Review of: Peak District National Park Wildfire Risk Assessment 2022

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Foreword

The meteorological conditions most closely associated with wildfire events are predicted to occur more frequently with a warming climate. One of the challenges is to identify the best way of assessing wildfire risk and what management either of land, people or resources, will reduce the occurrence and severity of wildfires. One of the first attempts at assessing wildfire risk at a landscape scale has been produced within the Peak District National Park and this review has been commissioned to examine the approach to and conclusions from that work.

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Executive summary

In January 2023 Drs Yallop and Thacker were contracted by Natural England to undertake a brief review of the Peak District National Park Wildfire Risk Assessment (Barber-Lomax and others, 2022). Several issues have prevented a thoroughgoing analysis of the extensive material contained within that document. The reader is referred to section 2.2 for a broad summary of these and the resultant caveats they impose. This review has therefore, by necessity, been restricted to making honest assumptions and best interpretations of the processes used and results presented in that document.

Barber-Lomax and others (2022) presents the results from a unique 3-tier approach, their reported meanings, and a consideration of wildfire risk mitigation options based on these outcomes. Tier 1 canvasses landowner opinions on many aspects of fire risk. This suffers from a number of serious methodological flaws that makes the results it presents, at best, unreliable.

Tier 2 adopts a GIS approach to visualisation of fire risk by combining a number of geographic datasets with the modelled outputs of McMorrow & Lindley (2006) and Dixon & Chandler (2019). However, this suffers from two main problems. Firstly, many of the data combined with the modelled outputs were already included within these models, effectively 'double-counting' their effects. Secondly it incorporates a deep peat mapping layer within the inputs, making the assumption that fire risk is higher in deep peat areas, something unsupported by evidence.

Tier 3 adopts the use of long-established models developed within the USA for forestry applications. However, given the absence of a history of their application in UK upland moorland they do require extensive testing and validation before their veracity in these landscapes can be assumed. Two aspects need particular examination: (i) the size of units considered as 'homogeneous' during modelling given interactions between the generally lower fire intensities, and the spatial scale of heterogeneities of fuel load, topography and moisture likely to occur in UK upland moorland compared to those regions and environments in which they are usually employed and (ii) the appropriateness of the fuel types need validation against UK upland vegetation communities using empirical data. Barber-Lomax and others (2022) do not adopt such a research approach, rather models for two basic meteorological conditions using existing fuel load models have been executed and presented as evidence. It is stated that fuel loads were determined using classified EO imagery although no details of this process, or the accuracies achieved, are presented. Discussion and justification for the process of matching Peak District National Park (PDNP) vegetation to the fuel models used is similarly absent. Nonetheless, in the latter case many of these choices do appear to be good first approximations for testing, although we do have concerns with regard to two: mature heather and new controlled burn 'scars'. The former could result in some over-estimation of fire intensity, although confirmation of this would require modelling beyond what has been possible during this review. An additional concern is the process used to create homogenous fire-behaviour polygons, as no rationale or justification for their determination is provided. The size of such units critically influences modelled fire behaviour and, in general, we have been unable to identify landscape features or vegetation patterns matching these.

Overall, given systematic problems in Tier 1 and 2 and, in particular, the total lack of clarity of methodology and assumptions in Tier 3, Barber-Lomax and others (2022) cannot be said to reach the standards required to be accepted as providing evidence suitable for informing either management or policy decisions.

Contents

Introduction

Barber-Lomax and others (2022) is published via http://www.peak districtwildfire.co.uk, where it appears alongside two précised versions. No ownership for the domain is shown on the website although it is assumed to be the Wentworth-Fitzwilliam Estate.

The document states that "… the primary objectives of this project are to provide stakeholders with unbiased evidence regarding the risk and potential scale of fire likely to occur within the moorland landscape of the PDNP, presenting this in a format that can be easily understood and used by all stakeholders to identify the regional and local threats posed by wildfire now and in the future". Such objectives are laudable and highly pertinent given fears of longer wildfire seasons and increased drying of underlying peat surfaces resulting from recent warmer and drier conditions being experienced throughout the year.

Barber-Lomax and others (2022) is not however a formally peer-reviewed research publication, although a number of supporting endorsements are provided, and it includes the logos of both Natural England and the PDNPA. Given that its stated aims are to provide evidence to stakeholders, especially those responsible for land management and legislation, the lack of any peer review is highly problematic.

This review will examine some of the content and claims made in Barber-Lomax and others (2022) to establish how well they meet its stated objectives, and to what extent its content can be regarded as providing valid and reliable evidence to guide wildfire mitigation and land management strategies.

Structure of this review

The first four sections of Barber-Lomax and others (2022) present background material and this critique has been restricted to the succeeding chapters. This should not however be interpreted as a wholesale acceptance of the content in the earlier parts of the document, much of which is contentious. However, it does not present original material and can be readily excluded from consideration without any loss of understanding.

Tier 1, a determination of fire risk factors based upon land managers opinion, is reviewed fairly extensively as it contains a number of what we consider to be major flaws in methodology. It also forms an extensive part of Barber-Lomax and others (2022). Tier 2 is a wider mapping assessment based on publicly-available spatial data. It uses a range of buffers to define risk zones. Since the "ignition" buffers are based on earlier published models, discussion of this tier is limited. Tier 3 presents fire behaviour modelling in the Derwent Focus Area. The review of this tier is extensive, and considers the methodology used for fuel mapping, the validity of fuel model selection and the utility of landscape-scale predictions of fire behaviour.

The authors of this review have found it difficult to maintain a consistent style in presenting our comments and observations. Some aspects are simpler than others and can be highlighted with short simple observations and bulleted points. Others, especially where they deal with contextual matters within larger blocks of text or understanding of fire-model behaviour have required longer explanatory comments. Within this review therefore both forms will be found.

n.b. this review contains a mix of units, imperial, and metric. This arises because the core fire models are produced in the USA using imperial measurement and Barber-Lomax and others (2022) present these tables and figures without converting them. For clarity in communication with what we are referring to we have followed this approach. Page numbers refer to the pages within the Barber-Lomax and others (2022) report.

Caveats, disclaimers, and acknowledgment of limitation to this review:

Several issues obstruct a proper review of Barber-Lomax and others (2022). The report presents no explicit protocols, model details, mathematical or GIS algorithms, or empirical data. Secondly, no tabulated empirical results, prediction confidence limits or accuracy statistics are presented. Where results are shown, they are invariably in the form of low-resolution illustrations and figures from which it is essentially impossible derive any meaningful information (e.g. Fig. B3). Thirdly, many figure and graph legends exhibit textural mistakes, further making interpretation difficult and unreliable. Finally, innumerable statements are made throughout the document that are not referenced, making it impossible to identify sources or ascertain veracity.

Given these constraints the authors feel this review should be taken as no more than an open and honest interpretation of Barber-Lomax and others (2022), made by two remote-sensing ecologists with over 2 decades experience of mapping aspects of moorland burning including wildfires. It should not be taken as a definitive and informed critique of the approach of Barber-Lomax and others 2002, or their claimed results, as such a thing is impossible without a full methodology and results being presented, or access to the material used during the project. We also admit that it is feasible we may have mis-inferred or mis-interpreted many aspects of the report, and we apologise if this has occurred. We could easily, for example, infer that something has not been done when indeed it has, just not reported: for example, a thorough accuracy-assessment of the EO vegetation mapping exercise that underpins the entirety of Tier 3 fire modelling may have been undertaken, but that Barber-Lomax and others 2020 have chosen not to reference it in any way in the report.

TIER 1

Tier 1, in itself, does not directly contribute to the formal fire modelling processes undertaken within Tiers 2 and 3, the latter of which can be seen as the primary original technical components of Barber-Lomax and others (2022). It might therefore be considered of subsidiary or secondary importance. However, it forms a substantive part (around 25%: excluding appendices) of the main report. So, it is integral to the overall impression created by the document. It also has to be assumed that Barber-Lomax and others (2022) include Tier 1 for a reason, and the material within it does feed forward into the discussion and conclusions presented in Section 12 ‘Combining the Tiers’ and later arguments regarding mitigation. Therefore, as it is presented and used in this way, some examination of the approach, results presented, and conclusions drawn has been undertaken.

It should be considered that any assessments of the potential strengths/weaknesses of the matrix approach need to be undertaken within the context of its purpose. This is, manifestly, not to gather empirical data for statistical analyses. It would therefore be unreasonable to judge it in this way. Rather Tier 1 is about collating and visually presenting stakeholder opinion in map form, and it should be judged from that perspective: i.e. how appropriate, robust and reliable are the methods adapted to that task and how much credence therefore can be placed on the results presented.

