the consideration of popularity indicators).

It is recognised that this does not account for all of the suggested processes from the workshop, although in some cases layers could be used as surrogate indicators of some of the more complex relationships. It is recommended that further work is undertaken to explore some of the interrelationships between socio-economic drivers of wildfire more fully and also investigate any differences in relationships between different parts of the park as advised by stakeholders.

As with the habitat layer, it is also the case that there may have been changes in some of the human factor layers over the time period covered by the wildfire database. This is likely to be most significant for path layers. Nevertheless, the human factor can be taken as broadly representative.

4.2 Settlements

The importance of distance to settlements was confirmed in both the online survey and the June workshop. Although it was noted that the relationships between distance to settlements and wildfires is not straightforward, distance to settlements acts as a useful surrogate for a number of the potential causes of wildfire that were discussed.

The settlement layer was generated from an assessment of 'urban' centres in and around the PDNP. It uses a definition of urban generated from a classification of Enumeration Districts developed from the UK Census of Population for 1991. Urban EDs were generalised into individual polygon representations with summed population counts. The geometric centroid for each of these areas was calculated with manual correction of points where large and/or irregular spatial extents lead to the problematic placement of points – for example in the case of Glossop. The use of an urban area classification has led to the inclusion of settlements such as Baslow, Tideswell, Bakewell, Hayfield, Marsden and Buxton, but the exclusion of settlements such as Hathersage, Bamford, Hope, Holme and Little Hayfield. Further work could revise the particular settlements to include in the analysis, perhaps with further input from project stakeholders. Settlements included and their relative population sizes are included in Figure 4.1.

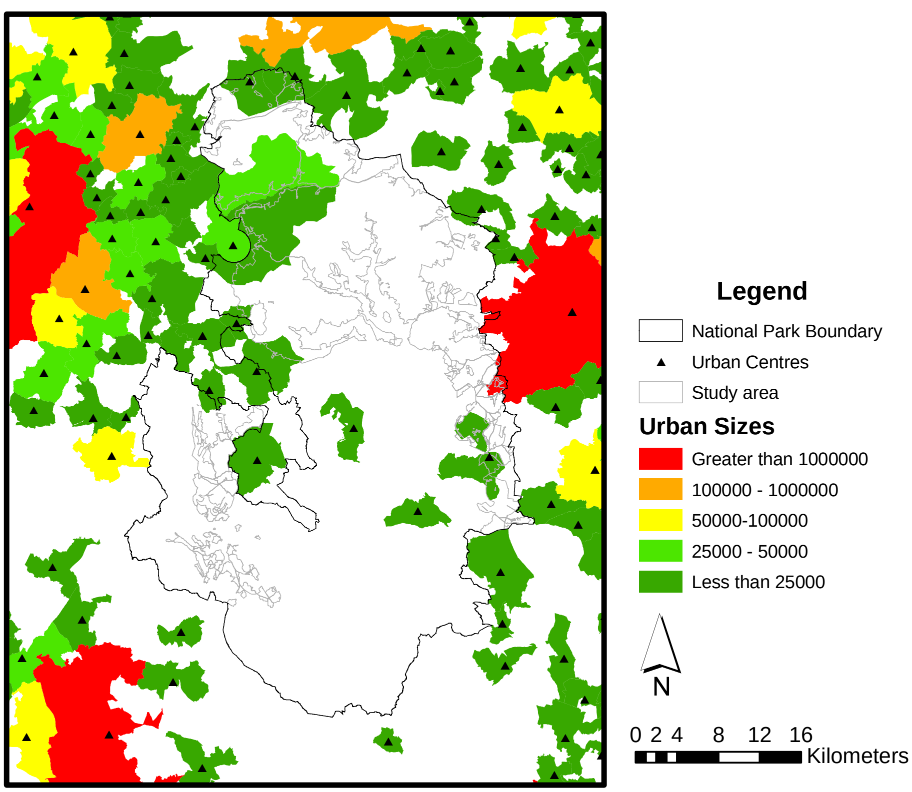


Figure 4.1: Urban classified settlement and their relative sizes in and around the PDNP (Source: Census 1991 and MIMAS)

Following the definition of settlement points to include in the analysis, a distance layer was generated and the distance from settlement values for each of the training wildfires within the study area were extracted. From these data, a set of distance decay graphs were generated to assess potential relationships between fire frequency and distance to settlements. Graphs were initially based on distance classes of 500m, but, as shown in Figure 4.2, there was little obvious distance decay in the resultant frequency distribution. Other class sizes were then considered with the most distinct distance decay pattern discernable for 5.5 km distance classes (Figure 4.3). Scores were therefore generated on the 5.5km distance classes, using the following scoring scheme:

Nearest 5500m = 10

5500- 11000 = 8

Greater than 11000 = 0

The resultant layer to input into the spatial model is shown in Figure 4.4. As with many of the scoring techniques, the specific scores and distance bands used are affected by some subjective decision making but are considered appropriate given the information available and the relationships suggested by the training fire data set.

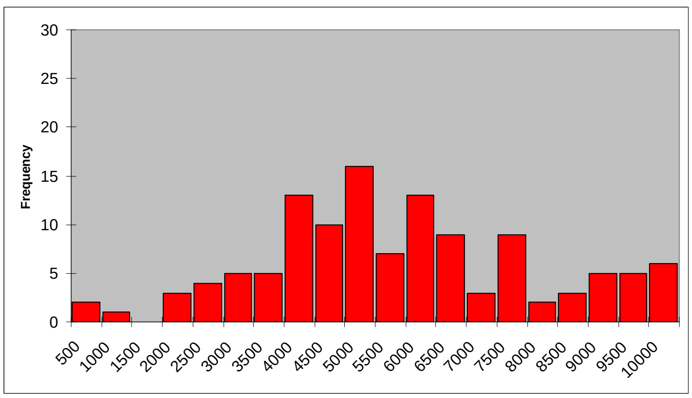


Figure 4.2: Frequency of wildfires within 500m distance classes from settlements. Bin labels on distance axis refer to right-hand tick point.

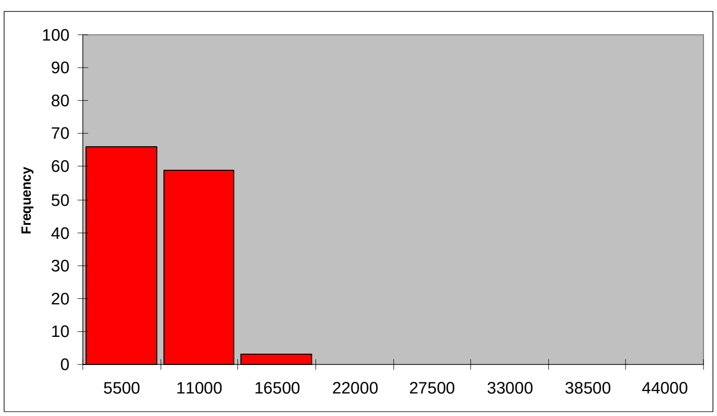


Figure 4.3: Frequency of wildfires within 5.5km distance classes from settlements (mean distance to training wildfires is around 5.7 km). Bin labels on distance axis refer to right-hand tick point.

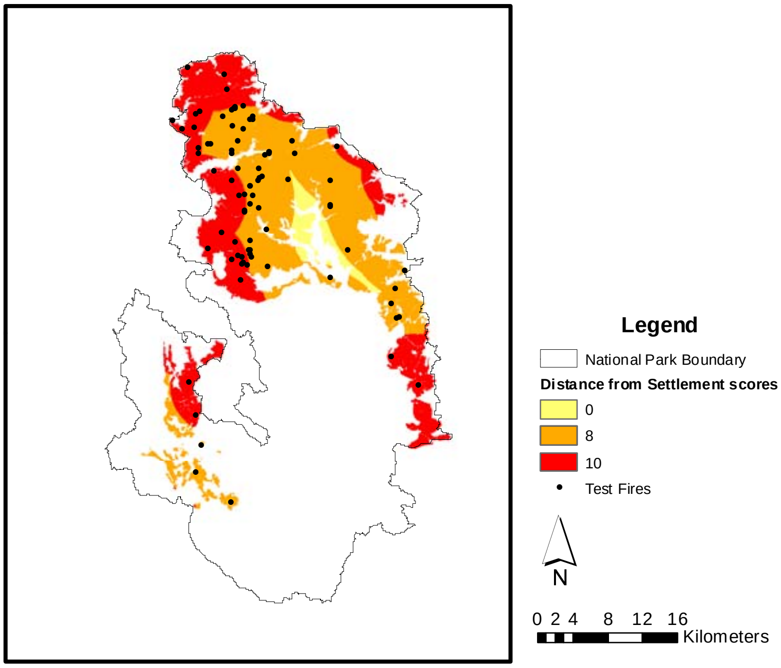


Figure 4.4: Final distance from settlements scores used as an input in the spatial model (test wildfires shown for reference

4.3 Roads and vehicle tracks

The workshop suggested that roads might be a stronger indicator of wildfires associated with arson rather than with accidental causes. However, the relationships are rather more complex in reality since many of the human factors are interrelated. For example, walkers are also likely to use car access points, which would tend to suggest that footpaths that are more accessible by car may be more important than those which are more remote.

The spatial influence of road access for different users would be expected to be different. For example, stakeholders suggest that walkers might be expected to cover between 2 and 10km during a day (suggesting a 1-5km buffer). However, arsonists are generally not equipped for walking and would only be expected to go 100-200m from roads (or paths). Arsonists are known to set fires on grass verges, even directly by the road side. This presents something of a problem in modelling both issues in one layer, since the implication is that each is associated with a different distance band.

One of the ways suggested ways of differentiating accidental fires from those set deliberately was to consider the temporal dimensions of fire incidence, since arson was believed to be greatest during the evening period. Although beyond the scope of this particular project, an assessment of the temporal characteristics of wildfires compared to individual human factors would be useful follow on work.

Another issue raised was the relative importance of different types of roads. In terms of wildfire caused by arson, it was felt that minor roads would be more important than major roads, as arsonists prefer remote areas to set fires so that they are not seen (e.g. to dispose of stolen vehicles). This would suggest that smaller, less trafficked roads, vehicle tracks or roads out of view would be important and associated with more fire. It was felt that this cause has been increasing in importance over time. Again, further work would be required to ascertain the degree to which this is the case.

Given this information, separate road layers were generated for major and minor roads and vehicle tracks to determine the degree to which frequency of reported wildfire changes with distance from roads. The empirical analysis could then be related back to comments made at the workshop in order to help decide on the most appropriate scoring scheme to use.

Major roads

Major roads have been taken as being equivalent to A class roads. These are shown in relation to the study area and the training fire dataset in Figure 4.5. Visual inspection of Figure 4.5 suggests that a number of the main roads may be associated with clusters or linear patterns of reported wildfires, particularly the cross Pennine routes (e.g. A635) in the North of the study area. However, there are other routes, such as the A57 where there is not a clear visual pattern.

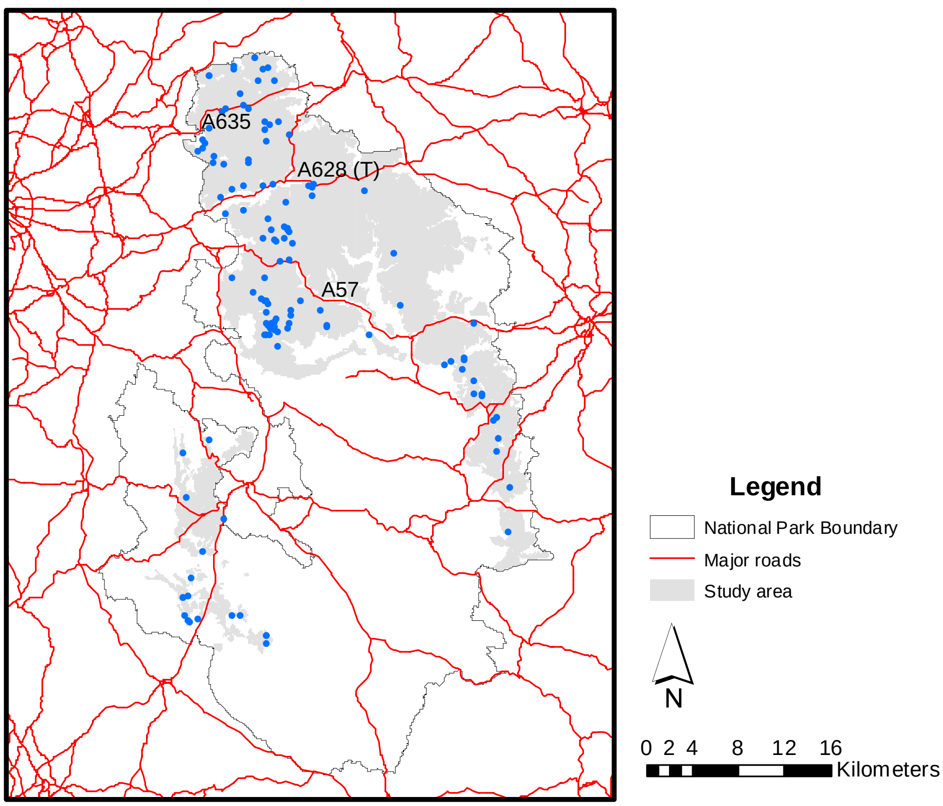


Figure 4.5 Major (A) roads and training fire locations (blue points)

Differences in the influence of specific roads may be one of the reasons that the analysis of frequency of wildfires with distance from major roads showed no clear distance decay trend, particularly for 200m distance classes, which would fit best with the reported behaviour of arsonists (Figures 4.6-4.7). Another reason is due to the distance decay analysis only being carried out for training wildfires within the study area. Since many of the major roads fall outside of the study area, a stronger relationship may be found if a training dataset with a wider spatial extent had been used to test distance decay relationships. This could be tested with follow on work.

Given these findings and the suggestion from the workshop that less trafficked roads may be a more important indicator, major roads have been omitted from the model. Whilst there could have been further experimentation with larger distance classes, this was not considered to be in keeping with stakeholder views that most of the impact of proximity to roads would occur in within a relatively narrow corridor of individual roads.

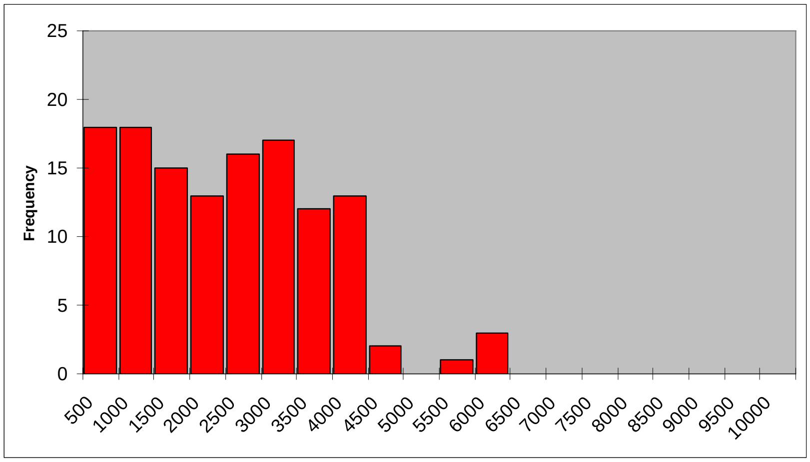


Figure 4.6 Frequency of wildfires within 500m distance classes from major roads (mean distance for training wildfires is around 2km). Bin labels on distance axis refer to right-hand tick point.

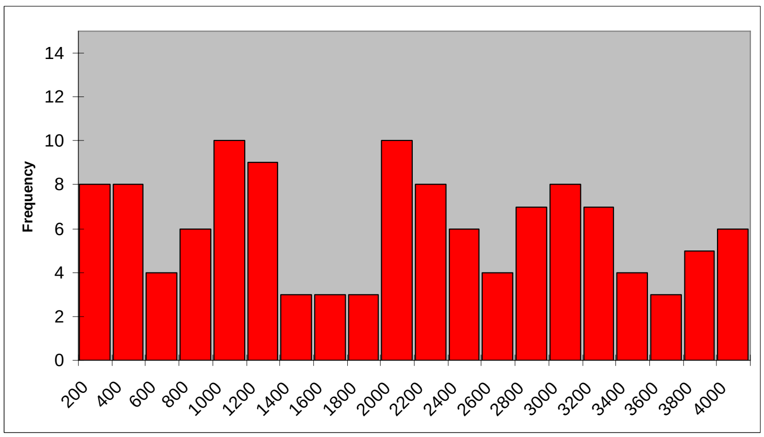


Figure 4.7 Frequency of wildfires within 200m distance classes from major roads. Bin labels on distance axis refer to right-hand tick point.

Minor roads and vehicle tracks

Figure 4.8 shows minor roads and vehicle tracks in and around the study area. Stakeholders suggested that the relationship between wildfire locations and minor roads (including vehicle tracks) may be stronger than that observed for major roads. Visual inspection would seem to suggest that the relationships may be stronger towards the south west of the study area but less clear in other parts of the study area. Further work could explore the degree of similarity between distance decay characteristics in different parts of the study area, but this was beyond the scope of the work conducted here.

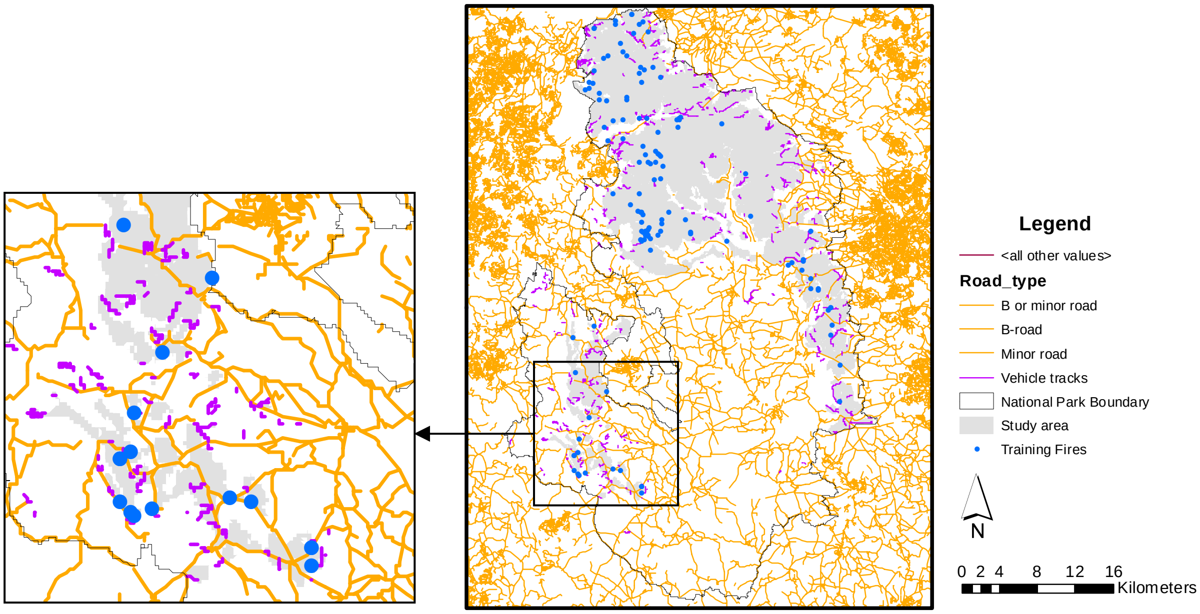
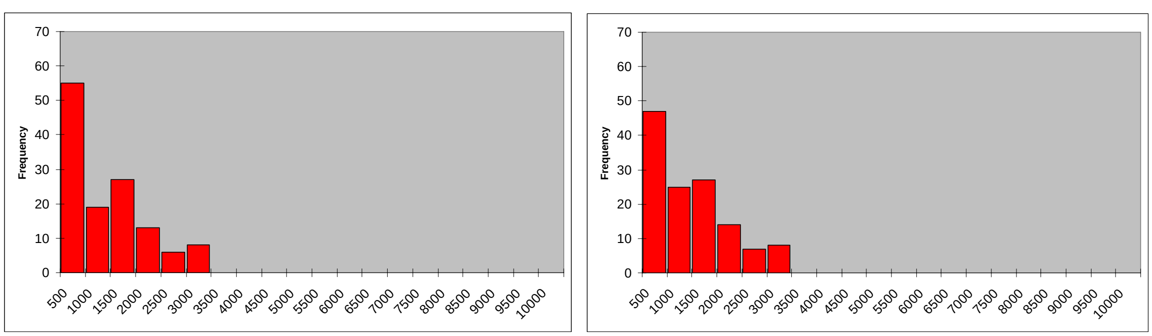


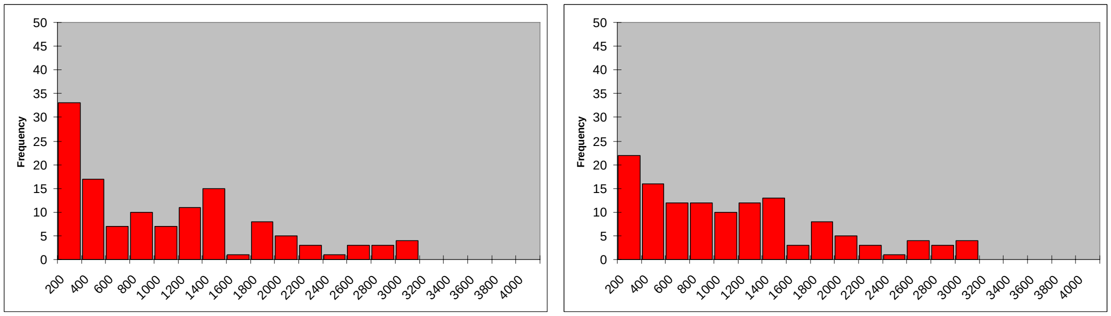
Figure 4.8: Minor roads (including vehicle tracks) and training fire locations (blue points)

Figures 4.9 and 4.10 show that the empirical analysis appears to confirm the suggested influence of proximity to minor roads on wildfire frequency, even taking account only those wildfires within the study area. Distance decays have been examined for all minor roads and for vehicle tracks alone. The results seem to suggest that these two road groups can be merged into a single factor using the same classification scheme. This is useful in view of the single stakeholder weight value given to minor roads.



(a) All minor roads *(b) vehicle tracks only*

Figure 4.9 Frequency of wildfires within 500m distance classes from (a) all minor roads and (b) vehicle tracks only. Bin labels on distance axis refer to right-hand tick point.



(a) All minor roads *(b) vehicle tracks only*

Figure 4.10 Frequency of wildfires within 200m distance classes from (a) all minor roads and (b) vehicle tracks only. Bin labels on distance axis refer to right-hand tick point.

Figures 4.9 and 4.10 demonstrate that all wildfires occur within approximately 3 km of minor roads. This is to be expected since there are few parts of the study area which lie beyond 3km of minor roads or vehicle tracks. The mean distance to wildfires is around 1km (913m and 988m for all minor roads and only vehicle tracks respectively). The largest influence can be seen within a fairly narrow 200m distance class immediately adjacent to roads, with a weaker influence at greater distances. In this case, 200m distance classes are used since stakeholders have specified that a strong effect is to be expected for arson causes very near to the roadside. However, since minor road access will also affect accidental fires at greater distances (up to around 1-5km based on stakeholder assessment of the distance covered by walkers), a smaller score has been given to other distance bands to account for that effect. The final classification used was:

0-200m = 10
200-400m = 5
400-1400 = 3
1400 – 3000 = 1
> 3000 = 0

The final minor road layer to use as an input to the model is shown in Figure 4.11.

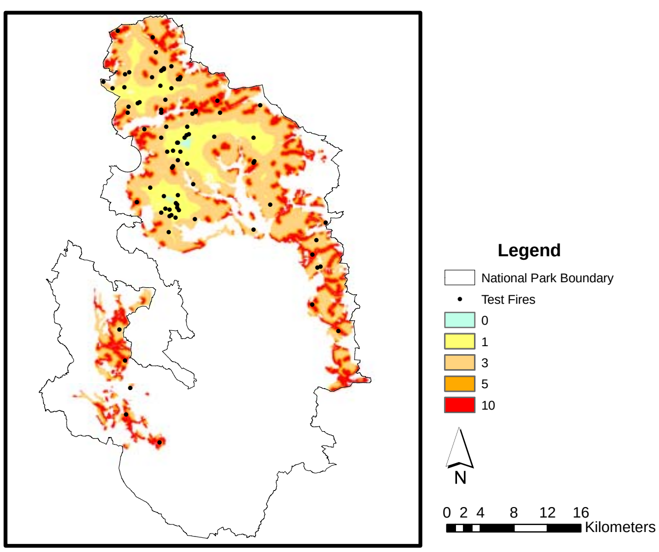


Figure 4.11: Final distance from minor roads scores used as an input in the spatial model (test wildfires shown for reference)

4.4 Car parks

Another potentially influential human factor affecting wildfire distribution is associated with proximity to car parks. This factor has been raised on a number of occasions by stakeholders as an influence on both arson and accidental fires and this is reflected in the results of the online survey presented in section 2. The locations of car parks in the PDNP are shown in Figure 4.12.

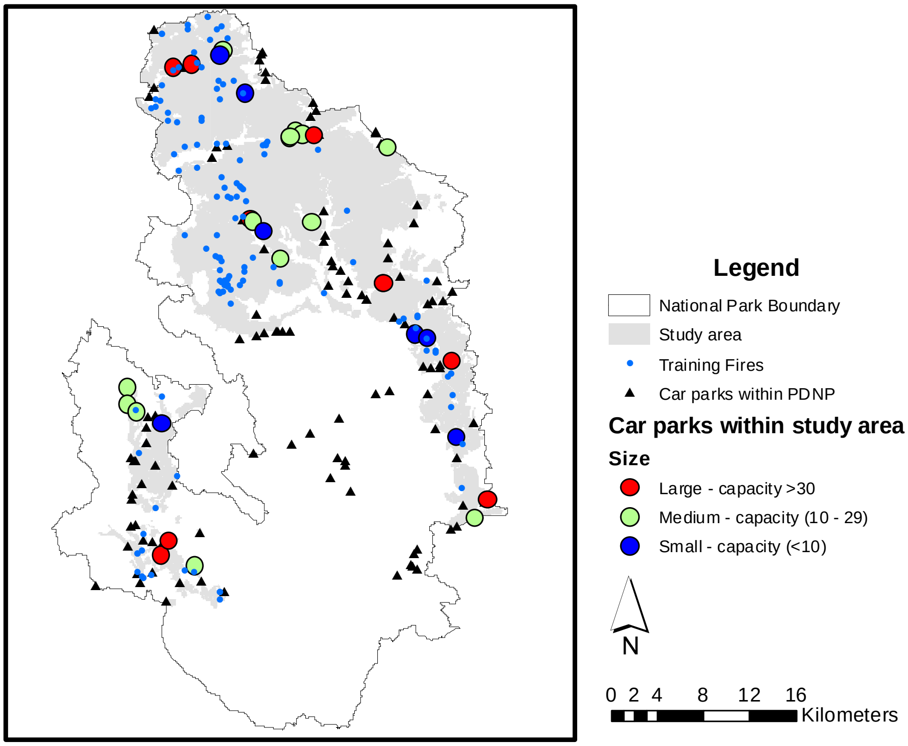
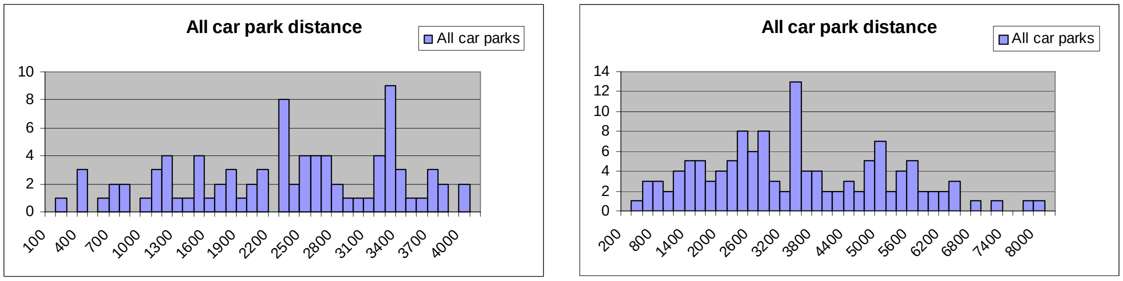


Figure 4.12: Car park locations in the PDNP and the sizes of car parks falling within the study area itself (training wildfires shown for reference)

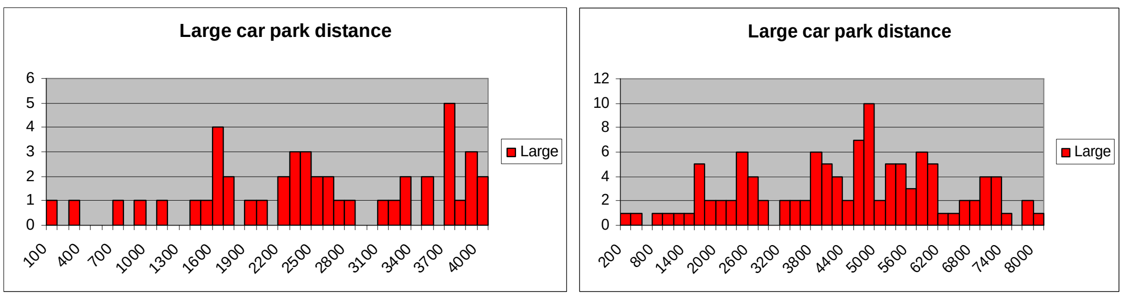
Given the perceived importance of car parks on wildfire distribution, the relationship between distance to car parks and wildfires was examined in a number of different ways. Initially, only car parks falling within the study area were considered. Distance decay graphs were generated for all car parks (Figure 4.13) and then for different car park sizes based on reported capacity (Figure 4.14). As can be seen from the Figures, there is no clear distance effect of car parks based on the empirical analysis, so it was not considered appropriate to include this layer. The distance decay data for small, medium and large car parks were also assessed statistically but no statistically significant differences were found.

One possible reason for a lack of clear distance decay for car parks might be the location of a number of car parks at the very edge of the study area which were not recorded as falling within the study area itself. However, consideration of the distance decay from all PDNP car parks for which information was available also showed no clear pattern using 100m or 200m distance classes (Figure 4.15) Once again, repeating the analysis with a training dataset with a wider spatial extent (i.e. not just wildfires within the study area) may reveal a different pattern. It should also be noted that the analysis carried out for the CCVE project also revealed no influence from car parks, although in that case only a subset of all PDNP car parks had been used.

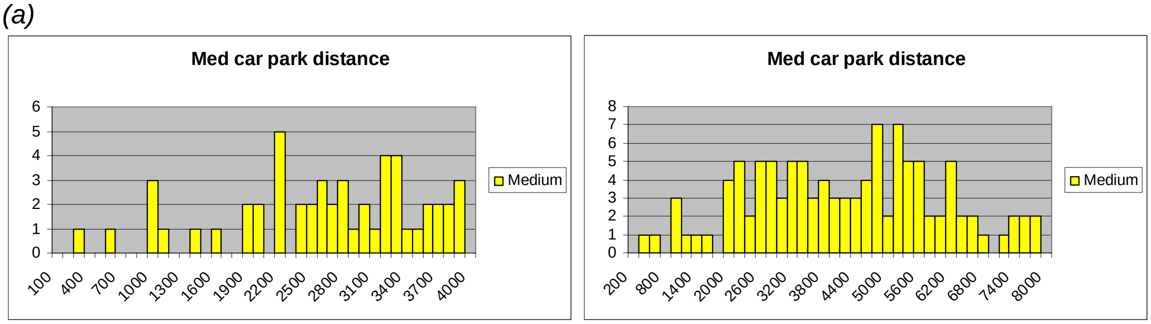


(a) 100 m distance classes *(b) 200 m distance classes*

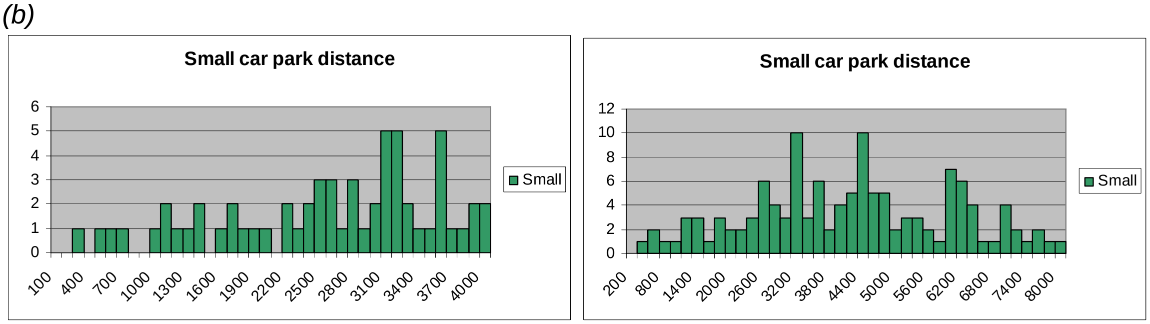
Figure 4.13 Frequency of wildfires within (a) 100m and (b) 200m distance classes from all car parks within the study area. Bin labels on distance axis refer to right-hand tick point.



(a)



(b)



(c)

Figure 4.14: Frequency of wildfires within 100m and 200m distance classes from different sized car parks within the study area – (a) large (capacity > 30 vehicles) (b) medium (capacity 10 – 29 vehicles) and (c) small (capacity <10 vehicles). For each pair of histograms, the left uses 100m distance classes and right uses 200 m classes. Bin labels on distance axis refer to right-hand tick point.

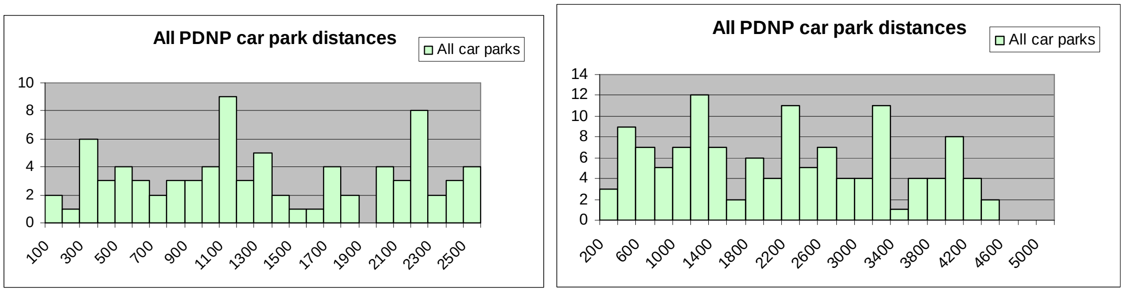


Figure 4.15: Frequency of wildfires within 100m and 200m distance classes using all PDNP car parks. Bin labels on distance axis refer to right-hand tick point.

4.5 Footpaths

The factors considered in sections 4.1 to 4.4 have largely dealt with access by vehicles, with access on foot being an indirect consequence of the need to use vehicles to initially reach areas to walk. The general consensus of the stakeholder workshop was that footpaths contributed 75% of the overall influence of human factors (although it must be stated that this was not universally agreed).

There was also discussion of the influence of path popularity, in that a higher number of users would be expected to be associated with a higher likelihood of wildfires. In the online survey, a high weighting was consistently given to the Pennine Way as the perceived most popular footpath in the PDNP. The analysis undertaken in this project aimed to build on the initial findings of the CCVE project which examined the influence of different path types (as indicated by Wayline attributes), and to extend this to include to the potential influence of *path popularity* on wildfire distribution.