Preliminary note: The preamble to this section (8.1) refers quite extensively to the template produced by the Uplands Management Group (UMG) used for assimilating data to inform wildfire risk assessment/mitigation approaches on blocks of moorland. It presents details of this approach, notes its advocacy by both Natural England (NE) and DEFRA, and suggests it represents an ‘obvious place to start’. However, Barber-Lomax and others (2022) then continue “...there are limitations to this approach which do not easily translate to a wider landscape approach, which requires a consistent set of parameters to be assessed by multiple land managers”. Hence, despite minor similarities, Tier 1 actually adopts an essentially different and novel approach, one that ultimately means it should not therefore be confused with the UMG in any way. The UMG delivers far more spatially explicit and detailed outputs, scaled to the phenomena being recorded.

The Matrix Approach

Before considering any generic concerns about the approaches of Tier 1 we feel it might be useful to briefly review each of the main ‘elements’ or sections of the matrix and derived ‘heat maps’ as presented in sections 8.4 through 8.7. Given that many of these concerns occur elsewhere within Barber-Lomax and others (2022) some repetition is inevitable, although we have attempted to minimise this.

Ignition

The initial component of the matrix seeks to assess the risk of ignition (page 43) by separating causes into three discrete categories: access, car parking and history of events. Such initial differentiation followed then by aggregation of scores assumes each measure is independent: i.e., that they are not simply highly correlated surrogate measures of the same ultimate cause. Yet in this case, for example, it might reasonably be assumed that much public access into the study area is facilitated by car journey, this necessitates parking and historically car parks have formed at Public Rights of Way (PROW) access points.

The appropriateness or reliability of using landowner opinion for assessment of this important measure is questionable given that the factors e.g., car park locations and the PROW network etc. are actually known and recorded phenomena. Thus, the method used here is simply neither the most direct nor reliable. A straightforward GIS approach using the known geographic location data and some simple visualisation (e.g buffering for example) would have produced repeatable metrics (i.e. free of issues arising from observer bias across the entire study area). Figure 27 (pg 43) identifies an apparently relatively low concordance between the PROW network and the stakeholder judgement. This disparity highlights one of the fundamental weaknesses with the Tier 1 approach, that of observer bias.

In any event the historical record provides a far more definitive reference to determine relative ignition risks at a finer spatial scale, mostly rendering this section unnecessary and irrelevant.

Given the actual importance of ignition, there will after all be no fire without it, the treatment of ignition here also appears somewhat cursory (n.b. it is also mentioned in 12.1.2). Wildfire in these landscapes results almost exclusively from an anthropogenic origin, whether inadvertent, carelessness or malice. As such reducing the chance or probability of ignition and potential for fire propagation from each new occurrence, at least from the first two of these causes, would seem to provide a sensible basis for planning. The 'data' gathered here are neither accurate or spatially detailed enough to facilitate this.

Combustion

Relies on stakeholder opinion on a complex range of metrics deemed the fuel complex aggregated over 1km^2.

Current management:

Purportedly determines fuel load based upon the management practices assessed using an arbitrary set of criteria. However, no rationale for the scale is given, and if one exists, it is not clear to the authors of this review.

For the scale of 1 for rotationally burned heather on shallow peat and 5 for non-rotationally burned heather on deep peat to have any credence requires acceptance that:

i: no, or very few, wildfires take place on shallow peat and a far higher number on deep peat: and

ii: controlled-burn managed moorland experience very few wildfires compared to unmanaged ones.

We currently know of no data that support either conjecture. In over 2 decades of mapping moorland management burning, during which time we have observed the ‘scars’ of innumerable wildfires, we have never observed evidence of wildfires avoiding rotationally burned heather moorland. Fire behaviour may change, but fires do not stop when they encounter heather growing on mineral soils and certainly not at the boundary of a fire-managed heather moorland.

n.b. later in the document we are informed this matrix was excluded from the overall Tier 1 summary. If this is so, we cannot understand why it is still presented here.

Existing breaks:

Firebreaks can manifestly influence fire behaviour and rate of spread: they are, after all, an important component of pre-emptive fire control planning as well as a reactive response measure. A clear understanding of the spatial distribution and extent of natural firebreak opportunities is clearly important in both long-term planning for wildfire control strategies as well as more immediate tactics in response to an active wildfire event. It is regrettable therefore that no detail or evidence is presented of how these features are integrated at the 1km^2 scale, or how to interpret the results. The outputs (for example Fig. 32 pg 48) seem to indicate that entire tracts of moorland exist that are functionally homogenous without any apparent changes in vegetation, slope etc. or the presence of any linear firebreaks, wet areas, or habitat mosaics. This does somewhat defy our understanding and extensive experience in mapping upland vegetation. Figure 32 also appears at variance to the FOG (Fire Operations Group) indicated natural breaks shown on the same figure, again highlighting issues with the protocol.

Peat depth:

Requires evidence that the stated conjectures in relation to peat depth are in any way correct.

Volatility:

We are interpreting this as meaning flammability or combustibility. The 1km^2 scaling of this component is again highly questionable as local topography, which will influence water retention as well as the vegetation mosaic will vary at far finer scales. It also appears to try to add a temporally variant component into the mix. Clearly moisture, for example, has large inter- and intra- annual variability. We cannot see how observer judgment at this scale can incorporate all this variability into a single rational numerical value.

Growth rate:

This is an inexplicable metric and, as far as we can interpret it, a spurious measure. Firstly, Tier 1 is a temporally static assessment – i.e. a risk at a given moment, not a prediction of change. Hence it is temporally invariant and growth rate, which is a measure over time, is not understandable to us in this context. It will also be highly correlated with vegetation type or the ‘fuel matrix’, hence will have the effect of ‘double counting’ a single phenomenon.

Wind:

We cannot understand what is being assessed here, how it is being judged and scored at 1km^2, or what the outputs are supposed to show.

Combining Tier 1 indices

Not including wind factors, Tier 1 comprises 12 separate sub-indices. Since it is likely that many of these are correlated with one another, it would be preferable to see perhaps a multivariate approach, e.g. a principal component analysis of the dataset, rather than a simple combination of sub-indices. The following investigates the statistical appropriateness of the adopted approach of combining Tier 1 sub-indices by addition. This has implications for the validity of conclusions about wildfire risk drawn in Tier 1.

For the Tier 1 analysis, stakeholders were asked to complete a questionnaire for each 1 km square for which they had responsibility. For every 1 km square, there were 12 separate sub-indices (excluding 4 wind indices), each given a value on a five point scale by the respondent. An example is the “current management” sub-index (8.5.1), where intensive management is accorded a score of 1 (low risk) and a very low level of management is accorded a score of 5 (high risk). The result is 5-rank ordinal data for each sub-index. This is a form of qualitative data: the 5 levels represent ranks (3 represents a higher risk than 2), but the absolute difference between them is not known (the degree to which 3 is a higher risk than 2 is not known).

The sub-indices are combined by addition. There are 3 sub-indices for the “Ignition” score, 5 sub-indices for the “Combustion” score, and 4 sub-indices for the “Control” score. Combining these sub-indices by addition causes statistical difficulties for the interpretation and presentation of the results.

There is no *a priori* reason to expect any particular frequency distribution for the 5-rank ordinal data collected for each sub-index. While measured (quantitative) data often approximates a normal distribution, no such *prima facie* assumption can be made about questionnaire data collected on a 5-point scale. The analysis below proceeds on the assumption that the questionnaire data is uniform for each sub-index, i.e. that the collected data falls evenly in each of the 5 bins. This distribution is considered a "best case" for combining sub-indices, because results would be less favourable if the questionnaire data were unimodal; middle values would more quickly predominate when sub-indices are combined by addition than occurs if the sub-index data are uniform.

Combining uniformly-distributed data by addition results in a Gaussian distribution (a typical example is the result of adding the scores of two independent dice). It is also easy to see that the minimum combined score increases by 1 with every added sub-index. For example, the potential range of two sub-indices of 1-5 added together is 2-10, and the range of 3 combined indices added together is 3-15.

As a result, care needs to be taken in presenting the combined scores. For example, the 3 scores for "Ignition" are combined and illustrated in BL22 Figure 30. The legend has 5 bins, as does each individual question. The bins are as follows (Table 1):

Table 1. The expected frequency of each map legend bin for the combined "Ignition" index.