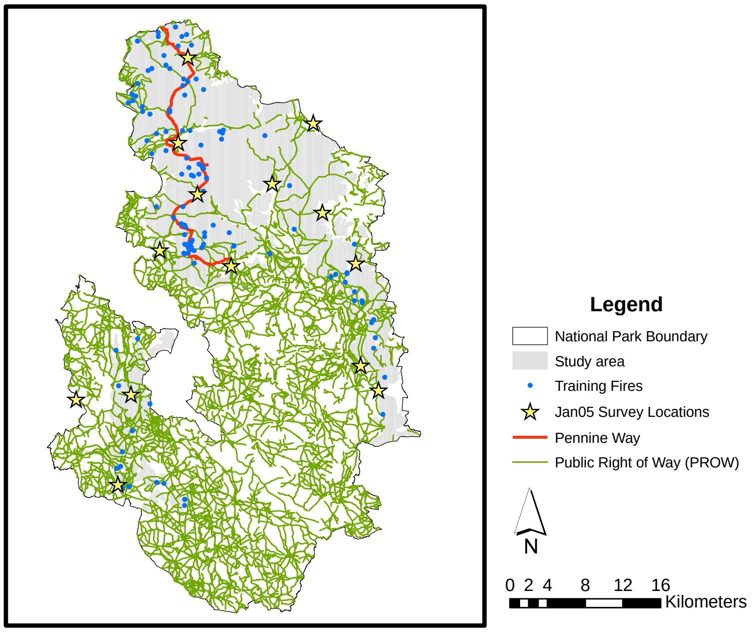


Figure 4.16: Locations of the Pennine Way and other PROWs in relation to training wildfires and visitor survey locations.

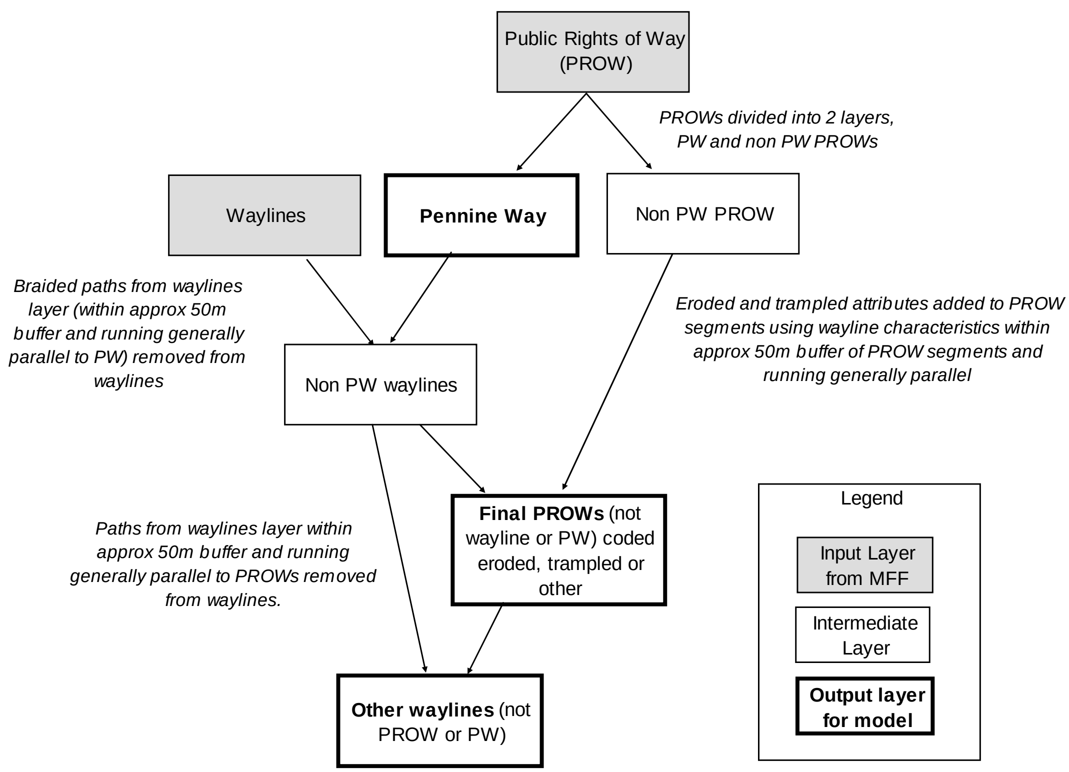
In order to assess path popularity, use was made of the MFF visitor surveys which are taken at key 'gateway' locations around the PDNP. Figure 4.16 shows the Public Right of Way (PROW) network, including the Pennine Way, and the locations of survey points during January 2005. The following sections report the work undertaken to prepare the initial path layers, to assess path popularity and to establish the nature of any relationships between distance to paths and wildfire frequency.

Path data were sourced to two key input data sets, Public Rights of Way (PROW) and Waylines. Each of these datasets was then reviewed in order to develop an appropriate layer for input into the spatial model. Figure 4.17 shows the processes undertaken to generate the three final path layers:

Pennine Way,

Final PROWs

Other Waylines.



4.17 Flow chart to illustrate the main processes undertaken to generate the final path layers

It was not possible to automate the entire process of allocating Wayline segments to PROWs and the Pennine Way. Allocation therefore made use of a two stage process of selecting line segments within 25m of PROWs and the Pennine Way and then reviewing the entire path layer to ensure that appropriate segments had been selected. PROW segments associated with Waylines were attributed as eroded, trampled or other according to the attributes of the associated Wayline (Figure 4.18). This was necessary in order to estimate popularity data for each of the line segments (see next section).

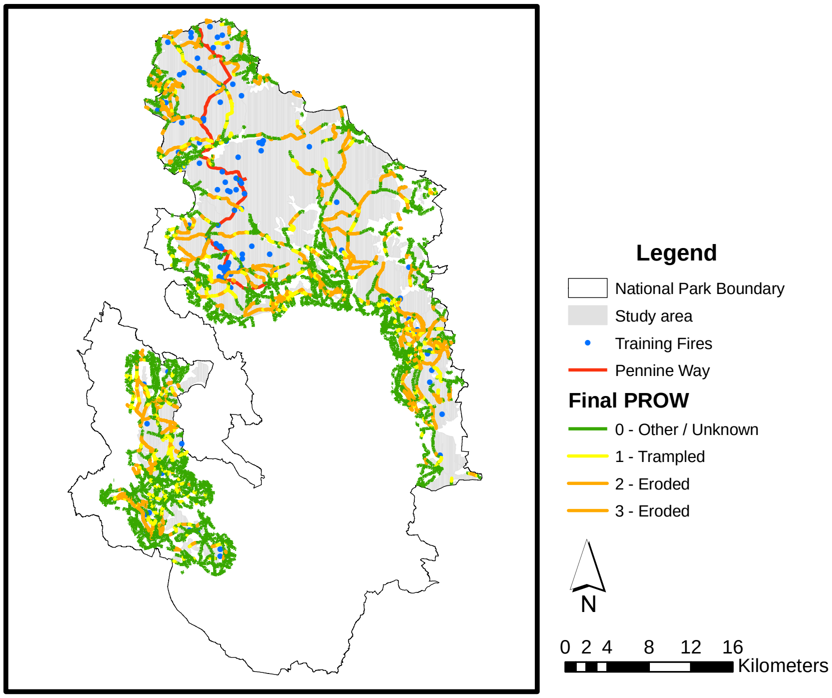


Figure 4.18: Final PROWs (i.e. not Pennine Way) layer classified as eroded, trampled or other/unknown.

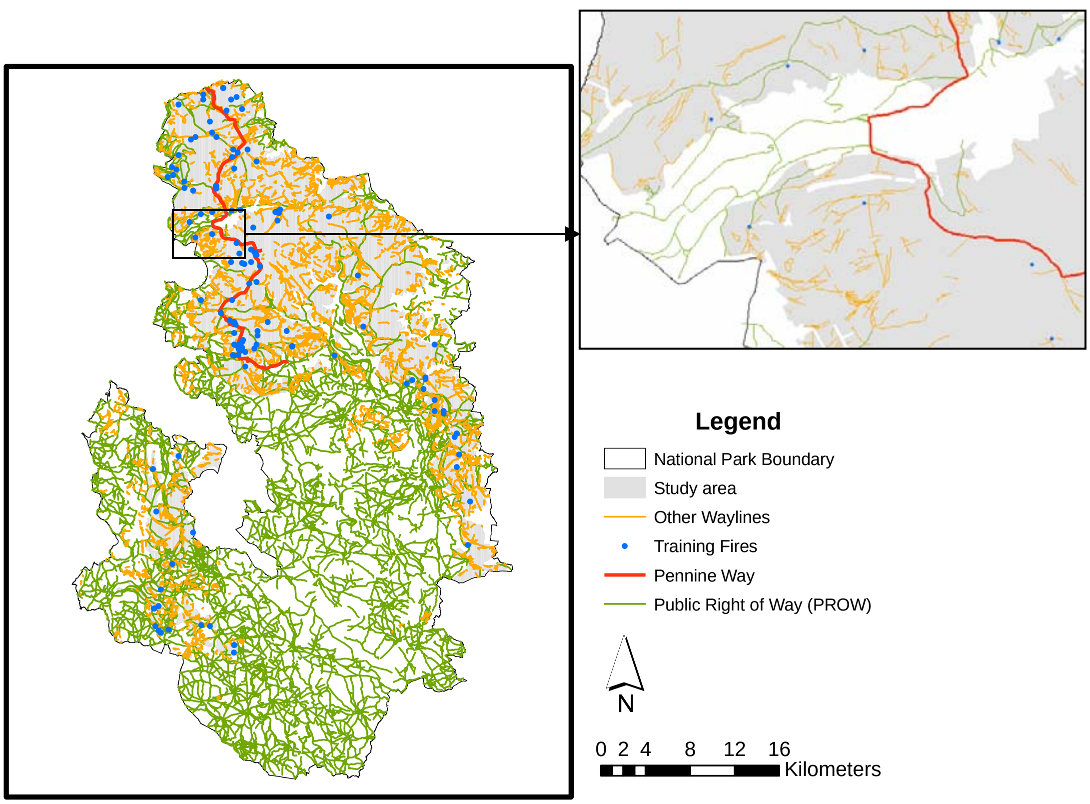
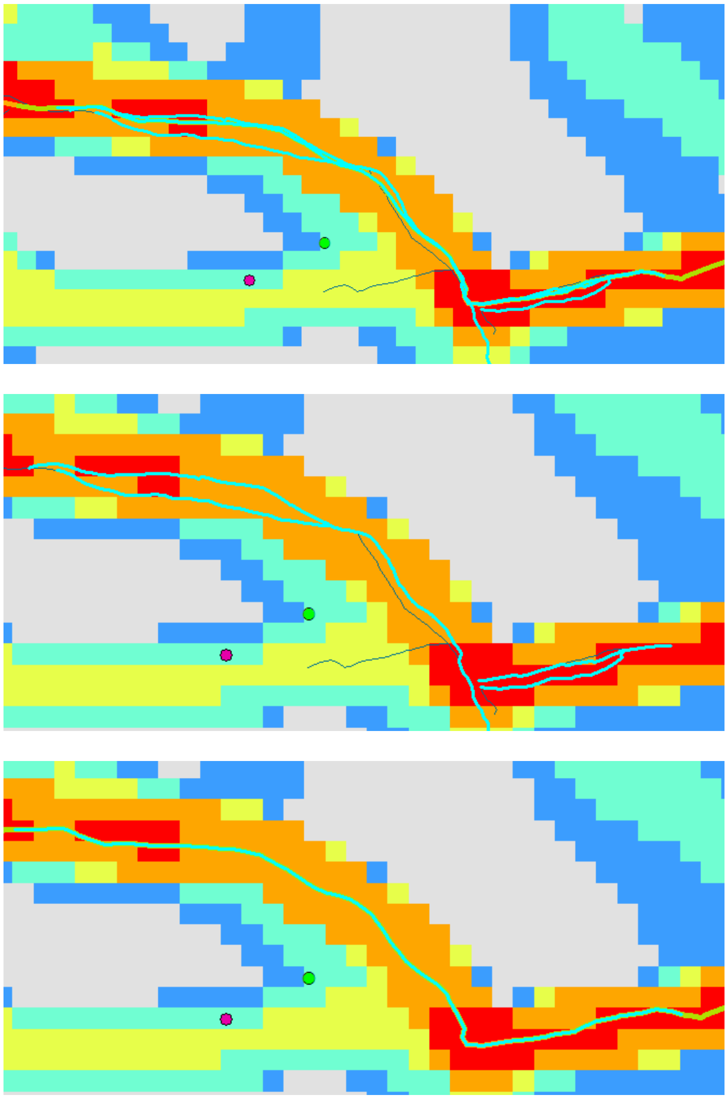


Figure 4.19: Pennine Way, Final PROWs (i.e. not Pennine Way) and Other Waylines (i.e. not PROW or Pennine Way).

Where individual Waylines were judged to be associated with a PROW (Pennine Way or other PROW) they were coded as PROW and a new Wayline layer generated for all non-PROW Waylines (Figure 4.19). A new layer was generated to avoid including the same paths multiple times due to the use of separate layers for each path type in the spatial model. Decisions about whether Waylines were PROW/Pennine Way or not were necessarily subjective, but used a general rule that Waylines more than approximately 50m of the Pennine Way or other PROWs were treated as a separate path, regardless of whether routes were parallel and/or subsequently rejoined the PW or PROW. Examples of some of the issues and final classifications are shown in Figures 4.20 and 4.21.



(a)

(b)

(c)

Figure 4.20: Example of the overlap between the Wayline dataset and PROW (Pennine Way only) dataset in the Bleaklow area. Underlying cells are 50m resolution. (a) both Pennine Way and Wayline datasets (b) just Wayline (eroded sections highlighted in cyan, trampled sections in dark green) and (c) just Pennine Way. The background layer is the path popularity results, discussed in section 3.

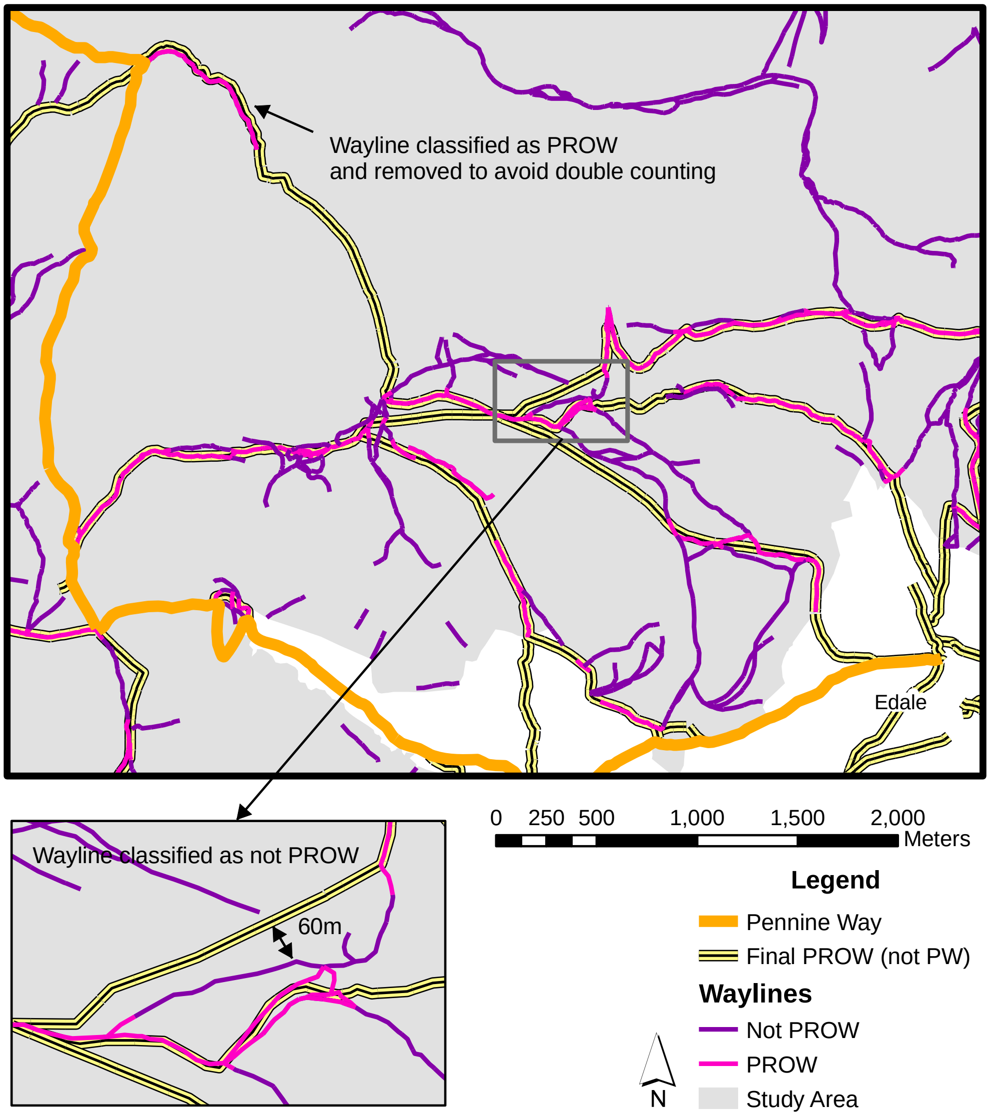


Figure 4.21: Classification of Waylines as either PROW or Not PROW. The marked example on the main map shows where Waylines have been classified as PROW due to being within an approximate 50m buffer of a PROW. The inset shows an example of a Wayline beyond that distance being classified as Not PROW.

Path Popularity

The estimation of path popularity for all of the path datasets was a relatively time-consuming task, but has generated a set of popularity estimates which can be taken as a reasonable initial indicator of the relative number of users associated with different parts of the path network.