Map Legend[a]	Description	Score Range	Expected Frequency [b,c]
1	Low	1-3	0.008
2	Low/Medium	4-6	0.152
3	Medium	7-9	0.416
4	Medium/High	10-12	0.344
5	High	13-15	0.080

[a] Barber-Lomax and others (2022: Table 6 for Figure 30).

[b] uniform, independent sub-indices

[c] the frequencies may be calculated by summation of the relevant coefficients on the third row of a fifth-order Pascal's triangle.

The score ranges for each bin seem natural, but it has to be remembered that (i) by summing the sub-indices, a Gaussian distribution results such that middle values predominate; and (ii) by summing the sub-indices, total scores of 1 and 2 are not possible, since the minimum of each sub-index is 1. As the final column shows, because the only possible total score that results in a map square being placed in the first bin is 3, the probability of any square being placed in the first bin is low (it is actually 0.008). Given this low probability, it is unsurprising that no grid squares are placed in the first bin on Barber-Lomax and others (2022) Figure 30. The medium/high bin is twice as likely to occur by chance than the low/medium bin, although at first sight it might seem equally likely. This has the effect of weighting the map towards producing a more alarming impression of fire risk in the study area. Similar comments apply to the combined indices for combustion and control, and it should be noted that the more sub-indices that are combined, the less likely it is for the lowest bin to occur.

The situation is more serious for the Matrix total, combining the “Ignition”, “Combustion” and “Control” indices. By combining these 3 indices, composed respectively of 3, 4 and 5 sub-indices, the likelihood of a particular map square falling into the lowest bin becomes extremely low (odds of over two hundred million to one). It is perhaps not surprising that there are no squares with a risk score of 1 in the “Overall Total” map (Barber-Lomax and others (2022) Figure 43). In fact, more than half of the map squares are expected to be in bin 4 if data from the 12 sub-indices are derived from a random uniform distribution.

Table 2. The expected frequencies for each map legend bin for the “Overall Total” index combining ignition, combustion and control indices.

Risk Score	Likelihood[b]
1	$4.09*10^{-9}$
2	0.002
3	0.320
4	0.644
5	0.033

[a] Overall Total - Barber-Lomax and others (2022) Table 19 for Figure 43

[b] Probability of a map square occurring in bin if data from sub-indices are drawn from a uniform random distribution

The three combined index maps (Figures 30, 37 and 42) and the overall combined map (Figure 43) are therefore uninformative and potentially misleading. The picture painted, of an entire landscape at risk, is simply a natural consequence of the way the data has been combined, not a consequence of the data itself. It does not therefore represent the 'reality' of the landscape.

Main generic points of concern regarding Tier 1

The choice of OS grid aligned 1km sq. as the observation/recording unit is not supportable given the actual spatial heterogeneity of the data it is supposedly collating and mapping:

i: upland landscape vegetation, and its contribution to fuel load or fire risk, is rarely homogenous at this scale and, even where such blocks may occur, the probability of them aligning with the OS grid is extremely small.

ii: slope and especially natural firebreaks such as roads, substantive wet areas/ watercourses etc. cannot be rationally incorporated or factored at this scale.

iii: it is not clear how fire control measures such as access and water availability can be usefully defined at a 1km scale. In the former case, for example, each 1km^2 sq. receives a score based on 1 km distances, or 15 or 30 minute travelling times from a particular point or linear feature. Yet basic geometrical consideration will show that large areas of a square/s assigned scores in entirety as ‘further away’ will actually be nearer to the feature phenomena than much of one rated in entirety as closer.

As with *ignition* (discussed above) this is an additional example of an inexplicable choice of method being used when far more appropriate sampling options, that deliver far higher grade data, are readily available. The subject here should have been assessed by a simple GIS based spatial mapping exercise.

iv: land ownership and hence the observer for these records is not aligned with 1km OS sq. No mention is made of how this issue is addressed pre-survey or what *post-hoc* action has been taken at the very large number of square crossing boundaries to derive the single values reported.

When planning a project to record spatial phenomena, consideration of two groups of primary inter-related factors is crucial in determining appropriate protocols. Firstly, a suitable spatial resolution of observation is used relative to the heterogeneity of the subject/s under study (Wiens 1989). Secondly appropriate metrics and scales of measurement are chosen considering the spatial scale of observation used.

The UMG risk assessment/mitigation template on which the Matrix approach is reportedly based upon actually utilises mapping of discrete land parcels of the area and shape required to identify relatively homogenous classes such as fuel load, watercourses, other potential barriers to fire spread and areas of greatest risk. The use of the OS aligned 1km^2 scale chosen here is inappropriate to assess the factors described in Tier 1.

The raison d'être given for the decision to abandon the UMG template protocol is given as '… limitations to this approach which do not easily translate to a wider landscape approach, which requires a consistent set of parameters to be assessed by multiple land managers.' (8.1 pg 40).

Yet the approach adopted relies entirely on subjective judgements by a series of independent observers of how to apply a very coarse 1km^2 scaling to a multiplicity of sub-1km^2 phenomena, a process that does not appear to have been tested to assess its ability to deliver consistent data. No *post-hoc* calibration or correction exercises to try to mitigate difference of opinion between observers appear to have been carried out.

If one observer can, for example, rate something as 5 whereas another would rate the same thing as 2 or 3 the outputs are as likely to map the spatial distribution of observer attitudes or biases as they are any physical phenomena.

All tables, images and statements within Tier 1 are based solely on observer opinions, assessed using a novel questionnaire/matrix and judged over inappropriately sized areas for the factors being considered. This makes meaningful interpretation essentially impossible.

This issue is recognised, in part, within Barber-Lomax and others (2022) by comments such as:

" The distinction between individual assessments is clear in some locations indicating the different sensitivities of some respondents". (8.6: pg.54)

" The subjectivity of this element of data also reiterates the need to gather data from a range of sources to ensure a robust picture is presented …". (8.8 pg.60)

". ..there are notable variances where particular land/vegetation managers have stronger opinion as to risk than others." (8.8 pg.60)

Given this apparent understanding of the weaknesses of Tier 1 we question why it is included.

The use of numeric values, for an ordinal scale, creates a number of problems, even ignoring issues arising from the subjective judgements used in estimating them:

Inter-factor scaling is clearly important, especially when values are aggregated as here. Tier 1 utilises a total of 12 indices. Unless the values being aggregated are proportionate in importance the final score is misleading as it is not providing the information claimed. In this case, for example, a value of 5 determined for vegetation growth rate will be given the same weight in the overall score as that for 'honeypot locations'. These do not seem proportionate measures of actual fire risk.

No comments can be found as to the processes or execution of the questionnaire, in particular how many land-managers were asked, how many responded, and the number of km^2 reported by each. While we understand confidentiality is important this information could, we feel, have been imparted in a format that would circumvent such concerns. Without such information it appears as though acceptance of the approach was universal, which may not be the case.

It is equally unclear how values shown were determined for areas where the land-manager contacted to provide local knowledge did not respond or co-operate. As the Tier 1 maps exhibit no gaps either the response was 100% or the values were determined by someone else. In terms of transparency this point ought to have been addressed.

Barber-Lomax and others (2022) make a number of statements with regard to Tier 1 in their conclusions (Sections 14.1) that require some response.

“ Some elements are more subjective than others but are based on sound analysis”.

They are in fact all totally subjective. However, no sound analysis is presented: no processes to remove/reduce subjectivity, without which Tier 1 only shows differences in opinion between observers; no consideration is given to the need to ensure the scales are graduated to allow for actual fire risk importance otherwise minor elements are given the same rating as major ones.

In addition, it appears that no sensitivity analysis has been executed. So many factors or elements are incorporated into the matrix that are then summed (twice) and then divided that at the end it is totally unclear which factors are actually determining the result presented for each location. This issue is especially important as all elements are judged on the same scale and no weighting of relative importance is undertaken.

“ Tier One assessments, whilst subjective, are particularly useful in identifying areas at high risk from ignition and lacking control measures. Arguably, with the level of detail provided by Tier Three, the group of combustion factors could be excluded from Tier One entirely”.

The freedom to choose to exclude or include factors at will during the process does not create a credible sampling and reporting system. It simply becomes a process that can be altered *ad nauseum* to output whatever result is desired. In this case if you can exclude combustion factors (however poorly they may be determined here) and still identify fire risk, it raises a question of what is driving the results, and what does any of Tier 1 actually represent?

Concluding remarks on Tier 1

Owing to the use of inadequate or inappropriate methodological approaches Tier 1 does not report the evidence it purports to, or if it does, it is practically impossible to determine what it might be. For this reason, we feel it should not be considered as providing any actionable evidence with regard to mitigation of fire risk.

Perhaps the most paradoxical comment under Tier 1, given that the central tenet of Barber-Lomax and others (2022) is one of reducing wildfire occurrence by management, is this:

" It is easy to remove or add matrix factors to the assessment. For example, owing to concerns raised about the current management matrix factor, this element was removed from the combustion total heat map and demonstrated that the removal of factors has very little bearing on the combined total combustion map." (8.8 pg. 60)

Stating that the overall Tier 1 risk assessment does not alter, whether management is included or not, seems a peculiar acknowledgment to make considering the importance given to management as a way of limiting fire risk within the rest of the document. As far as we can interpret, this recognition can only mean one of two things, either:

i: that management has no measurable role to play in overall fire risk;

ii: that Tier 1 is so flawed that it produces evidence contrary to the overall conclusions.

TIER 2

Our evaluation of Tier 2 is brief. This arises from the complexities of some of the underlying data and techniques used from McMorrow & Lindley (2006) and Dixon & Chandler (2019) and their application and meaning in this context. These are too labyrinthine and complex to fully present and explain here, given the nature of this brief review. We have however, attempted to summarise enough to identify some concerns with Tier 2. Otherwise, the brevity of this section should in no way be taken as implying an acceptance of any of the other content.

Tier 2 appears part reiteration/part replacement for Tier 1 but utilises a number of GIS analytical/presentational approaches of actual geographic data instead of mapping landowner opinion. As stated earlier, in principle, this is a preferable approach for most of the elements considered within Tier 1, because it is able to deliver more objective and methodologically transparent data. The geographical data that underpins such analyses are generally something of a known quantity, but for the above statement to hold true requires the appropriate choice, and parameterisation, of algorithm being executed. As GIS display algorithms are essentially simple and mechanistic, they will output, within model bounds, whatever is asked of them. In essence, they can be parameterised to produce whatever output for display that is desired. So, whilst the presentation and visualisation of spatial data is one of the main roles of a GIS, it cannot be stated too emphatically that the use of such tools says absolutely nothing about the validity or quality of the data being displayed.

The analysis

The factors considered in Tier 2, as in Tier 1, are grouped as ignition, combustion, and control. The types of data used for 'ignition' are: public rights of way (PROW), pedestrian/vehicular access (from FOG data) and locations of historical fire events. Note this latter factor is not derived from historical events *per se*, but from the outputs of the models of McMorrow & Lindley (2006) and Dixon & Chandler (2019). This raises some concerns.

Combustion factors comprise peat depth and areas of extensive habitat management and the control factor considers vehicular access and the locations of known sources of water.

These data layers are subject to differing extents of spatial ‘buffering’ within the GIS to generate ‘risk zones’, which are then combined to create a combined vulnerability map. The outputs are forwarded to Section 12 where the three Tiers are combined.

Main generic points of concern regarding Tier 2

Buffer zones for the ignition factor are derived from the empirical data of Dixon & Chandler (2019), which builds on the model developed by McMorrow & Lindley (2006). Roads, vehicular access tracks and PROWs, are given a 200 m buffer; car parks one of 2 km. Barber-Lomax and others (2022) however, do not present a buffer for ‘waylines’ (informal paths not listed as PROWs), despite acknowledging in text (p.62) that 90% of ignition events documented by Chandler & Dixon 2019 occurred within 200m of such a 'wayline'. There is an obvious problem with this formulation, which goes unmentioned in Barber-Lomax and others (2022): this striking correlation between a 200 m buffer around waylines and ignition events is a partly spurious one. This is because there are so many waylines, and they are so widely distributed, that almost everywhere in the PDNP is within 200 m of one of them (McMorrow & Lindley 2006, Figure 4.19). The contribution of waylines to Dixon & Chandler’s ignition risk model can be seen in Barber-Lomax and others (Figure 46), which appears to be based on Dixon & Chandler's logistic regression model rather than its multi-criteria evaluation one. Perhaps reasoning that a 200 m buffer around 'waylines' would not successfully represent areas at higher risk of ignition than elsewhere, Barber-Lomax and others (2022) do not include 'waylines' in Tier 2, despite them being variables included in the best two of McMorrow & Lindley's 2006 wildfire models and all three of Dixon & Chandler's (2019) models. As stated, this is the correct decision, but it would have been helpful if Barber-Lomax and others (2022) could have stated the reasons for excluding 'waylines'.

A 2 km buffer is applied around car parks. This is acknowledged in Barber-Lomax and others (2022) as an arbitrary choice. More detail about this choice would be useful since McMorrow & Lindley (2006, p.38) states definitively that car parks were excluded from their model because there was no distance effect of car parks.

Ignition history (9.3.2). The maps of risk based on historical ignition data presented in section 9.3.2 are not independent of those based on public access data presented in section 9.3.1. What is presented here is not really ignition history i.e. based on actual events in the study area. The buffers around access lines and points in 9.3.1 are actually based on Dixon & Chandler's (2019) MCE model, which itself derives from the historical ignition data (Dixon & Chandler 2019, Figures 9-12). These data are then subject to an additional buffering exercise in Figure 48 (a 500 m buffer). In Figure 48, a 200 m buffer is also drawn around Dixon & Chandler's high-risk ignition zone: the 90th centile of the risk distribution from their logistic model. The independent variables in this model, built to explain historical ignitions, are all indirect measures of public access. The same data are therefore effectively presented in three different ways: as raw data (historical ignition points with 500 m buffer in Figure 48); as a variable used in a model to predict the position of the historical ignition points (distance to minor roads and PROWs in Figure 45); and as a buffer drawn around the output of a model based in part on that variable (Figure 48).

The combustion vulnerability zone in Barber-Lomax and others (2022) Tier 2 follows the distribution of deep peat. This assumes that the deeper the peat is, the more wildfire risk there is (p.65). But deep peat areas are generally wetter areas and at lower risk of combustion or in the areas optimally located for re-wetting. In any event the conjecture that deep peat carries a higher wildfire risk requires supporting evidence.

The control map in Tier 2 presents a 1 km buffer around vehicular access and water availability. It seems paradoxical that a variable used to predict ignition events is also used to predict the ability to control such events.

The combined vulnerability map appears to be almost identical to the control element of the Tier 2 analysis. This is despite the fact that it is almost the inverse of the ignition element. In other words, control appears to have been given far more weighting in the output than ignition (or combustion).

The buffers in Barber-Lomax and others (2022) are simple representations of the decay functions derived by McMorrow & Lindley (2006). As Dixon & Chandler (2019, Figures 4 & 5) shows, the McMorrow & Lindley (2006) models built with updated data produce very different risk maps. In creating such models, there is always the possibility of engaging in the sharpshooter’s fallacy, that of drawing the target around the bullet holes. The key question is whether the distribution of ignition events makes it possible to predict future ignition events. The ignition events documented in Dixon & Chandler (2019) are a poor match to the predictions of McMorrow & Lindley's 2006 models, with far fewer events in core areas of moorland in the 2007-2018 dataset. This may indicate that a simple heuristic might be the most appropriate: that the more people use a particular area, the higher the risk of an ignition.

TIER 3

Tier 3 is the technical 'heart' of Barber-Lomax and others(2022). It presents the results of modelled fire behaviour in the Derwent Focus Area, based on weather, the fuel complex represented by the vegetation communities present and landscape connectivity. Two weather scenarios are presented, one of them extreme yet plausible, the other more moderate. Fuel classification has several apparent iterations. Estimates of fire behaviour under the two weather scenarios appear to use FlamMap. Fire behaviour polygons are created, to represent areas of “homogenous fire behaviour” (p.81); the estimated connectivity between these polygons represents the ability of fire to travel across the landscape. This provides, at a wider scale, the identification of fire highways – key potential fire paths across the landscape under different conditions (Figure 69, p.87). The fire behaviour polygons and fire highways are used to identify likely best places to apply fuel reduction management, thereby breaking the connectivity between polygons and weakening the fire highways themselves.

Weather scenarios

The weather scenarios include reasonable worst case fire-supportive conditions, with a dry east wind and temperatures of 27°C.

Fuel complex mapping

The mapping of the Peak District fuel types is based on an improved version of a method used by Aragoneses & Chuvieco (2021), who mapped fuel types over the entire Iberian Peninsula.