The first task was to use the MFF visitor surveys to generate a data layer showing the relative popularity of different parts of the path network during 2004/5. Path popularity for individual segments of the path network was already available for August 2004. Routes from the January 2005 survey were digitized to generate an individual route for each survey respondent. A density function was then used to estimate the number of individual routes falling within a particular zone around each 50m resolution cell in a data layer covering the area surveyed. A small buffer distance was used in order to account for visitors generalizing their route in the 'draw your route' question of the visitor survey and in subsequent digitizing. This process generated a path popularity layer for January 2005. A density function was also used for August 2004, using the given path popularity field as a weighting function. Finally, the two layers for August 2004 and for January 2005 were summed using the Spatial Analyst Raster Calculator in order to generate a layer which would be representative of path popularity through a calendar year (Figure 4.22). It must be noted that the path popularity values themselves are *relative* measures and are not intended as an absolute measure of number of people. It is also important to note that there is some unavoidable spatial bias towards the initial survey points.

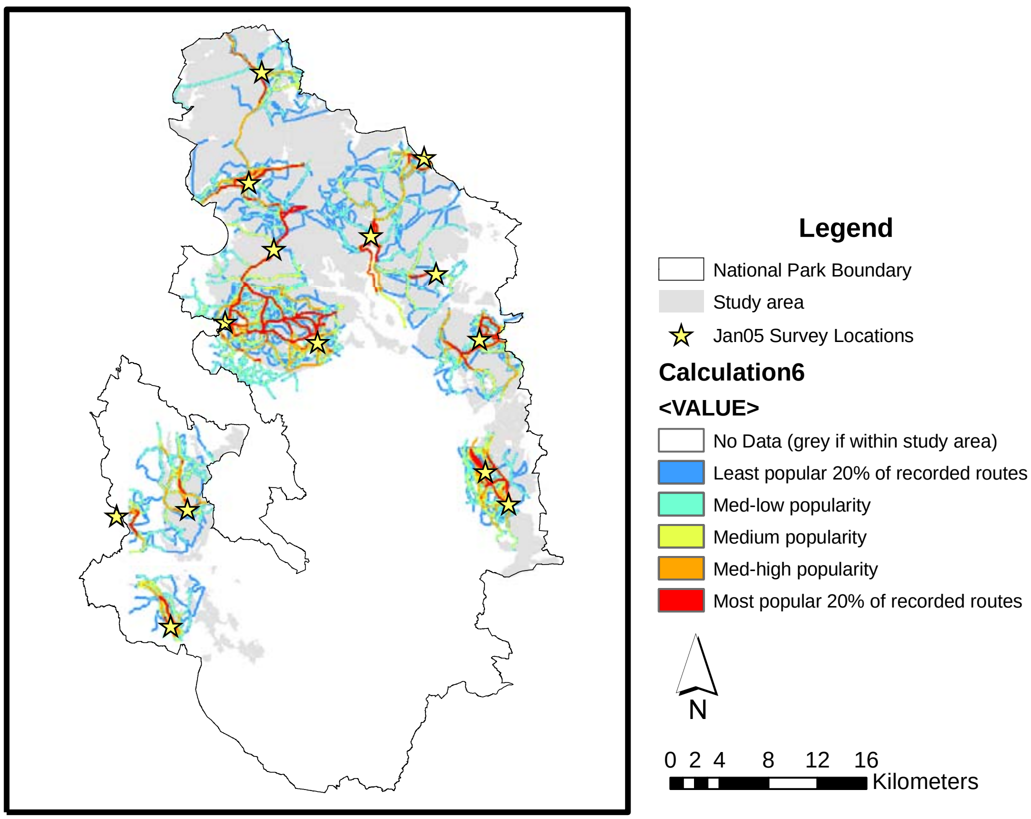


Figure 4.22: Relative popularity of routes recorded in the August 2004 and January 2005 visitor surveys.

The next stage was to attribute estimated relative popularity measures generated from MFF survey data to the individual path layers, Pennine Way, Final PROW and Other Wayline. To do this, a zonal extract function was used, which matches attributes from the (raster) cells in one layer to (vector) line-based segments of paths which cross individual cells in another. Since path segments varied in length in the original path layers, each path layer was overlaid with a 50m vector grid in order to generate path segments of approximately equivalent length. Mean popularity data for each segment could then be calculated.

For the Pennine Way, all but a very small proportion of segments were attributed a popularity value and subsequent class using this method. An average value was estimated for the few segments which did not appear to have any data from the Jan

2005 or Aug 2004 surveys, based on values for adjacent path segments (*i.e*. neighbouring parts of the Pennine Way). Final values were cross-checked in order to identify any seemingly artificial changes (e.g. sudden changes from high to low values over a short distance with no other footpaths in the vicinity).

For Final PROWs and Other Waylines there were proportionally more path segments without popularity data. Estimates of popularity for missing segments were based on a set of averages derived for paths of the same type with individual averages generated for segments classified as trampled, eroded and other (Table 4.1). In turn, these values could be assigned to parts of the network where it was known from Wayline attributes if a path was eroded or trampled, but where there was no information about popularity.

The mean values, although only relative, appear to be reasonable, since it would be expected that eroded paths would have a higher number of people using them compared to trampled paths, and that PROWs (even excluding the Pennine Way) would have higher popularity compared to Other Waylines.

Table 4.1 Average relative popularity values for PROWs and Other Waylines depending on whether segments are classed as trampled or eroded.

Type of Wayline	*Mean of segments classified as Trampled*	*Mean of segments classified as Eroded*	*Mean of segments classified as Other*
Final PROW (excluding Pennine Way)	58	104	61
Other Wayline	38	53	Not applicable

The final stage was to assign these average values to segments of the Final PROW and Other Wayline layers without specific popularity data. Final path popularity data for the Pennine Way and other PROWs are shown in Figure 4.23.

Once popularity data had been estimated for all segments in the three path layers, it was possible to determine the nature of any differences in the influence of distance from parts of the network with different levels of popularity on the frequency of wildfires. Each of the three path layers was divided into three classes of popularity: high, medium and low (Figure 4.24), based on the quantile classification approach which places an approximately equal number of segments into each class.

Unavoidably, for the Final PROW and Other Wayline layers, despite using the quantile approach, there were a disproportionately large number of segments in the medium class due to the use of average values. This made the determination of any difference between classes difficult, especially for the Other Wayline dataset, where the selection of high, medium and low popularity class boundaries had a particularly marked effect on the results. For this reason, the Other Wayline data were modelled as a single layer.

A set of distance decay graphs were then generated (Figures 4.25-4.26). For the Pennine Way and other PROWs, distance bands of 200m were selected as stakeholders felt that the influence of individual footpaths would be most pronounced within a narrow distance corridor of 100 to 200m.

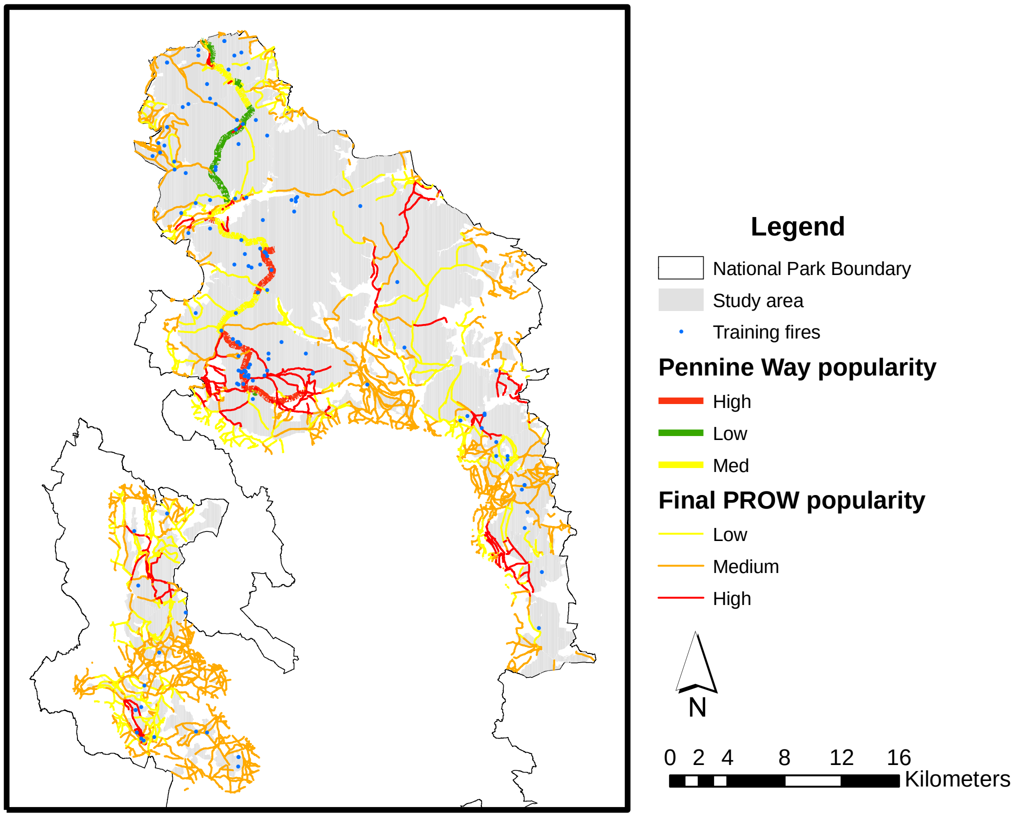
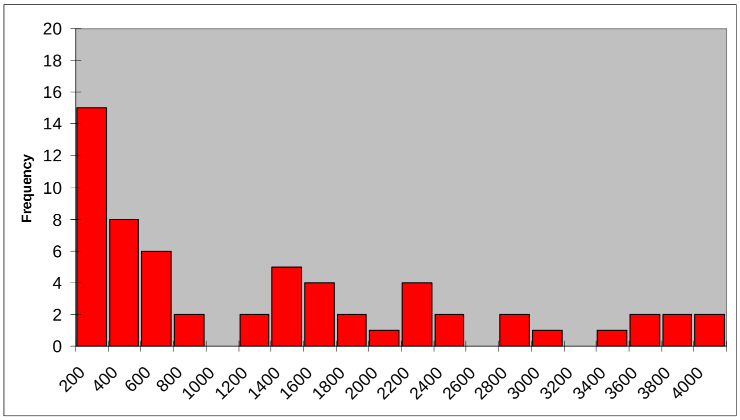


Figure 4.23: Estimated path popularity for the Pennine Way and other PROWs (Final PROW layer)

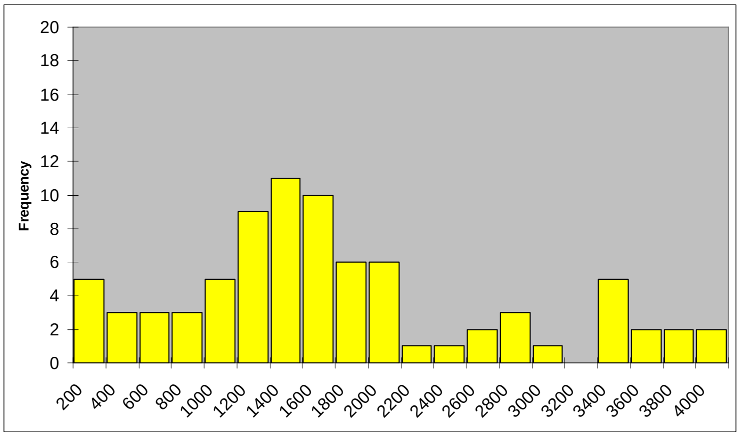
Figure 4.25 shows that only the most popular segments of the Pennine Way have any clear distance relationship with wildfire frequency. It was decided that these high popularity segments should be modelled as a distinct layer and that this layer should be attributed the weight value for the Pennine Way as identified in the stakeholder surveys and workshop exercises. Rather than omitting the medium and low popularity Pennine Way segments, these were instead merged with the Final PROW layer for the purposes of developing a model layer. The scores allocated to distance bands for the high popularity Pennine Way layer were as follows:

0-200 m = 10
200 – 400 m = 5
400- 600 m = 4
600 – 800 m = 2
> 800 m = 1

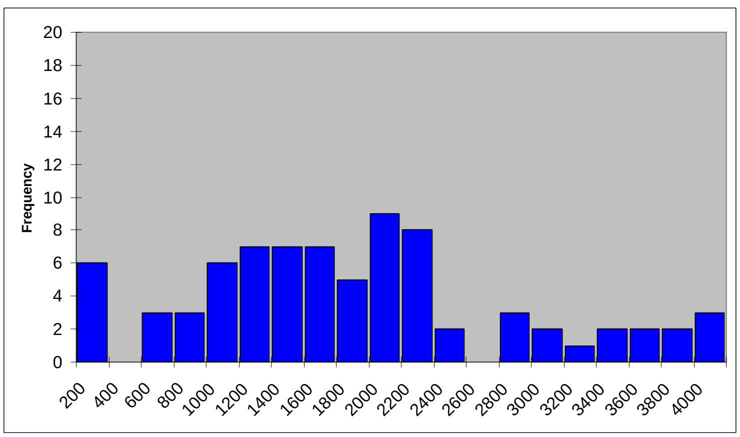
From views expressed at the workshop, stakeholders generally felt that the influence of the Pennine Way should be restricted to around 0.5km. Although the scoring system above extends the influence to a small degree, the majority of the influence will be seen within the 0-600m classes. An alternative that could be tested through future work would be to allocate a value of zero to distance bands beyond 600m. However, the overall influence of scores beyond 600m on final risk values is likely to be minimal.



(a) High popularity Pennine Way path segments

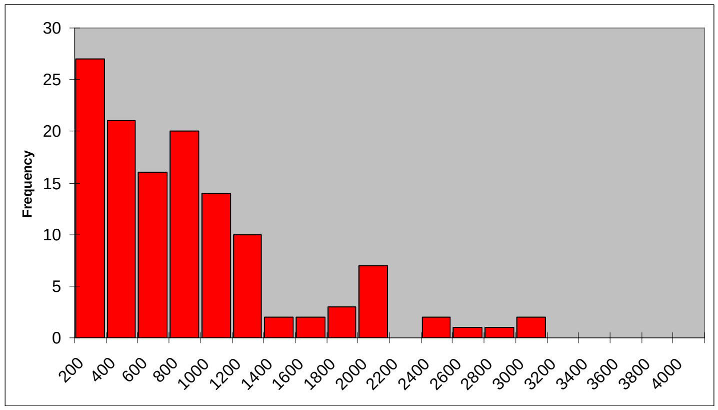


(b) Medium popularity Pennine Way path segments

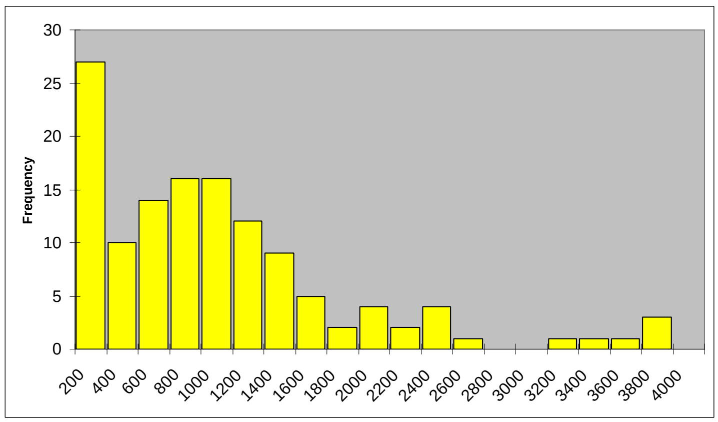


(c) Low popularity Pennine Way path segments

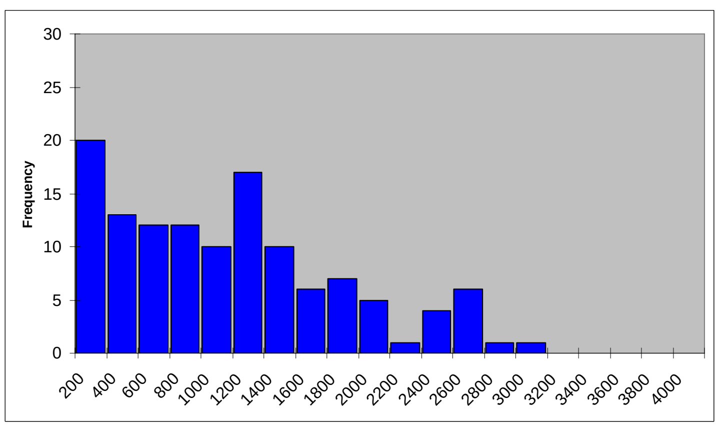
Figure 4.25: Frequency of wildfires within 200m distance classes from parts of the Pennine Way with different levels of popularity. Bin labels on distance axis refer to right-hand tick point.



(a) High popularity Final PROW path segments



(b) Medium popularity Final PROW path segments



(c) Low popularity Final PROW path segments

Figure 4.26: Frequency of wildfires within 200m distance classes from parts of other PROWs (associated with the Final PROW layer excluding the Pennine Way) with different levels of popularity. Bin labels on distance axis refer to right-hand tick point.