Aragoneses & Chuvieco used Sentinel-3 [300m; 5 band] imagery. Two derived bands (NDWI & SAVI) were added, and three seasons of imagery were combined, resulting in 21 bands for classification. 403 training pixels were selected for 14 initial categories, assisted by Google Earth. The initial classes were later merged into 5 “burnable” classes and one “non-burnable” class. A non-parametric classification algorithm was used. Validation was done using Sentinel-2 [20m] imagery and used 500 randomly selected pixels to check majority cover. The 5 burnable classes were divided into 3 densities using MODIS and into 3 biogeographical zones, giving 5 * 3 * 3 = 45 vegetation classes. These were translated into Rothermel fuel classes. There was some overlap between the vegetation classes, resulting in 19 fuel types. The translation between mapped vegetation classes and Rothermel fuel classes is poorly described, and seems to use parameters that are not key features of Rothermel fuel types, including horizontal continuity (Aragoneses & Chuvieco 2.2.2 (D)).

Importantly however Aragoneses & Chuvieco (2021) provides (i) a confusion matrix for their classification and (ii) a translation between their mapped vegetation types and the Rothermel fuel classes. Although Barber-Lomax and others (2022) (p.74) refers to

Aragoneses & Chuvieco (2021), it does not provide a number of vital details about the way the Aragoneses & Chuvieco method was implemented, beyond describing its method as an improvement because it is based on higher-resolution imagery. The following are lacking:

i: date of imagery, the bands used.

ii: information on the selection of training pixels.

iii: details about the classification algorithm (an “Artificial Intelligence” algorithm is mentioned).

iv: information on the selection of validation pixels.

v: accuracy assessment, confusion matrix:

the statement “drone footage was used to confirm data sets” is a wholly inadequate description for the process that should have been undertaken.

vi: translation between mapped vegetation classes and Rothermel fuel classes (the selection of these classes is discussed below in detail).

The situation presented here then is one in which it is impossible to judge the accuracy of the classification, and by extension, any of the conclusions that flow from it.

Finally, it is unclear how peat is incorporated into the model. Rothermel fuel classes do not consider below-ground biomass. This is an important question when the presence of deep peat is presented elsewhere in the Barber-Lomax and others (2022) as a serious risk factor.

The validity of Rothermel fuel classes for UK habitats

Fuel model selection and fire behaviour

Fuel model selection is crucial when predicting fire behaviour. Selecting a more hazardous fuel type than is reflected in the observed community will give rise to more extreme modelled fire scenario predictions, as well as exaggerate the potential of fuel reduction management. Conversely, selecting fuel types with relatively low hazard levels will have the effect of downplaying wildfire risks. This section investigates whether the fuel models used in Tier 3 are appropriate.

Relevant parameters

There were 11 fuel models in Rothermel's 1972 classification, which was expanded to 13 models later in the 1970s. Scott & Burgan (2005) added a further 40 models, which represent in part a sub-setting of the original 13 to capture more of the variability present in each class. The original, more generic types are retained, so that the total available number of fuel types (absent custom models) is 53. An innovation was that the subset of the Scott & Burgan models with a herbaceous content became dynamic, allowing material in the "live" category to be transferred to the "dead" category via curing. This process allows the expanded set to simulate fires outside the period of peak fire risk conditions, which the original model set was unable to do. This situation limits the usefulness of the original grass classes (1-3) in conditions sub-optimal for fires.

The defined parameters that vary between fuel models are:

i: fuel load (dry weight) by size class and category (5 parameters).

ii: the surface area – volume ratios (SAVs) (3 parameters).

iii: fuelbed depth.

iv: the extinction moisture content of dead fuel.

v: the energy content of live and dead fuels.

Fuel loadings are divided among five biomass classes. The two live classes are live woody and live herbaceous. Dead fuel is represented in terms of increasing diameter as 1 hour, 10 hour and 100 hour fuels, as follows:

1 hour fuel = narrower than 0.25"

10 hour fuel = between 0.25" and 1"

100 hour fuel = between 1” and 3”

The surface area – volume ratios are constant for 10 and 100 hour fuels, so only vary for 3 of the 5 fuel classes. The fuel SAVs are combined to create a “characteristic” SAV, which emphasises the contribution of finer fuels. The extinction moisture content is the moisture level at which dead fuels will no longer burn freely. Finally, the energy content of the fuel itself varies only for one of the 53 classes (GR6, or number 106).

The set parameters give rise to derived variables that are important in the calculation of fire spread, in particular bulk density and relative packing ratio. The following equations, which are relevant to discussions below, are taken from Andrews (2018).

Bulk density, ρ_b is the fuel load in lb/ft^2 divided by the fuelbed depth in ft:

$$\rho_b = w_0/\delta$$

Packing ratio, β is bulk density divided by particle density, which is held constant:

$$\beta = \rho_b/\rho_p$$

Packing ratio is a measure of how spread out the fuel is. If there are no air spaces at all, bulk density would equal particle density, and β would be 1. In natural fuels the packing ratio is very much smaller than 1. Importantly, increasing the fuel bed depth automatically decreases the packing ratio, which in turn increases slope and wind factors in the rate of spread equation (increasing the rate of spread and other measures of fire behaviour). The optimum packing ratio is the packing ratio that optimises the countervailing forces of fire residence time and reaction intensity, and is a function of the characteristic SAV. The relative packing ratio is the ratio between the packing ratio and the optimum packing ratio; reaction velocity is at a maximum when the ratio is 1.

Fuel model choice: Peak District Fuel Models in Tier 3

The choice and parameterisation of the fire behaviour fuel models reported in Tier 3 is in no way made clear. In particular there is no discussion or rationale, no tables or text, regarding the crucially important process of matching Rothermel fuel models developed for the US forestry service to Peak District vegetation communities.

The only map of fuel models shown is for Bradfield Moor (Barber-Lomax and others 2022: Figure 62), which does not have a legend or associated text explaining what it shows. However, more detail on the probable fuel models used can be gleaned from the appendices.

The following discussion therefore is based upon what, to us, appears to be the reasonable assumption that the descriptions in the appendices represents, in general, the method reported in Tier 3 as a whole.

The first case study in Appendix B (Figure B3 – to which the reader is urged to refer for clarity) presents a poor quality fuel model map of Mossy Lea, this time with a legend showing fuel classes from the expanded Scott & Burgan (2005) set. From this figure it can be seen that Polygon 4 appears to be rotationally-managed heather and the colours in this polygon match classes 4, 5 and 6 in the legend. These classes and their description are shown in Table 3 (overleaf).

Table 3. Fuel models used in the Barber-Lomax and others(2022) Mossy Lea case study, with the vegetation types they represent.

Model code	Description in Anderson (1982) and height of fuelbed in model	Apparent vegetation type represented by model in Figure B3 (via inspection of satellite imagery)
1	Short grass 1’	Improved grass (enclosed)
2	Timber (grass and understorey) 1’	Grass/sedge
4	Chaparral 6’	Mature heather
5	Brush 2’	Young heather
6	Dormant brush, hardwood slash 2.5’	New burn in the rotationally-managed heather area; potentially a mixture of bilberry and grass/sedge elsewhere
9	Hardwood litter 0.2’	Woodland adjacent to reservoir
98	Open water (Scott & Burgan, 2005)	Reservoir

Some of the fuel models appear to be appropriate, but at least two are questionable: the mature heather and new burn classes. The following discussion is largely restricted to the choice of chaparral, Rothermel fuel class 4, for mature heather, but it is noted that fuel class 6 is unlikely to represent new burns well, and it is arguable that enclosed grazing might be better represented by the agricultural (non-burnable) class NB3 (93).

Chaparral is taller than heather, and even if it was otherwise representative of *Calluna*-dominated moorland, the overestimation of fuel depth that choosing it results in is likely to lead to excessive modelled predictions of fire behaviour.

As noted bulk density is calculated by dividing the fuel load by the fuelbed depth. The density is therefore inversely related to the fuelbed depth. Bulk density appears in the denominator of the Rothermel rate of spread equation (similar comments apply to fireline intensity and flame length, which are derived from the rate of spread). (This is not a direct and simple relationship, because bulk density is used to calculate packing ratio, which appears in the equation used to calculate the optimum reaction velocity and the propagating flux ratio.) Figures 3 and 4 illustrate the effect of fuel model choice on predicted fire behaviour. In each case the comparison is between Rothermel class 4 – chaparral – and class SH6 (low load, humid climate shrub) from the expanded set of Scott & Burgan, both here representing potential models for mature *Calluna* stands, chaparral as apparently used in Barber-Lomax and others (2022), and SH6 as a potentially plausible alternative.

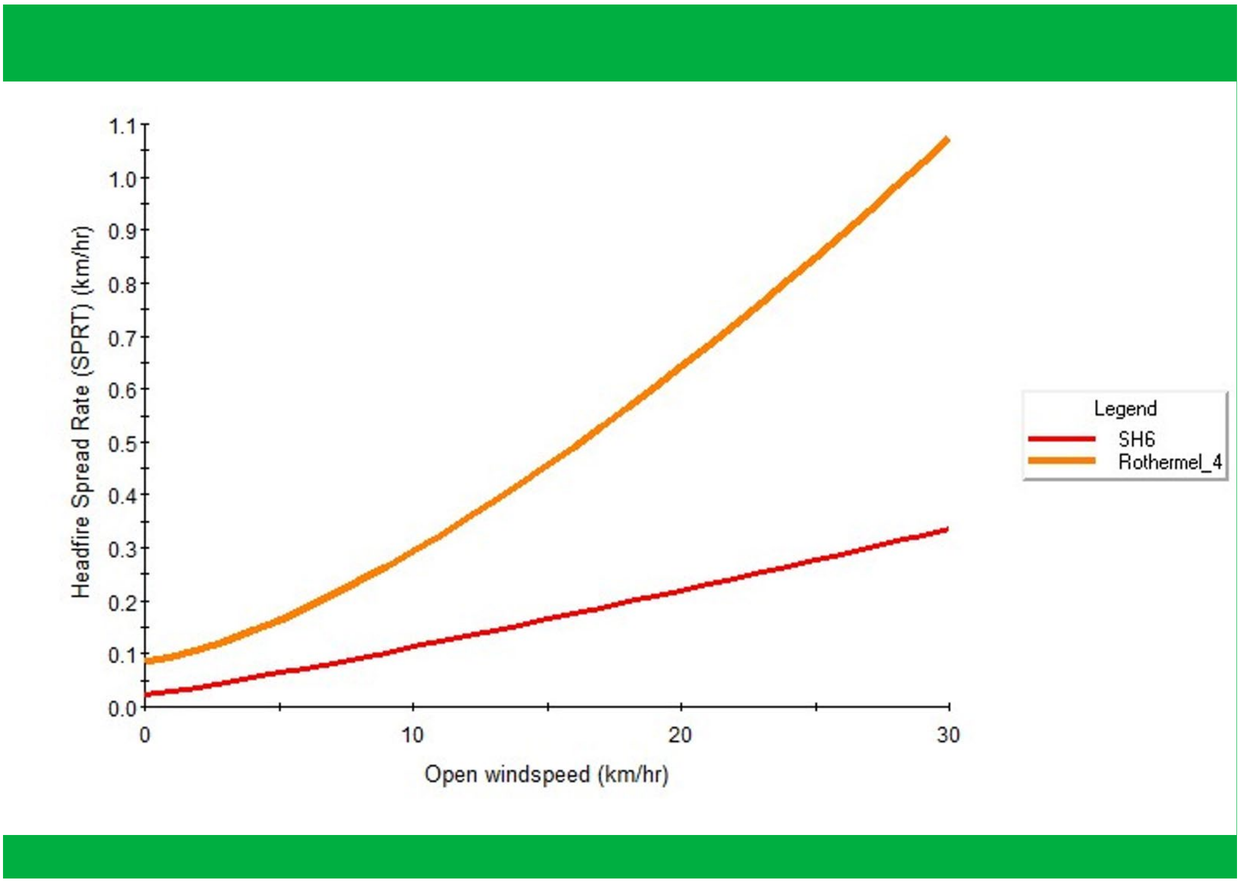

Figure 1. Rate of spread for Rothermel class 4 and Scott & Burgan's SH6 on level ground; non-fuel parameters held constant. Output from Nexus 2.1. © 2018 Pyrologix.

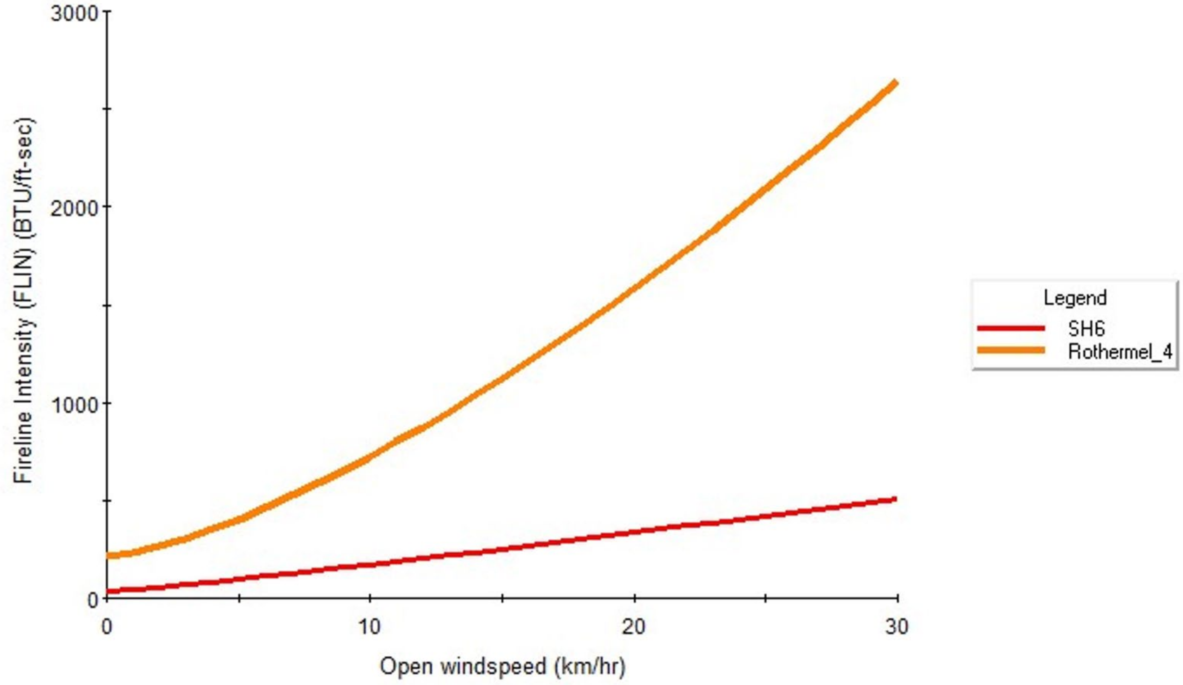

Figure 2. Fireline intensity for Rothermel class 4 and Scott & Burgan’s SH6 on level ground; non-fuel parameters held constant. Output from Nexus 2.1. © 2018 Pyrologix.

The alternative fuel model used here, SH6, is “Low load, humid climate shrub.” It is described thus: “The primary carrier of fire in SH6 is woody shrubs and shrub litter. Dense shrubs, little or no herbaceous fuel, fuelbed depth about 2 feet. Spread rate is high; flame length high.”

Whether SH6 is the appropriate class to use to represent mature heather is discussed below. But another clear illustration of the principle is shown in the following two figures. Here, a custom fuel model has been used in Nexus 2.1, which contains all the same parameters as Rothermel 4 (chaparral) but is reduced to 3’ high instead of 6’.

Note on the graph in Figure 3 that the orange line representing the Rothermel 4 fuel model, is concealed under the 6 Chapparal fuel model that is represented by the green line.