The relationships between distance to segments of the remaining PROW network associated with high, medium and low popularity and wildfire frequency are very similar (Figure 4.26). Arguably, parts of the PROW network associated with high and medium popularity exhibit a stronger distance decay influence, but this is not considered to be

very marked (the 0-200m distance class for high medium and low popularity segments are all associated with between 20 and 27 wildfires with few wildfires occurring beyond 2km).
Due to the similarities, all of the PROW paths have been modelled together (including medium and low popularity segments of the Pennine Way). Further work could explore the effects of different popularity classifications and explore the effect of modelling the high and medium popularity path segments separately from the low popularity segments

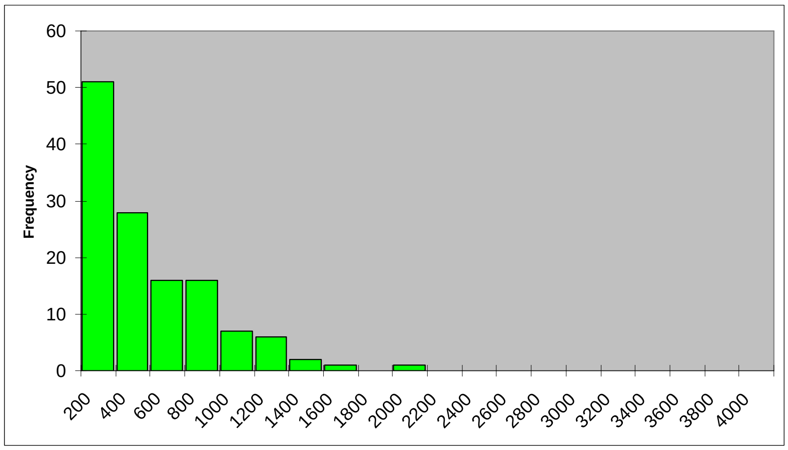


Figure 4.27 Frequency of wildfires within 200m distance classes from all other PROWs (associated with the Final PROW layer excluding the Pennine Way). Bin labels on distance axis refer to right-hand tick point.

The distance decay observed for all PROWs (excluding Pennine Way) is shown in Figure 4.27. From this the following scores were allocated:

0-200 m = 10
200-400 m = 5
400 – 800 m = 3
800-1400 m = 2
1400 – 2000 m = 1
> 2000 m = 0

Again, it is recognised that this scoring system has extended the influence of paths beyond what was considered ideal by stakeholders. However, as with the high popularity Pennine Way segments, most of the influence will be seen within a narrow corridor of the footpaths - in this case most of the influence is within the 0-400m distance bands. Given additional time, other distance bands might have been tested and further work could explore the impacts of different scoring criteria on the final risk maps.

It has been noted above that the Wayline data have been modelled as a separate layer without accounting for relative popularity due to the difficulties in generating appropriate popularity categories. The relationship between proximity to other Waylines and wildfire frequency is shown in Figure 4.28. Here a very pronounced influence was observed specifically within a narrow distance band immediately adjacent to footpaths. For this reason, 100m distance bands were used as the basis for the scoring system. Allocated scores, shown below, reflect the importance of the 0-100m distance bands, with most of the influence for this path type clearly within 300m. As with the other path layers, other scoring alternatives might have been explored but was restricted due to time constraints.

0-100 m = 10
100-300 m = 4
300 – 500 m = 2
500 – 1000 m = 1
> 1000 m - 0

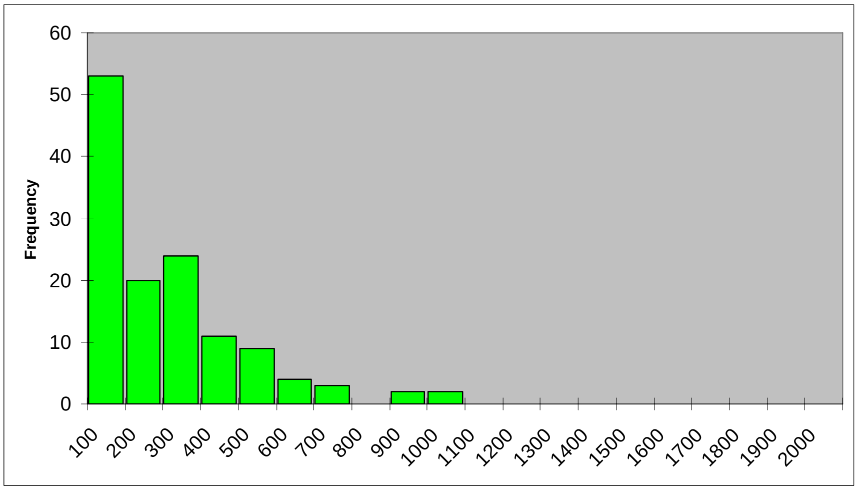


Figure 4.28: Frequency of wildfires within 100m distance classes from other Waylines (i.e. that are not associated with the PROWs or the Pennine Way). Bin labels on distance axis refer to right-hand tick point.

The final set of layers to include in the model are shown in Figures 4.29 - 4.31.

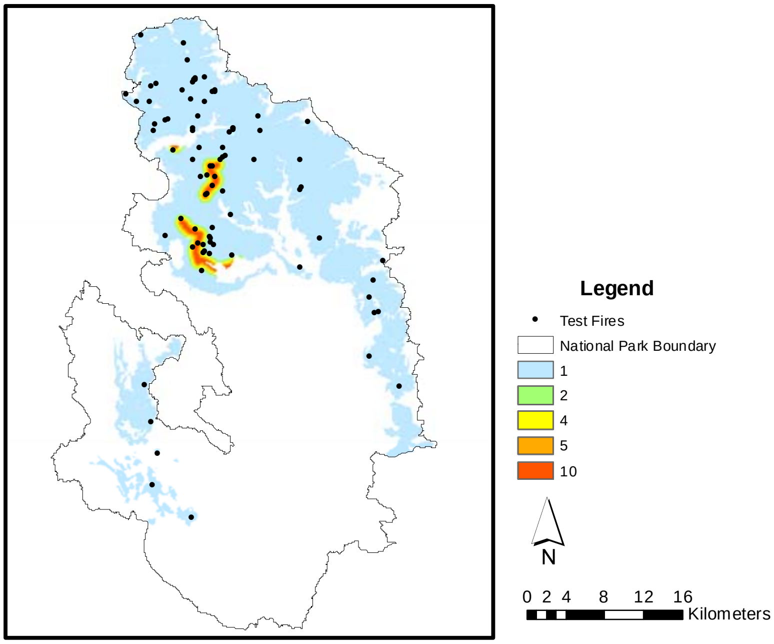


Figure 4.29: Final distance from high popularity Pennine Way segment scores used as an input in the spatial model (test wildfires shown for reference)

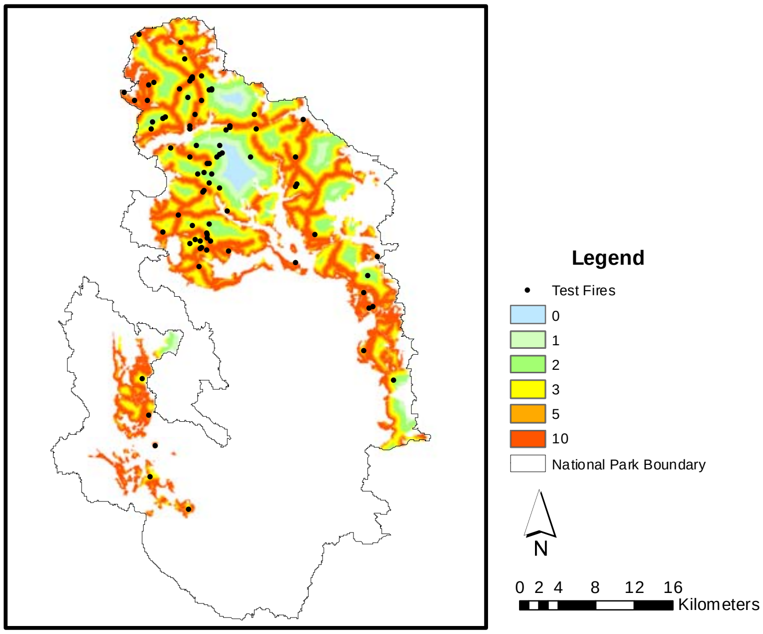


Figure 4.30 Final distance from PROW scores (including medium and low popularity sections of the Pennine Way) used as an input in the spatial model (test wildfires shown for reference)

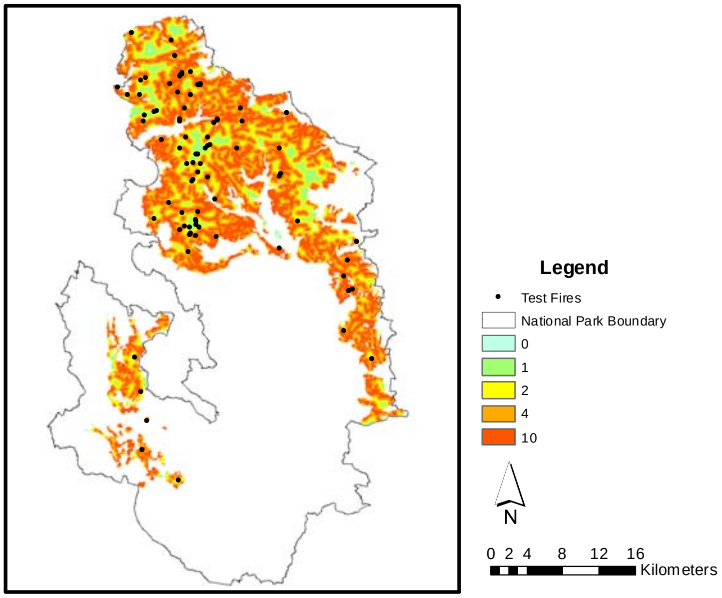


Figure 4.31 Final distance from Other Wayline scores used as an input in the spatial model (test wildfires shown for reference)

4.6 Other human factors

The only remaining human factor which has not been modelled has been Access Land. The overall weighting allocated to Access Land has been consistently small through the online survey and workshop weighting exercises, so the overall impacts on the spatial patterns of modelled wildfire risk is therefore considered to be minimal. Nevertheless, further work could explore the influence of Access Land in more detail.

5. Other physical factors

A climatic factor was included in the online survey as a result of the pilot study (Appendix 2, '7.2.4a'). It was not possible to include a climate layer in the analysis as no spatially distributed climate data exists at a suitable spatial resolution, or a sufficiently dense network of points from which to construct such layers.

The role of topography was discussed at the stakeholder workshop and covered in the online survey. The online survey rated topographic factors as the least important in accounting for the location of wildfires (Appendix 2, '7.2.4a'). Only 29% of respondents who answered this question regarded it as extremely important, compared to 57-64% for other factor groups. When asked to rank the groups of factors, three-quarters of respondents ranked it lowest. Most fires were regarded as occurring on south facing slopes in the highest areas, with aspect regarded as the most important topographic variable.

At the workshop, it emerged that that topography was regarded as important in terms of fire *spread* after ignition, but not as an indicator of where wildfires are ignited. Despite careful wording of questions in the online survey, it seems that respondents' answers may have been referring at least partially to the role of topography in helping fire to spread. Indeed, it was the factor in which they had the least confidence in their rating and ranking.

Because of the low ratings and rankings for topography and time constraints, topography has not been included in the model. The findings of the weighting exercise discussed in the next section suggest that all topographic effects should be allocated only 5% of the total weights (compared with 73% human factors and 22% land cover factors), so this is unlikely to have had a major impact on the results. Nevertheless, it would be useful to carry out further work on aspect and other topographic factors

6. Results and discussion

6.1 Weighting results

The weighting results for the online survey were presented in section 2.4. As well as inconsistency between the rating and ranking methods there was also a wide degree of variation in the responses about some of the factors and factor groups. This is not unexpected when conducting a survey of this type involving input from a range of stakeholders with expertise in different areas (in terms of themes and geographical areas). Indeed, an interesting follow up study would be to survey a larger number of stakeholders, perhaps from different regions and including members of the public to help establish differences in views and the potential reasons for differences. However differences in views (see results in Appendix 1) do make establishing a set of preferred weights more difficult. For this reason, particular emphasis has been given to weights generated from the stakeholder workshop instead of the online survey.

Estimated weights derived from the stakeholder workshop are shown in Tables 6.1 – 6.5. These weights were used as the basis for the initial weighting scheme for the model runs. It should be noted that even at the stakeholder workshop there was not universal support for the final set of scores generated. Disagreement was particularly marked in relation to the balance of weights to be allocated to foot and car access factors (and even whether such a differentiation was useful). For this reason, alternative weightings for the foot and car access group layers have been included as well as variations in the weightings for habitat layers.

Furthermore, some modification to the weights were required in the light of the results of the empirical analysis undertaken (sections 3-5). A combination of assessing the weights from all three methods and the empirical analysis also helped in establishing the final group of layers to model (Figures 2.2 and 2.3). It is recognised that some subjective decision-making has influenced the derivation of a final set of layers and weights to be tested. However, it is considered that decisions have been consistent with views expressed throughout the various stages of the programme of work and provide a reasonable balance between the results of the analysis of stakeholder views and the findings of the empirical data analysis, given the time and resource constraints of the project.

Table 6.1: Results of stakeholder factor weighting for car access

Factor/Layer	*Estimated Layer weights*
Distance to roads	4%
Distance to other car access	13%
Distance to car parks	25%
Distance to settlements	59%

Table 6.2: Results of stakeholder factor weighting for foot access

Factor/Layer	*Estimated Layer weights*
Distance to Pennine Way (PW)	46%
Distance to other footpaths (FP)	11%
Access Land	5%
Major	34%
Minor	5%

Table 6.3: Results of stakeholder factor weighting for topographic factors

Factor/Layer	*Estimated Layer weights*
Slope	19%
Aspect	17%
Elevation	63%

Table 6.4: Results of stakeholder factor weighting for factor groups

Factor/Layer	*Estimated Layer weights*
Topography	5%
Land cover	22%
Humans	73%

Table 6.5: Results of stakeholder factor weighting for foot versus car access

Factor/Layer	*Estimated Layer weights*
Car	25%
Foot	75%

6.1 Models tested

Sections 3 to 5 explained the selection and construction of the data layers which were used to build the wildfire spatial risk models. Stakeholder weights have been presented in section 6.1 above. Since some of the original layers were omitted after empirical analysis, it was necessary to revise the initial weighting scheme. A final set of stakeholder weights were calculated by redistributing the weights for omitted layers. The results are shown in Table 6.6.

Table 6.6 New factor group and layer weightings used in the Model 'A' runs

Factor	***Main Factor Group and original weighting***	***Main Factor Group and new weighting***	***Factor subgroup and original weighting***	***Factor subgroup and new weighting***	***Original layer weight***	***New layer weight***
Distance to settlements (Dist_settle)	Human 73%	Human 77%	Car access 25%	Car access 25%	59%	82%
Distance to minor roads (Dist_minor)	Human 73%	Human 77%	Car access 25%	Car access 25%	13%	18%
Distance to high popularity sections of the Pennine Way (Dist_hiPW)	Human 73%	Human 77%	Foot access 75%	Foot access 75%	46 (all Pennine Way)	48%
Distance to other PROWs (including medium and low popularity sections of the Pennine Way_(Dist_PROW)	Human 73%	Human 77%	Foot access 75%	Foot access 75%	34% (major)	35%
Distance to Other Waylines (Dist_way)	Human 73%	Human 77%	Foot access 75%	Foot access 75%	16%	17%
Habitat (various versions)	Physical 22%	Physical 23%	NA	NA	100%	100%

A number of model runs were carried out using:

- different *habitat layer variants* to produce model numbers 1 to 6. Those chosen were 36, 18 and 6 class variants with various buffers (section 3.3).
- different *weighting schemes* for factors, indicated by run letters A to G.

Six combinations of the habitat layer were used based on the sensitivity analysis in section 3. Lack of time did not allow all combinations of habitat classes and buffers to be modelled and tested. It was considered more important to vary the weighting of layers. Again, it was not possible to test every variation. In view of the lack of consensus on the relative importance of foot *versus* car access, two variations of the foot and car access weights have also been used with the best model(s) from previous runs (Table 6.2 and Appendix 4). In all, eight runs were used. Seven are presented here (variant B is omitted):

- A: adjusted weightings in table 6.6, human 77%, physical 23% (models 1A to 6A)
- C: human 50%, physical 50% (models 1C to 6C)
- D: human 60%, physical 40% (models 1D and 2D)
- E: human 77%, physical 23%, but with 25% foot, 75% car access (model 2E)
- F: human 77%, physical 23%, but with 50% foot, 50% car access (model 2F)
- G: human 50%, physical 50%, but with 25% foot, 75% car access (model 2G)
- H: human 50%, physical 50%,%, but with 50% foot, 50% car access (model 2H)

Open water areas were set to zero in the final risk maps using the open water category from the 36 class ESA habitat map.