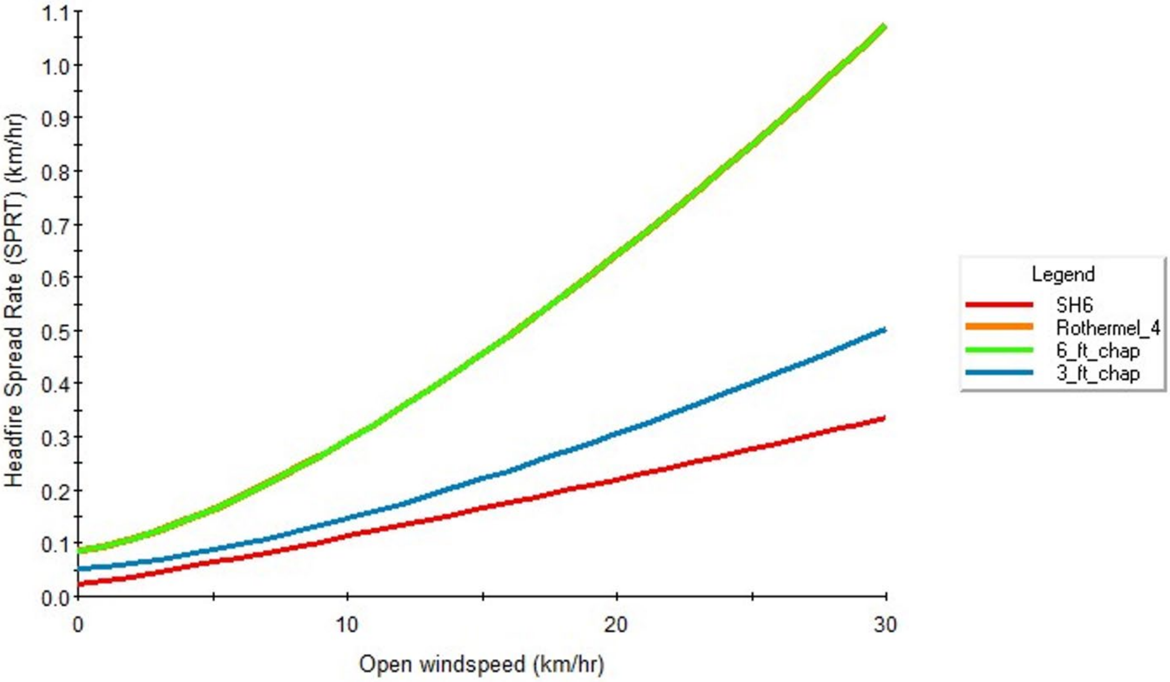

Figure 3. Rate of spread for two custom fuel models, 6’ chaparral and 3’ chaparral. SH6 is still shown. The original line for Rothermel 4 is hidden behind the new emulated fuel model for 6’ chaparral in green, showing that the two fuel models are identical. Level ground; non-fuel parameters held constant. Output from Nexus 2.1. © 2018 Pyrologix.

Note on Figure 4 below that the orange line representing the Rothermel_4 fuel model, is concealed under the 6 Chapparal fuel model that is represented by the green line.

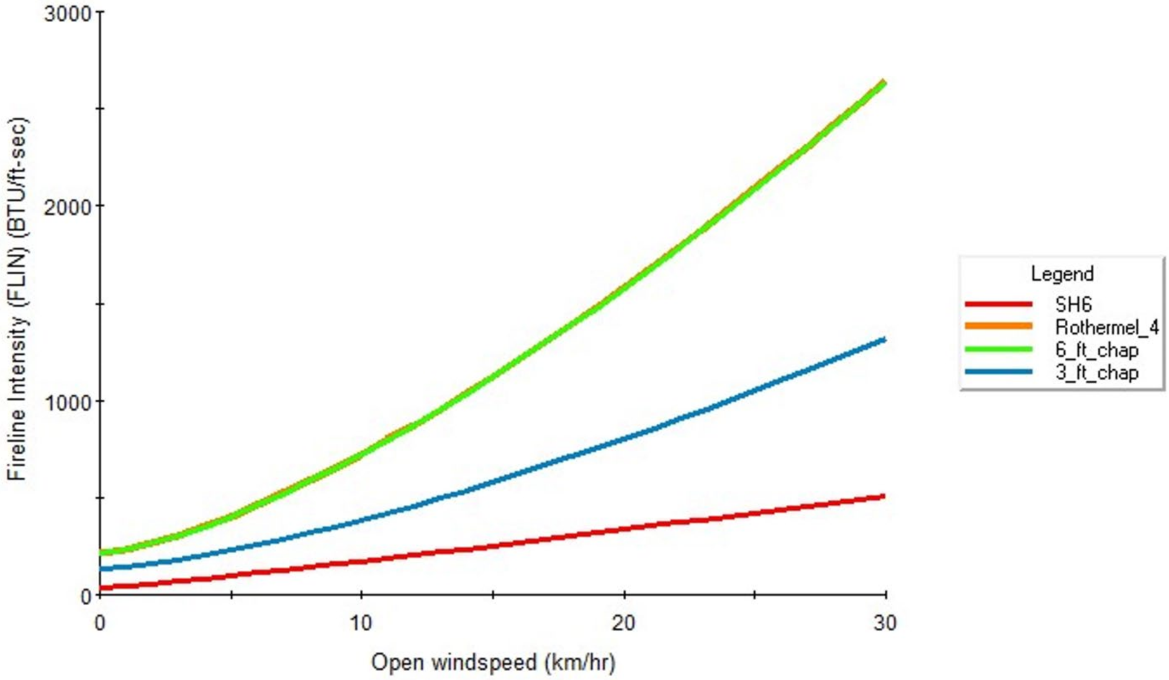

Figure 4. Fireline intensity for two custom fuel models, 6’ chaparral and 3’ chaparral. SH6 is still shown. The original line for Rothermel 4 is hidden behind the new emulated fuel model for 6’ chaparral in green, showing that the two fuel models are identical. Level ground; non-fuel parameters held constant. Output from Nexus 2.1. © 2018 Pyrologix.

Both figures 3 and 4 show the effect of selecting a fuel model whose fuelbed depth is too high, which is to overestimate potential fire behaviour.

There is therefore evidence that in some cases the use of inappropriate fuel models may have given rise to excessive modelled predictions of fire behaviour. As well as giving rise to excessive risk estimates, the use of more hazardous fuel models than is warranted may also overstate the potential for fuel management to mitigate that risk. In FlamMap, the treatment optimization module (TOM) compares the existing fuel map with an “ideal” landscape where fuel loads are greatly reduced. It then identifies places in the landscape where fuel treatments have the strongest effect on slowing the rate of spread of a fire under particular conditions. It is likely therefore that TOM will select areas of the landscape with excessively-hazardous fuel models, e.g. areas mapped as chaparral, for treatment. Barber-Lomax and others (2022) do not appear to have used TOM in FlamMap to determine the best location for potential firebreaks (e.g. Barber-Lomax and others (2022) Figure 77); the method used for generating these is unclear.

It is beyond the scope of this review to assign fire behaviour fuel types to all Peak District moorland communities. The key community at issue from the perspective of Barber-Lomax and others (2022) appears to be rotationally-managed *Calluna*, the mature phase of which appears to have been classified as Rothermel fuel class 4 in Barber-Lomax and others (2022). The following table compares the parameters that Legg and others (2007) estimated for mature heather with those for two standard Rothermel classes: 4, as apparently used to represent mature heather in the Mossy Lea case study (and presumably more widely) and SH6, presented here as a potential alternative fuel model in the above figures.

Table 4. Legg and others Calluna fuel model compared with Rothermel class 4 and Scott & Burgan's SH6

Parameter value/estimate	*Calluna* stands with "high" fuel load [1]	4 (original set) (chaparral)	SH6 (exp. set; 146) (low load, humid climate shrub)
Load, t/ac **Of which:**	6.2	16	5.75
1-h	1.3	5.0	2.9
10-h	0.0	4.0	1.45
100-h	0.0	2.0	0.0
Live herbaceous	0.0	0.0	0.0
Live woody	4.9	5.0	1.4
Fuelbed depth (ft)	1.33	6.0	2.0
Dead fuel moisture of extinction (%)	30	20	30
Characteristic SAV, σ (ft^{-2}/ft^{-3})	2640	1739	1144

Parameter value/estimate	*Calluna* stands with "high" fuel load [1]	4 (original set) (chaparral)	SH6 (exp. set; 146) (low load, humid climate shrub)
Bulk density, ρ_b (lb/ft^3)	0.22	0.12	0.13
Relative packing ratio, β/β_{opt}	1.31	0.52	0.39

[1] Legg and others 2007. [2] Andrews, 2018 Table 8a. [3] Andrews, 2018 Table 8c

Key features of the Legg and others (2007) *Calluna* model are its short stature and high surface area to volume ratio. Chaparral is too tall to be a realistic model for *Calluna*, therefore exhibiting more extreme fire behaviour than *Calluna* stands. SH6, although of appropriate stature for a model representing *Calluna*, has a relatively low characteristic surface area to volume ratio and might therefore be too conservative a choice. This suggests that a custom fuel model might be required to represent mature *Calluna* rather than selecting one from the original set of 13 or the expanded set of 53 Rothermel fuel models.

It is likely that appropriate models are available in the expanded Rothermel set for Peak District grass/sedge communities, but it is unclear whether appropriate mixed shrub/grass models are available. Available models may adequately capture bilberry/grass mixtures but not necessarily *Calluna*/grass mixtures because of *Calluna*'s high surface area to volume ratios.