Table 6.7: Description of the models used. Filenames used during spatial analysis are in brackets

Model	***Weights***	***Layers***					
1A	As in Table 6.6	Dist_settle (0.158)	Dist_minor (0.035)	Dist_hiPW (0.277)	Dist_PROW (0.202)	Dist_way (0.098)	Habitat 36 pt (0.23)
2A	As Table 6.6	Dist_settle (0.158)	Dist_minor (0.035)	Dist_hiPW (0.277)	Dist_PROW (0.202)	Dist_way (0.098)	Habitat 18 pt (0.23)
3A	As Table 6.6	Dist_settle (0.158)	Dist_minor (0.035)	Dist_hiPW (0.277)	Dist_PROW (0.202)	Dist_way (0.098)	Habitat 36 200m buffer (0.23)
4A	As Table 6.6	Dist_settle (0.158)	Dist_minor (0.035)	Dist_hiPW (0.277)	Dist_PROW (0.202)	Dist_way (0.098)	Habitat 18 200m buffer (0.23)
5A	As Table 6.6	Dist_settle (0.158)	Dist_minor (0.035)	Dist_hiPW (0.277)	Dist_PROW (0.202)	Dist_way (0.098)	Habitat 18 100m buffer (0.23)
6A	As Table 6.6	Dist_settle (0.158)	Dist_minor (0.035)	Dist_hiPW (0.277)	Dist_PROW (0.202)	Dist_way (0.098)	Habitat 6 pt (0.23)
1C (1h50)	Based on 50% habitat	Dist_settle (0.103)	Dist_minor (0.023)	Dist_hiPW (0.18)	Dist_PROW (0.131)	Dist_way (0.064)	Habitat 36 pt (0.50)
2C (2h50)	Based on 50% habitat	Dist_settle (0.103)	Dist_minor (0.023)	Dist_hiPW (0.18)	Dist_PROW (0.131)	Dist_way (0.064)	Habitat 18 pt (0.50)
3C (3h50)	Based on 50% habitat	Dist_settle (0.103)	Dist_minor (0.023)	Dist_hiPW (0.18)	Dist_PROW (0.131)	Dist_way (0.064)	Habitat 36 200m buffer

							(0.50)
4C (4h50)	Based on 50% habitat	Dist_settle (0.103)	Dist_minor (0.023)	Dist_hiPW (0.18)	Dist_PROW (0.131)	Dist_way (0.064)	Habitat 18 200m buffer (0.50)
5C (5h50)	Based on 50% habitat	Dist_settle (0.103)	Dist_minor (0.023)	Dist_hiPW (0.18)	Dist_PROW (0.131)	Dist_way (0.064)	Habitat 18 100m buffer (0.50)
6C (6h50)	Based on 50% habitat	Dist_settle (0.103)	Dist_minor (0.023)	Dist_hiPW (0.18)	Dist_PROW (0.131)	Dist_way (0.064)	Habitat 6 pt (0.50)
1D (1h40)	Based on 40% habitat	Dist_settle (0.123)	Dist_minor (0.027)	Dist_hiPW (0.216)	Dist_PROW (0.158)	Dist_way (0.077)	Habitat 36 pt (0.40)
2D (2h40)	Based on 40% habitat	Dist_settle (0.123)	Dist_minor (0.027)	Dist_hiPW (0.216)	Dist_PROW (0.158)	Dist_way (0.077)	Habitat 18 pt (0.40)
2E	As Table 6.1 but with 25%/75% foot/car access	Dist_settle (0.474)	Dist_minor (0.104)	Dist_hiPW (0.092)	Dist_PROW (0.067)	Dist_way (0.032)	Habitat 18 pt (0.23)
2F	As Table 6.1 but with 50%/50% foot/car access	Dist_settle (0.316)	Dist_minor (0.069)	Dist_hiPW (0.185)	Dist_PROW (0.135)	Dist_way (0.065)	Habitat 18 pt (0.23)
2G (2eh5 0)	25%/75% foot/car access and 50% habitat	Dist_settle (0.308)	Dist_minor (0.068)	Dist_hiPW (0.06)	Dist_PROW (0.044)	Dist_way (0.021)	Habitat 18 pt (0.50)
2H (2fall5 0)	50%/50% foot/car access and 50% habitat	Dist_settle (0.205)	Dist_minor (0.045)	Dist_hiPW (0.12)	Dist_PROW (0.088)	Dist_way (0.043)	Habitat 18 pt (0.50)

6.2 Statistical test results

Results are presented in table 6.8 and the significance values for models which perform best are indicated in bold. Statistically, the best models are those for which there is a good fit between final risk scores for the training and test fire sets. This indicated by a high Mann Whitney significance, since we wish to accept the null hypothesis that training and test fire scores distributions are not significantly different (section 2.8). It is also desirable that the means of the two distributions are as high as possible, since it is already known that wildfires have occurred at these locations.

Table 6.8: Results of Mann-Whitney testing. Higher significance values indicate better agreement between training and test distributions (section 2.8). Higher means preferred.

Model	***Habitat layer variant***	***Human: physical factor group weighting***	***Foot: car access weighting***	***Mann Whitney significance***	***Training mean***	***Test mean***	***Figure***
Model 1A	Pt, 36 class	77:23	75:25	0.269	5.34	5.16	6.2a
Model 2A	Pt, 18 class	77:23	75:25	0.462	5.42	5.29	6.3a
Model 3A	200m, 36 class	77:23	75:25	0.238	5.27	5.08	
Model 4A	200m, 18 class	77:23	75:25	0.464	5.30	5.17	
Model 5A	100m, 18 class	77:23	75:25	0.453	5.31	5.17	
Model 6A	Pt, 6 class	77:23	75:25	0.480	5.31	5.18	
Model 1C	Pt, 36 class	50:50	75:25	**<u>0.989</u>**	5.40	5.39	6.1a, 6.2a
Model 2C	Pt, 18 class	50:50	75:25	**0.673**	5.59	5.69	6.3c
Model 3C	200m, 36 class	50:50	75:25	**0.842**	5.26	5.22	
Model 4C	200m, 18 class	50:50	75:25	0.606	5.33	5.41	
Model 5C	100m, 18 class	50:50	75:25	0.607	5.34	5.43	
Model 6C	Pt, 6 class	50:50	75:25	0.604	5.35	5.44	
Model 1D	Pt, 36 class	60:40	75:25	**0.741**	5.38	5.3	
Model 2D	Pt, 18 class	60:40	75:25	**0.931**	5.52	5.54	
Model 2E	Pt, 18 class	77:23	25:75	0.169	6.86	6.76	6,3b
Model 2F	Pt, 18 class	77:23	50:50	0.346	6.14	6.03	
Model 2G	Pt, 18 class	50:50	25:75	**<u>0.944</u>**	**6.52**	**6.64**	6.1b, 6.3d
Model 2H	Pt, 18 class	50:50	50:50	**0.804**	6.05	6.16	

The best models result from runs C, D, G and H, that is consistently those where the physical factor (habitat) has more weight than the 27% suggested by stakeholders (and adjusted to 23% when topographic factors were omitted (Table 6.1)). A heavier weighting for habitat seems to be more important than the habitat variant or the weighting between foot and car access.

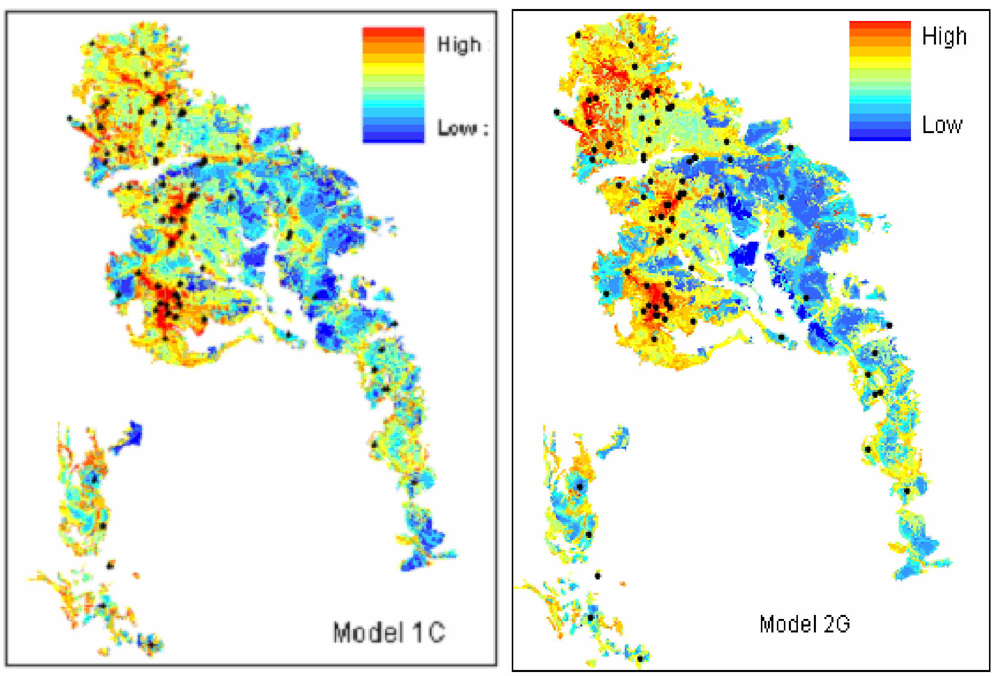
Performance was best when a 50:50 human: physical weighting was used with point data for 36 habitat classes (model 1C), and with point data for 18 habitat classes and 25:75 weighting in favour of car access (model 2G). Model 2G also had the highest mean scores.

Statistical testing does not take spatial anomalies into account. Therefore, both maps are presented and provided in digital form\t to allow stakeholders to make the final choice.

6.2 Interpreting the final maps

Map display

Figure 6.1 shows the best two models from statistical testing, models 1C and 2G. A palette different from the CCVE maps has deliberately been used. The digital data is supplied separately for these two maps so that the palette can be customized (section 2.9). A palette can be devised which divides the map into three classes (as suggested by stakeholders) or into more classes. Classification and palette choice can be carried out separately for each FRS or other area by first clipping out its spatial extent.



(a) *(b)*

Figure 6.1: Statistically best models for risk of reported wild fire, (a) Model 1C: 36 point data habitat classes, adjusted stakeholder weights as in table 6.6 (human 77%: physical 23% and foot 75%: car 25%), Mann Whitney significance 0.989, test mean 5.39; (b) Model 2G: 18 point data habitat classes, human 50%: physical 50% and foot 25%: car 75%, Mann Whitney significance 0.944, test mean 6.64. Test wildfires are shown as black dots.

Pattern of risk

The models show higher risk for the western moorlands, especially in the Dark Peak, near the Pennine Way and on areas of eroding peat. It emphasises the feedback between fire risk and visitor pressure. The two largest areas of very high risk are the Bleaklow plateau, between Snake Pass and Longdendale, and Kinder Scout, in a triangle between Edale, Hayfield and Chinley. Two other areas of high risk are found farther north at Featherbed Moss, near Chew Reservoir, and where the Pennine Way crosses Wessenden Moor.

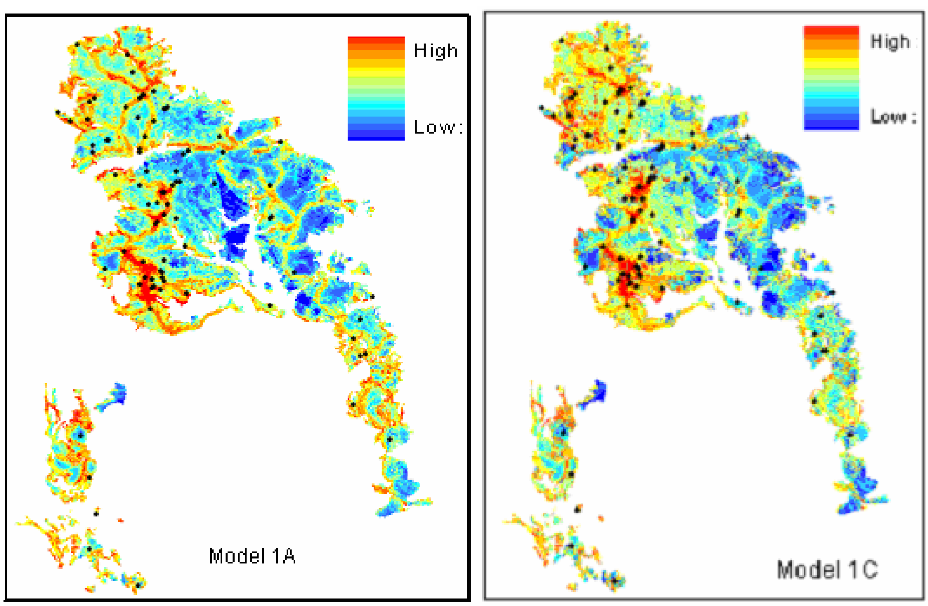
The southeastern and eastern moors, where much managed heather grouse moor is found, have lower risk of reported wildfires. The pattern, by definition, reflects the scoring and weighting of the layers, in which higher risk is assigned to eroding moorland and areas close to paths, and lower risk to heather habitats.

Effect of varying human-physical factor weighting

Both the two statistically best models, 1C and 2G, used a higher weight for habitat factors than the (adjusted) weights recommended by stakeholders, *i.e.* 50:50 instead of 77:23. As already observed, human-physical weighting is the dominant control on the statistical significance of the risk maps and the proportion of the area which is high risk. Increasing the weight of the physical (habitat) factor keeping all other settings constant produces a statistically better model. This can be seen by comparing models 1A, 1D and 1C, which used point data for 36 habitat classes. It was less clear-cut for 2A, 2D and 2C based on point data for 18 habitat classes:

Human: Physical weight	*77:23*	*60:40*	*50:50*
	Model 1A 0.269	Model 1D 0.741	Model 1C 0.989
	Model 2A 0.462	Model 2D 0.931	Model 2C 0.673

[Figures are the Mann Whitney significance from Table 6.8.]

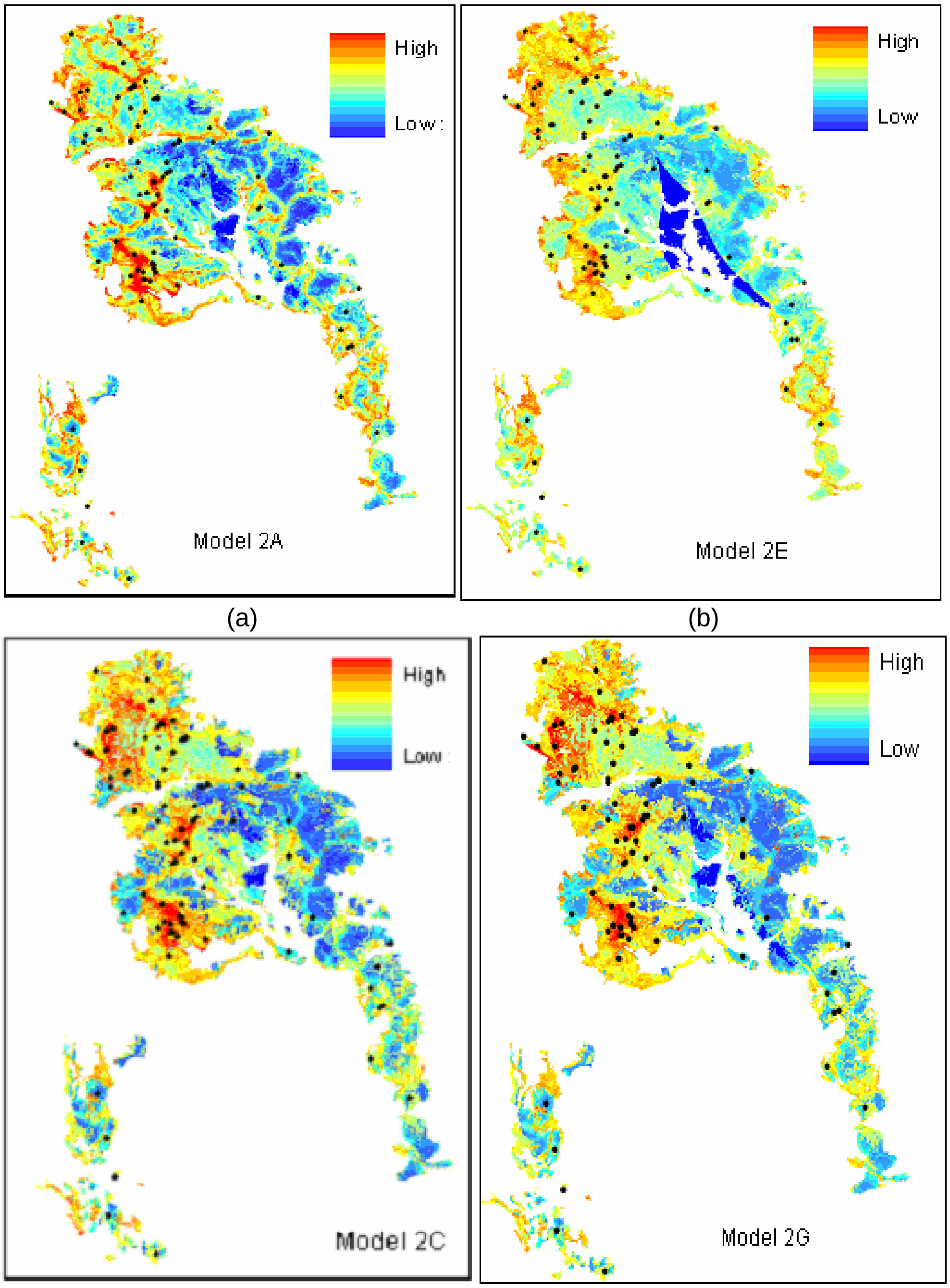


(a) (b)

Figure 6.2: Comparison of the effect of different human to physical factor weighting. (a) Model 1A: adjusted stakeholder weighting (human 77%, physical 23%); (b) Model 1C: human 50%, physical 50%. Both use point data for 36 habitat classes and weight and foot: car access 75:25. Test wildfires are shown as black dots.

The spatial effect, as expected, was to lessen the concentration of high risk around access lines (Fig 6.2). More of the area became high risk and the mean risk score was increased when habitat was weighted more strongly.

Effect of foot: car access weighting



(c) (d)

Figure 6.3: Comparison of the effect of foot to car access weighting. (a) and (c): foot access 75%, car access 25%. (b) and (d): foot access 25%, car access 75%. (a) and (b) use adjusted stakeholder weighting (human 77%, physical 23%). (c) and (d) use human 50%, physical 50%. All use point data for 18 habitat classes. Test wildfires are shown as black dots.

Results were equivocal; the effect depended on how strongly human factors were weighted. For models where human factors were weighted 77%, statistical significance improved as foot access was decreased in favour of car access. The opposite was true for models with 50% human factor weighting:

Foot: car access weights	*75:25*	*50:50*	*25:75*
Human 77%, physical 23%	Model 2A 0.462	Model 2F 0.346	Model 2E 0.169
Human 50%, physical 50%	Model 2C 0.673	Model 2H 0.804	Model 2G 0.944

[Figures are the Mann Whitney significance from Table 6.8]

As would be expected, spatial effects were more marked for models in which human factors dominated (2a and 2E, Figures 6.3a and b), whereas little change is seen between Figure 6.3c and d. Greater emphasis on car access (roads, settlements) in Figure 6.3b reduced risk around paths and concentrated low risk in a central wedge, farthest from major towns. This map had the poorest fit of all those tested. However, we cannot conclude from this that car access is less important than foot access in causing wildfire because the second strongest model favoured car access (Model 2G, Fig 6.3c and Fig 6.1b). A more clear-cut picture may emerge if the fire database allowed malicious and accidental fires to be modelled separately, since stakeholders felt that arson was associated with (quiet) roads. Other socio-economic factors within settlement need to be investigated.

Effect of habitat variants

Results were similarly equivocal, again depending on how human and physical factors were weighted. For models where human factors were dominant, best results were obtained with fewer habitat classes. The opposite was true for models with equal weighting of human and physical factors:

No. of habitat classes, point data	*36*	*18*	*6*
Human 77%, physical 23%	Model 1A 0.269	Model 2A 0.462	Model 6A 0.480
Human 50%, physical 50%	Model 1C 0.989	Model 2C 0.673	Model 6C 0.604

[Figures are the Mann Whitney significance from table 6.8]

The spatial effect of class number is again most marked when habitat has a higher weighting, as can be seen if Model 1C (36 classes point data, Figure 6.1a and 6.2b) is compared with Model 2C (18 classes point data, Figure 6.3c). The high risk areas north of Longdendale are more pronounced with 18 classes and the moors east of Howden and Ladybower reservoirs are a slightly lower risk.

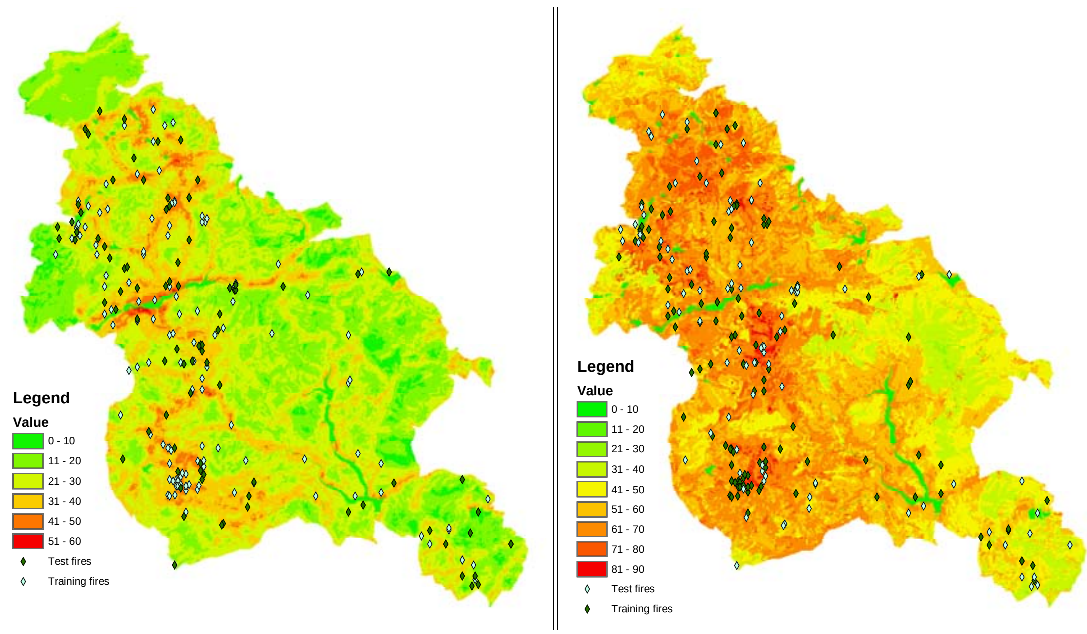
There was no clear trend for the effect of positional accuracy (points versus buffers) for any of the models.

Comparison to CCVE maps

The CCVE report presented a protocol for mapping fire risk, which was illustrated with two extremes (Figure 6.4). Many other variants were produced, which more closely resembled those in this report. The two sets of maps are not directly comparable due to differences in spatial coverage and the layers, scoring methods and weighting used.

The most obvious reason for differences is the spatial coverage. CCVE maps covered only the Dark Peak and included an area in the extreme north, near Marsden, where Wayline data was missing. The present models are restricted to section 3 moorlands and where all the input data layers are available. They therefore omit the area north of Marsden and represent the combined situation for quite contrasting areas of the PDNP, from the Dark Peak to the Southwest Peak. It is likely that separate models for different areas of the park would produce better results. This would be possible for the Dark Peak (as for CCVE, but using the improved methods presented here), however, the fire database is currently is not large enough to allow this for other areas.

The CCVE models used two methods of scoring access layers and two variants of the habitat map. This report adopted the frequency-weighted distance decay method in Fig 6.4a, which concentrates risk more tightly around access lines, and the habitat method shown in Figure 6.4b. Therefore, the models presented here (Fig 6.1) lie between these two CCVE extremes.



(a) *(b)*

Figure 6.4: Two of the fire risk maps produced for CCVE (McMorrow et al, 2006a). (a) used a method similar to that in this report to assign scores for the access layers (Pennine Way, other paths, roads) and weights physical factors as 37% (equally shared between habitat and aspect. (b) used linear distance decay for access layers and weights physical factors as 55% (Habitat 44%, aspect 11%). Neither map used car parks or Access Land

6.5 Summary of recommendations

This section includes recommendations under five headings:

- The management section includes recommendations for applying the model.
- The next three headings suggest specific actions and further work for improving the model.
- The last section recommends strategic actions at a national and local level.

Management

1. Preparing the risk map for operational use. It is recommended that the final category breaks are generated from the digital risk maps with a view to management as well as aesthetic considerations. For example, this may take account of resource considerations for identifying critical risk thresholds. The findings of the online survey provide a guide to preferred format (section 2.4).

2. Locate fire watches at hotspots. The fire risk map shows the hotspots of highest risk where fire watches could be mounted at times of highest risk as indicated by the FSI, possibly supplemented by the CCVE temporal model.

3*. Locate fire ponds at hotspots*. When combined with a map of travel time of fire-fighting helicopters from existing water sources, the risk map can be used to identify areas which are both outside the critical travel time and hotspots for fire risk. These are candidate areas for locating fire ponds, in which hydro-geological survey should be undertaken to assess permeability of the substrate. As high risk areas are also those which are popular with visitors, and may be ecologically important, there will also be issues of safety, aesthetics and ecology to take into account.

4. Control demand at hotspots: The link between degree of access and fire risk is clear, so it may be necessary to hold back on improvements to access at hotspots. Less controversially, rather than closing all Access Land at times of high risk, ideally access could be restricted only to the hotspots. Clearly, reducing fire risk by restricting access has to be balanced against loss of revenue and complaints from the public.

5. Continue moorland restoration. Continued investment in revegetating bare peat should help to reduce fire risk, but attention will need to be paid to fuel loading. The effect of gully-blocking in raising the water table should also reduce risk. The survival of restored areas if water tables fall as a result of climate change remains a concern.

6. Monitor and manage fuel load, especially in restored areas. Heather habitat has fewer wildfires than would be expected, so the evidence here suggests that prescribed burning for grouse moor management successfully controls fuel loading. Prescribed burning on all habitats will need to be even more carefully managed in drier, hotter conditions. Some form of fuel load control should be considered for restored areas, to avoid excessive build-up of brown biomass (e.g. grazing, cutting or carefully managed burns). A method for monitoring relative fuel load build up on restored and other moorland habitats in dry periods is required. The Met Office Fire Severity Index goes some way towards this, but it has a coarse spatial resolution and is not as yet optimised for moorland habitats. The remote sensing pilot study at the permanent plots begun in July 2006 by one of the authors and MFF for the NERC hyperspectral (SPECIM Eagle/Hawk) flight could be extended for this purpose, especially since the SPECIM data may be re-flown in 2006 (this is separate to data acquisition for the project on gas emissions from active fires to be undertaken by Chris Gibbons).

Fire database

7. Maintenance of fire digital database: The fire database should be updated using Rangers log sheets from July 2004 and continue to be updated on a weekly or monthly basis. The database is a unique and valuable record of moorland wildfires. This project and the temporal modelling undertaken for CCVE would not have been possible without it Very few areas of the UK have such a record. It is important that it is maintained and become part of the national initiatives currently under consideration.

8. Standardise location point. The fire location point recorded in the field on the Rangers log sheet should be an agreed, standard point, e.g. the upwind edge of the fire scar or the likely ignition point. It should continue to be recorded with GPS.

9. Map boundary of all wildfires. The fire scar boundary should continue to be mapped with GPS as soon as possible after the fire is extinguished. This is already done for large wildfires, but ideally should be extended to all wildfires. The database should contain the name of the GPS file and information derived from it: that is, co-ordinates of the maximum and minimum bounding rectangle of the fire scar polygon; its centre of gravity as a retrospective point location for the fire, and the area of the fire scar. These data will improve on use of a single point to derive habitat scores, and allow relationships to be investigated between fire size (indicator of impact), spatial factors and weather.

10. Include FRS incident number in the data base to allow cross-referencing between databases; for instance, to provide information on fire severity from number of tenders and length of time employed, and possibly to provide data on suspected cause which would allow accidental and malicious fires to be modelled separately.

11. Cross-check completeness of database. A pilot study is required to compare the completeness of the Rangers fire log against other data sources, for instance, FRS databases and active fires from satellite remote sensing.

Spatial datasets

12. Improve metadata. Full metadata is essential so that the provenance of spatial data is known and error tracking is possible. Metadata for the layers used in this project are supplied separately, based on UK geospatial standards. Gaps reflect lack of information in the metadata for the input layers and further progress towards full metadata for all MFF maps is strongly encouraged.

13. More work on settlement layer: Further investigate the effect of proximity to settlements, perhaps with further input from project stakeholders.

14. More work on footpath layer. Further work could explore the effects of different popularity classifications and the effect of modelling high and medium popularity path segments separately from the low popularity segments. The impacts of different distance bands and scoring criteria could be explored. Stakeholders suggested that footpath condition and steepness may explain popularity (section 2.4). Popularity data for the whole study area and over longer periods of time would improve the model (see below), as would a direct measures of path condition and slope (from digital elevation model).

15. Extend visitor survey locations and questions; Additional survey locations for the ‘draw your route’ question of the visitor survey are recommended. This would allow a popularity rating to be assigned directly to all paths. The visitor survey questionnaire should be extended to include awareness and attitudes to fire risk and its management responses. This would allow relationships between terrain, popularity, fire awareness and fire occurrence to be investigated (section 2.4, stakeholder workshops).

16. Further work on omitted layers. Explore topographic factors more fully, especially aspect and the influence of Access Land and car parks.

17. Time series of habitat maps. Habitat maps for other dates, especially, pre-1991 are needed to disentangle the cause and effect relationship between eroded peat and fire, and improve empirical scoring of the habitat layer. This would also provide evidence of the persistence of fire scars as landscape features. Maps used in fire risk modelling must include a bare peat class. Alternative data sources need to be more fully evaluated.

18. Include data on managed fires. Data from interpretation of 2002 aerial photographs should be included to confirm if fewer wildfires occur there. However, data for other years is required and could be obtained from aerial photographs of satellite remote sensing.

Conceptual

19. Include temporal dimensions. An assessment of the timing of wildfires compared to individual human factors would be useful follow on work, as would seasonal timing of wildfires in relation to habitat and path popularity. Separate models for spring and summer fire risk may be possible if additional fire data are provided (see Fire database recommendations above)

20. Vary spatial extent. First, further work could spatially *constrain* the spatial extent of modelling to explore regional relationships between different parts of the PDNP, for example, the Dark and White Peak. Secondly, it could *increase* the spatial extent since many of the major roads and car parks fall outside of the study area, so a stronger relationship may be found if a training dataset with a wider spatial extent is used to test distance decay relationships.

21. Study visitor-weather relationships. People are such a key part of the fire risk equation and numbers of visits to the moors may increase with climate change. However, more knowledge is required about existing and projected relationships between weather and visits to the moors.

22. Study the role of socio-economic factors. Further work should explore more fully the interrelationships between socio-economic drivers of wildfire to better understand the causes of wildfires (Martin, 2005). This should include investigation of whether socio-economic differences explain why the model fits better in some parts of the PDNP than others, or whether this is due to physical factors such as variation in managed burning. It should also separately investigate arson-specific factors, such as whether smaller roads, vehicle tracks and roads out of view are associated with more fire.

23. Vary the resolution of analysis. This should include testing of the effect of different cell sizes to investigate scale dependence in the spatial model.

24. *Explore alternative approaches to spatial modelling*. These may include regression (Martínez *et al.,* 2004) or artificial neural networks based on fire density (Vasconcelos *et al.,* 2001).

Strategic

25. Part-fund a studentship. Urgently to part-fund a PhD CASE studentship, based at the University of Manchester, to carry out critical aspects of the further work recommended here, especially to investigate novel approaches and resolution issues.

26. Extend stakeholder consultation. Consultation with a wider range of stakeholders is required (Cornelly and Richardson, 2006). This could include a public consultation based on the online survey developed for this project, or extend to a pubic participation GIS, where interactive web mapping is used to show participants the spatial outcomes of their preferences (Evans *et al*., 2004).

27. Develop a decision support tool. The maps and data layers provide a basic tool for allocating fire-fighting resources and moderating access. However, given further resources to incorporate some of the research suggestions above and design a user interface, this could be developed into a more sophisticated decision support tool (Xanthopoulos et al., 2004)

28. Establish a UK study group. Research on moorland fire risk requires an interdisciplinary approach. A UK wildfire study group should be set up incorporating a wide range of disciplines and feed into European initiatives such as EUFURELAB (see for instance Martín *et al*., 2006) and FireParadox (online). A meeting has been arranged in Manchester in January 2007 to explore the feasibility and seek funding.

29. Lobby for national action. The Department for Communities and Local Government have recently recognised that national action may be required in the field of wildfire management in view of climate change and with the introduction of the Fire and Rescue Services Act 2004 (Gazzard and Hutchinson, pers, comm., 2006). Rapid *ad hoc* submissions were solicited for a government consultation on the 11th December 2006. Fortuitously, evidence from the PDNP was included, but a wider, more co-ordinated consultation is required. This should include National Parks, all FRS covering moorland areas, land mangers and researchers.

The PDNP has a head start. The fire database, this report and the sister one on costed options (Aylen *et al.,* 2006), together with the partnership approach pioneered by the Fire Operations group (FOG) and Fire Advisory Panel (FAP) are all tangible evidence that PDNP is leading the way in managing wildfire risk. The PDNP is in an excellent position to lobby for such as consultation and play a leading role in developing national policies to reduce the threat of increased wildfire risk from climate change.

Acknowledgements

This report was produced with funding from Moors for the Future under their small research grant scheme. We also gratefully acknowledge the support of DEFRA, the Environment Agency and the Northwest Development Agency for the Climate Change and the Visitor Economy CCVE project from which the spatial modelling work conducted here has been developed.

The authors would especially like to thank Dan Boys (MFF), Ian Hurst (PDNP), other members of the Fire Operations Group and all those who participated in the online survey and stakeholder workshop. Thanks also go to Karl Hennermann, Spatial Data Research Officer in the School of Environment and Development, University of Manchester for assisting with the preparation of data layers, especially the path popularity data.

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Appendix 1: Online survey

Introductory pages

Peak District National Park

Fire Operations Group

Exit the survey >>

Modelling spatial risk of moorland wildfire - Questionnaire Survey, Spring 2006

Introduction

This questionnaire survey will provide information to help map where wildfire risk is greatest in the Peak District National Park. It is part of a research project which aims to develop an approved wildfire risk map for practical application to planning and management tasks. For example, it might be used to find places where fire breaks or ponds would be most useful.

The work is part of a wider project funded by Moors for the Future. **This particular project looks at where wildfires are more likely rather than when fires are more likely.** The results of this questionnaire will help us to produce a map showing general patterns of wildfire risk averaged over the whole year (rather than for specific time periods). *We are not considering managed fires.* A second project is looking at the best ways to reduce wildfire risk. Both projects build on findings from the Climate Change and the Visitor Economy (CCVE) project. You can view the technical report of the CCVE wildfire risk research by clicking here. Use your browser's *Back* button to return to the survey after viewing any external websites.

The research is being conducted by Julia McMorrow and Sarah Lindley of the School of Environment and Development, University of Manchester. with the support of the Peak District Fire Operations Group.

Please allow 20 minutes to complete the survey. The next page provides other tips that you may find useful.

CCVE was funded through Defra, the Environment Agency and the North West Development Agency. A report of the findings from the work is available from Sustainability North West who host the CCVE project website. You will be directed to this website at the end of the survey.

Next >>

Peak District National Park

Fire Operations Group

Exit the survey >>

Modelling spatial risk of moorland wildfire - Questionnaire Survey, Spring 2006

Instructions for respondents

The survey has seven short sections. Although there are no compulsory questions, we request that you complete all the questions in each section. If you are unable to answer a particular question please use the *Don't Know* or *Not Applicable* options before progressing.

Please use the *free text* boxes to record any other comments that you have. There is at least one question in each section which has a free text box (i.e. one which you can use to type in any further information about that section). We would also welcome any suggestions you have about relevant publications and/or datasets that you feel may be useful to the project team.

We recommend that you complete the whole survey in one session. If you are using a shared computer this is essential to avoid your responses potentially being lost. During completion of the survey, if you wish to modify any of your earlier responses, you can return to previous sections by clicking the *Prev* link at the bottom of each section. Use the *Next* link to go forward to where you left off - your answers up to that point will be saved.

Remember to use your browser's *Back* button to return to the survey after viewing any external websites.

Please email sarah.lindley@manchester.ac.uk or call Sarah on 0161 275 8685 if you require further help and/or have any queries.

<< Prev Next >>

Modelling spatial risk of moorland wildfire - Questionnaire Survey, Spring 2006

Section 1 (of 7) - About You

Please use this section to tell us about the capacity in which you are completing this survey.

1.1 Which of the following best describes the capacity in which you complete this questionnaire? Click as many as apply.

- ☐ Fire Service Officer
- ☐ National Park Officer
- ☐ Representative of the Rambler's Association
- ☐ Representative of a utility company
- ☐ Representative of a fire operations company
- ☐ Representative of the National Trust
- ☐ Representative of Natural England
- ☐ Private land owner
- ☐ Member of the public
- ☐ Academic/researcher
- ☐ Farming tenant
- ☐ Member of the Peak District Fire Operations Group
- ☐ Other (please specify)

1.2 What geographical area of the Park does your expertise generally cover? Click as many as apply. Please complete the remaining questions from your knowledge of these areas.

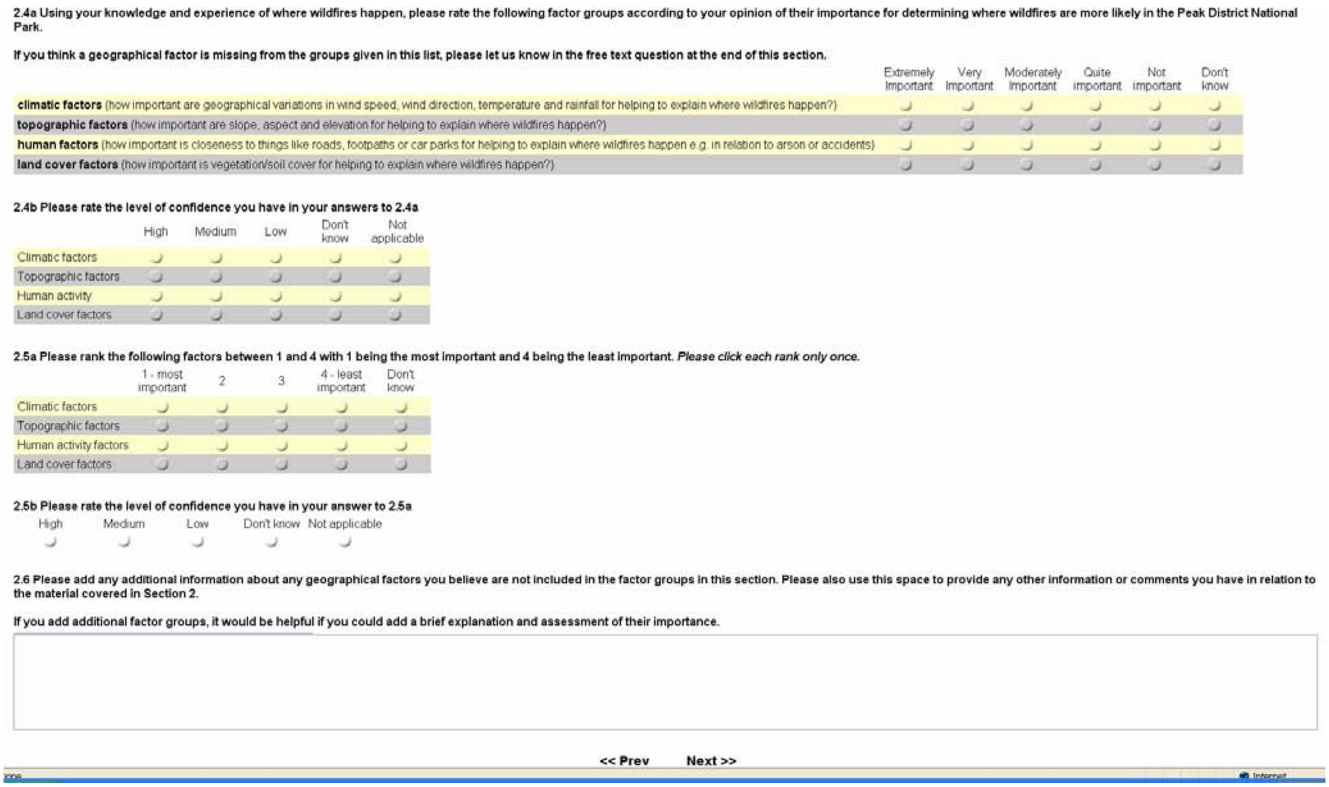
- ☐ The whole of the Peak District National Park
- ☐ Mainly Cheshire parts
- ☐ Mainly Staffordshire parts
- ☐ Mainly Derbyshire parts
- ☐ Mainly Greater Manchester parts
- ☐ Mainly West Yorkshire parts
- ☐ Mainly South Yorkshire parts
- ☐ None
- ☐ Other (please specify, e.g. for a particular geographical area or landscape type)

1.3 Does your expertise relate only to the moorland areas of the Peak District National Park?

Yes	No	Don't know	Not applicable
○	○	○	○

<< Prev **Next >>**

Example of a page for rating and ranking factor groups



2.4a Using your knowledge and experience of where wildfires happen, please rate the following factor groups according to your opinion of their importance for determining where wildfires are more likely in the Peak District National Park.

If you think a geographical factor is missing from the groups given in this list, please let us know in the free text question at the end of this section.

	Extremely Important	Very Important	Moderately Important	Quite important	Not important	Don't know
climatic factors (how important are geographical variations in wind speed, wind direction, temperature and rainfall for helping to explain where wildfires happen?)						
topographic factors (how important are slope, aspect and elevation for helping to explain where wildfires happen?)						
human factors (how important is closeness to things like roads, footpaths or car parks for helping to explain where wildfires happen e.g. in relation to arson or accidents)						
land cover factors (how important is vegetation/soil cover for helping to explain where wildfires happen?)						

2.4b Please rate the level of confidence you have in your answers to 2.4a

	High	Medium	Low	Don't know	Not applicable
Climatic factors					
Topographic factors					
Human activity					
Land cover factors					

2.5a Please rank the following factors between 1 and 4 with 1 being the most important and 4 being the least important. ***Please click each rank only once.***

	1 - most important	2	3	4 - least important	Don't know
Climatic factors					
Topographic factors					
Human activity factors					
Land cover factors					

2.5b Please rate the level of confidence you have in your answer to 2.5a

High	Medium	Low	Don't know	Not applicable

2.6 Please add any additional information about any geographical factors you believe are not included in the factor groups in this section. Please also use this space to provide any other information or comments you have in relation to the material covered in Section 2.

If you add additional factor groups, it would be helpful if you could add a brief explanation and assessment of their importance.

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Example of pages for rating and ranking individual factors: topographic factor

Modelling spatial risk of moorland wildfire - Questionnaire Survey, Spring 2006

Section 4 (of 7) - Topographic factors

In this section, you will be asked to rate and rank individual factors within the topography category that you think help to explain where wildfires occur.

Click here to see examples of topographic factors (pdf, 232KB). Again, if you wish to view this file, please do so before answering any of the questions in this section. Click the *Back* button on your browser to return to this section.

There is space at the end of this section to add any other comments or observations.

4.1 In your experience, which of the following slope types would you say tend to have the most wildfires?

- Mainly steep areas
- Mainly flat areas
- Slope not important
- Don't know
- Not applicable
- Other (please specify)

4.2 In your experience, which of the following aspect categories (the direction in which hill sides are facing) would you say tend to have the most wildfires?

East facing slopes	North facing slopes	South facing slopes	West facing slopes	Aspect not important	Don't know	Not applicable

4.3 In your experience, which of the following elevations would you say tend to have the most wildfires?

Highest areas	Medium elevations	Lowest areas	Elevation not important	Don't know	Not applicable

4.4a Please rate the following topographic factors according to your opinion of their importance for helping to explain where wildfires occur in the Peak District National Park.

Please use Question 4.6 to state and explain any other topographic factors you think have been missed.

	Extremely Important	Very Important	Moderately Important	Quite important	Not important	Don't know
Aspect						
Elevation						
Slope						

4.4b Please rate the level of confidence you have in your answer to 4.4a

	High	Medium	Low	Don't know	Not applicable
Aspect					
Elevation					
Slope					

4.4b Please rate the level of confidence you have in your answer to 4.4a

	High	Medium	Low	Don't know	Not applicable
Aspect					
Elevation					
Slope					

4.5a Please rank the following factors between 1 and 3 with 1 being the most important and 3 being the least important. *Please give only one rank for each factor.*

	1 - most important	2	3 - least important	Don't know
Aspect				
Elevation				
Slope				

4.5b Please rate the level of confidence you have in your answer to 4.5a

High	Medium	Low	Don't know	Not applicable

4.6 Please use the space below to add any additional topographic related factors that you think should be considered in explaining where wildfires happen.

It would be helpful to provide a short explanation and an assessment of the importance of any factors you suggest.

You can also use this space to record any other observations about this section.

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Appendix 2: Online survey results

Example of results of rating and ranking factor groups

7. 2.4a Using your knowledge and experience of where wildfires happen, please rate the following factor groups according to your opinion of their importance for determining where wildfires are more likely in the Peak District National Park. If you think a geographical factor is missing from the groups given in this list, please let us know in the free text question at the end of this section.

	Extr-emely Import-ant	Very Import ant	Mod-erately Import -ant	Quite import-ant	Not import-ant	Don't know	Response Average
Climatic factors (how important are geographical variations in wind speed, wind direction, temperature and rainfall for helping to explain where wildfires happen?)	**57% (8)**	29% (4)	0% (0)	0% (0)	0% (0)	14% (2)	**1.33**
Topographic factors (how important are slope, aspect and elevation for helping to explain where wildfires happen?)	**29% (4)**	21% (3)	14% (2)	14% (2)	14% (2)	7% (1)	**2.62**
human factors (how important is closeness to things like roads, footpaths or car parks for helping to explain where wildfires happen e.g. in relation to arson or accidents)	**64% (9)**	21% (3)	14% (2)	0% (0)	0% (0)	0% (0)	**1.50**
Land cover factors (how important is vegetation/soil cover for helping to explain where wildfires happen?)	**57% (8)**	36% (5)	7% (1)	0% (0)	0% (0)	0% (0)	**1.50**
						Total Respondents	**14**
						(skipped this question)	**2**

Example of results for rating and ranking topographic factors

23. 4.4a Please rate the following topographic factors according to your opinion of their importance for helping to explain where wildfires occur in the Peak District National Park. Please use Question 4.6 to state and explain any other topographic factors you think have been missed.

	Extremely Important	Very Important	Moderately Important	Quite important	Not important	Don't know	Response Average
Aspect	15% (2)	23% (3)	8% (1)	8% (1)	15% (2)	**31% (4)**	**2.78**
Elevation	8% (1)	23% (3)	15% (2)	15% (2)	8% (1)	**31% (4)**	**2.89**
Slope	0% (0)	23% (3)	23% (3)	8% (1)	15% (2)	**31% (4)**	**3.22**
						Total Respondents	**13**
						(skipped this question)	**3**

25. 4.5a Please rank the following factors between 1 and 3 with 1 being the most important and 3 being the least important. *Please give only one rank for each factor*.

	1 - most important	2	3 - least important	Don't know	Response Average
Aspect	**46% (6)**	8% (1)	15% (2)	31% (4)	**1.56**
Elevation	15% (2)	15% (2)	**38% (5)**	31% (4)	**2.33**
Slope	8% (1)	**46% (6)**	15% (2)	31% (4)	**2.11**
				Total Respondents	**13**
				(skipped this question)	**3**

Appendix 3: Attendance list for stakeholder workshop

MFF Spatial modelling of moorland wildfire risk workshop

University of Manchester, June 8th 2006

List of Attendees

Name	***Organisation***
Gordon Danks	PDNPA
Ian Hurst	PDNPA
Steve Yearsley	Greater Manchester Fire and Rescue
Frank Cummings	Staffordshire Fire & Rescue
Garry Goodwin	Staffordshire Fire & Rescue
Richard Pollitt	English Nature
Andrew Shaw	National Trust
Jon Walker	MFF
Dan Boys	MFF
Gina Cavan	University of Manchester
Sarah Lindley	University of Manchester
Julia McMorrow	University of Manchester
Karl Hennermann	University of Manchester

Appendix 4: Summary of models

Arranged by model number (habitat variant) and, within this, by factor weighting. Results for models in square brackets are not presented.

Model 1A
[habitat_pt36 - habitat_pt36] * 0.23 + [rec_settle1 - rec_settle1] * 0.15785 + [recminorroad] * 0.03465 + [recpwhi1] * 0.2772 + [recpwmdlon1] * 0.202125 + [recway1] * 0.098175

[Model 1B]
1h27
[habitat_pt36 - habitat_pt36] * 0.27 + [rec_settle1 - rec_settle1] * 0.14965 + [recminorroad] * 0.03285 + [recpwhi1] * 0.2628 + [recpwmdlon1] * 0.191625 + [recway1] * 0.093075

Model 1C
1h50
[habitat_pt36 - habitat_pt36] * 0.50 + [rec_settle1 - rec_settle1] * 0.1025 + [recminorroad] * 0.0225 + [recpwhi1] * 0.18 + [recpwmdlon1] * 0.13125 + [recway1] * 0.06375

Model 1D
1h40
[habitat_pt36 - habitat_pt36] * 0.4 + [rec_settle1 - rec_settle1] * 0.123 + [recminorroad] * 0.027 + [recpwhi1] * 0.216 + [recpwmdlon1] * 0.1575 + [recway1] * 0.0765

Model 2A
[habitat_pt18] * 0.23 + [rec_settle1 - rec_settle1] * 0.15785 + [recminorroad] * 0.03465 + [recpwhi1] * 0.2772 + [recpwmdlon1] * 0.202125 + [recway1] * 0.098175

[Model 2B]
2h27
[habitat_pt18] * 0.27 + [rec_settle1 - rec_settle1] * 0.14965 + [recminorroad] * 0.03285 + [recpwhi1] * 0.2628 + [recpwmdlon1] * 0.191625 + [recway1] * 0.093075

Model 2C
2h50
[habitat_pt18] * 0.50 + [rec_settle1 - rec_settle1] * 0.1025 + [recminorroad] * 0.0225 + [recpwhi1] * 0.18 + [recpwmdlon1] * 0.13125 + [recway1] * 0.06375

Model 2D
2h40
[habitat_pt18] * 0.4 + [rec_settle1 - rec_settle1] * 0.123 + [recminorroad] * 0.027 + [recpwhi1] * 0.216 + [recpwmdlon1] * 0.1575 + [recway1] * 0.0765

Model 2E
(reversed footpath and car)
[habitat_pt18] * 0.23 + [rec_settle1 - rec_settle1] * 0.47355 + [recminorroad] * 0.10395 + [recpwhi1] * 0.0924 + [recpwmdlon1] * 0.067375 + [recway1] * 0.032725

Model 2G
2eh50 (reversed footpath and car)

[habitat_pt18] * 0.50 + [rec_settle1 - rec_settle1] * 0.3075 + [recminorroad] * 0.0675 + [recpwhi1] * 0.06 + [recpwmdlon1] * 0.04375 + [recway1] * 0.02125

Model 2F
(equal footpath and car)
[habitat_pt18] * 0.23 + [rec_settle1 - rec_settle1] * 0.3157 + [recminorroad] * 0.0693 + [recpwhi1] * 0.1848 + [recpwmdlon1] * 0.13475 + [recway1] * 0.06545

Model 2H
2fall (equal foot and car plus habitat 50)
[habitat_pt18] * 0.50 + [rec_settle1 - rec_settle1] * 0.205 + [recminorroad] * 0.045 + [recpwhi1] * 0.12 + [recpwmdlon1] * 0.0875 + [recway1] * 0.0425

Model 3A
[hab_b200_36] * 0.23 + [rec_settle1 - rec_settle1] * 0.15785 + [recminorroad] * 0.03465 + [recpwhi1] * 0.2772 + [recpwmdlon1] * 0.202125 + [recway1] * 0.098175

Model 3C
3h50
[hab_b200_36] * 0.50 + [rec_settle1 - rec_settle1] * 0.1025 + [recminorroad] * 0.0225 + [recpwhi1] * 0.18 + [recpwmdlon1] * 0.13125 + [recway1] * 0.06375

Model 4A
[hab_b200_18] * 0.23 + [rec_settle1 - rec_settle1] * 0.15785 + [recminorroad] * 0.03465 + [recpwhi1] * 0.2772 + [recpwmdlon1] * 0.202125 + [recway1] * 0.098175

Model 4C
4h50
[hab_b200_18] * 0.50 + [rec_settle1 - rec_settle1] * 0.1025 + [recminorroad] * 0.0225 + [recpwhi1] * 0.18 + [recpwmdlon1] * 0.13125 + [recway1] * 0.06375

Model 5A
[hab_b100_18] * 0.23 + [rec_settle1 - rec_settle1] * 0.15785 + [recminorroad] * 0.03465 + [recpwhi1] * 0.2772 + [recpwmdlon1] * 0.202125 + [recway1] * 0.098175

[Model 5B]
5h27
[hab_b100_18] * 0.27 + [rec_settle1 - rec_settle1] * 0.14965 + [recminorroad] * 0.03285 + [recpwhi1] * 0.2628 + [recpwmdlon1] * 0.191625 + [recway1] * 0.093075

Model 5C
5h50
[hab_b100_18] * 0.50 + [rec_settle1 - rec_settle1] * 0.1025 + [recminorroad] * 0.0225 + [recpwhi1] * 0.18 + [recpwmdlon1] * 0.13125 + [recway1] * 0.06375

Model 6A
[habitat_pt6] * 0.23 + [rec_settle1 - rec_settle1] * 0.15785 + [recminorroad] * 0.03465 + [recpwhi1] * 0.2772 + [recpwmdlon1] * 0.202125 + [recway1] * 0.098175

[Model 6B]
6h27

[habitat_pt6] * 0.27 + [rec_settle1 - rec_settle1] * 0.14965 + [recminorroad] * 0.03285 + [recpwhi1] * 0.2628 + [recpwmdlon1] * 0.191625 + [recway1] * 0.093075

Model 6C
6h50
[habitat_pt6] * 0.50 + [rec_settle1 - rec_settle1] * 0.1025 + [recminorroad] * 0.0225 + [recpwhi1] * 0.18 + [recpwmdlon1] * 0.13125 + [recway1] * 0.06375