It is worth noting at this point that the original 13 Rothermel classes have a number of disadvantages over the Scott & Burgan expanded set. As Scott & Burgan (2005, p.2) state:

"The original 13 fire behavior fuel models are "for the severe period of the fire season when wildfires pose greater control problems..." (Anderson 1982). Those fuel models have worked well for predicting spread rate and intensity of active fires at peak of fire season in part because the associated dry conditions lead to a more uniform fuel complex, an important assumption of the underlying fire spread model (Rothermel 1972). However, they have deficiencies for other purposes, including prescribed fire, wildland fire use, simulating the effects of fuel treatments on potential fire behavior, and simulating transition to crown fire using crown fire initiation models".

In other words, the original set of 13 classes are appropriate for considering worst case scenarios, but not for typical conditions or assessing fuel treatments. Of the original grass models, Scott & Burgan (2005) say (p.2-3):

"For example, the original grass models 1 (short grass) and 3 (tall grass) are fully cured to represent the most severe part of the fire season. Applying those fuel models to situations in which the grass fuelbed is not fully cured (that is, outside the severe part of the fire season) leads to overprediction".

The 40 additional fuel models that include herbaceous fuel (i.e. mostly the grass and shrub/grass classes) are dynamic, which is to say that live fuel is transferred to dead fuel as curing occurs in extended periods of dry weather. For this reason, class 1 and 2 from the original set (apparently used by Barber-Lomax and others (2022) in the Mossy Lea case study, and presumably elsewhere) would only produce valid predictions under extreme conditions, even if the underlying class type choice was correct. This means that dynamic fuels from the expanded set should be chosen for the grass/sedge communities. (It is acknowledged that one of the two main scenarios presented in Barber-Lomax and others (2022) is an extreme one, in which fully-cured fuel is appropriate.)

An additional point is that the seasonal growth of certain herbaceous fuels complicate the use of fuel classes from the original or expanded set, and make the use of custom fuel models more appealing. Two obvious examples here are *Molinia* and bracken, with seasonal variation in the quantity of dead material that does not peak in summer (e.g. Santana & Marrs, 2016 for *Molinia*). More detailed consideration of these issues is warranted.

Mapping structure rather than species; time-dependent processes

As noted above, the different seral phases of heather are mapped as different fuel classes in Barber-Lomax and others (2022). This is an appropriate approach to take in principle, but brings with it potential practical difficulties. The first is the difficulty of assigning fuel classes to the different heather stages. As Table 3 shows, there is evidence that this has not been done appropriately in the Mossy Lea case study at least. If, however, appropriate Rothermel classes are found, or if appropriate custom fuel models are built, a second practical problem arises, which is that the fuel model map will have to be updated annually for predicted fire behaviour to make sense. This would require an annual mapping process to update areas of managed burns, as well as a mechanism to allow heather stands to move into the next fuel class as time passed.

Flame length, rate of spread and fireline intensity

Maps of these three measures of fire behaviour are presented by Barber-Lomax and others (2022) for two scenarios: an easterly wind of 9 km/h at 21C and 31% R.H. (Scenario A), and an easterly wind of 30 km/h, 27C and 19% R.H. (Scenario B).

Recognising the uncertainty over the suitability of the fuel mapping, there is reason to suppose that these fire behaviour maps do not represent realistic predictions. However, although the choice of fuel model is critical, FlamMap runs also require environmental parameters. For example, it is unclear whether a weather stream was used to condition fuels, or whether fixed fuel moisture levels were used. The height at which the wind is measured may also vary, between the U.S. default (20') and the standard elsewhere (10 m). Because wind increases with height above the ground, the effective windspeed difference between the two heights is a factor of 1.33. The wind at 10 m or 20' is reduced in the model based on the degree of shelter and the fuel type; default or custom values may be used. The resultant effective midflame windspeed has a direct effect on fire intensity.

The extreme depiction of fire behaviour shown (e.g., for flame length showing values of >6.5 m in Barber-Lomax and others (2022) Figure 63(b)) appears to be a potential output from Nexus under some settings for Rothermel fuel model 4 (chaparral) but not SH6 from the expanded set (low load, humid climate shrub), showing the critical importance of selecting the correct fuel model. Similar comments apply to rate of spread and fireline intensity.

Fire behaviour polygons, connectivity and fire highways

Fire behaviour polygons

The method for creating fire behaviour polygons (described as "polygons of homogenous fire behaviour") is unclear. The algorithm "combines data on watershed, aspect, slope and fuel type, predicting projected fire behaviour." (Barber-Lomax and others (2022), p.81). The reader is referred to Castellnou and others (2019) for in-depth information on the fire behaviour polygons approach. However, the description of the method provided in Castellnou and others (2019) is one that is not directly applicable to the Peak District. The clearest description of the method in Castellnou and others (2019), regarding the 2014 Tivissa fire, is "Four polygons were identified representing the fire potential according to type of fire behavior based on terrain and fuel types (Fig. 4). Historical fires in the area, from years 1989 and 1967 (3285 ha and 11 598 ha, respectively), were also used as references to define the polygons." The implication is that the fire polygons are even-aged stands of pine divided by slope, aspect and elevation parameters, but there is insufficient detail to allow replication.

"A polygon of fire potential identifies spatial units for which fire behaviour (i.e., high, medium, low) is expected to be homogeneous", according to Castellnou and others. (2019). The implication, as translated to the Peak District, is that terrain and plant communities within fire behaviour polygons will themselves be uniform. However, inspection of the 400 ha polygons developed for the Derwent focus area in Barber-Lomax and others (2022) show that polygon boundaries frequently follow watercourses and that they do not necessarily contain (visually at least) homogenous plant communities. Watercourses may offer good opportunities to interrupt wildfires, and it may be rational to divide the Peak District landscape up in this manner. But in this sense the properties of the polygons themselves seem to be less important than the properties of their boundaries. In other words, fuel in the polygons appears to be less important than the potential firebreaks between them.

The fireline intensity maps (Figure 65a,b; p.80-81) appear to have discontinuities jumping several categories (up to 6 in Figure 65b). The boundaries between fire behaviour polygons are “where fire behaviour is likely to alter” (p.81) but they do not follow the discontinuities in previous figures. It is appreciated that the fireline intensity maps are calculated for wind from a certain direction and that polygons might be generated in more generalised ways. Nevertheless, as stated, polygon boundaries often follow landscape features (particularly channels), indicating that the fuel model is less important than natural firebreaks in determining the polygons.

Although the reader is referred to Castellnou and others (2019) for the landscape-dividing method, insufficient detail is provided there to apply it to a new landscape.

Landscape connectivity between polygons; fire highways

The method for determining the strength of connection between adjacent polygons is unclear. This may be based on a combination of the probability that a fire from a certain vector will bridge the gap between polygons and the fuel types of the donating/receiving polygons, but no detail on this is provided in Barber-Lomax and others (2022) or Castellnou and others (2019).

Figure 66b shows the strength of connection between 400 ha polygons in the Derwent focus area under weather scenario “B”. The strength of connections is difficult to interpret. As an example, the connection between Polygon 26 and Polygon 25 is red – beyond FRS control – but the fireline intensity for 100s of metres either side of their common boundary (Figure 65b) is low (within FRS control). Similarly, most of the connections between polygons whose fireline intensity is generally low (within FRS control) are medium (potentially within FRS control). Without a full description of the method, it is impossible to understand the reasons for such apparently anomalous behaviour.

The fire highways (Figure 69) do not appear to resemble the strength of connections between polygons. They generally approximate the wind direction of the relevant weather scenario, but it is worth noting that two of the fire highways for the “B” weather scenario are parallel and at about 23° to the direction of the wind. Without a sufficient explanation of the method for deriving them, it is impossible to assess their value.

Fire behaviour heat map

In their Figure 70, Barber-Lomax and others (2022) present a “fire behaviour heat map”, combining three measures of fire behaviour – rate of spread, fireline intensity and flame length – into one map. This is not a useful presentation because the three metrics of fire behaviour are not independent from one another. Rate of spread, R, is a function of reaction intensity I_R (equations simplified from Andrews, 2018):

$$R = f(I_R)$$

Fireline intensity, I_B, is a function of the product of R and I_R:

$$I_B = f(R.I_R)$$

And flame length, F_B is a direct function of fireline intensity:

$$F_B = f(I_B)$$

In other words, these variables are all different ways of measuring the same thing – the intensity of fire behaviour. Stacking them can only have the effect of making variation across the landscape appear more extreme (in effect, turning an arithmetical relationship between measured fire risk into a geometrical one).

Mitigation; strategic management areas

Landscape connectivity as described is used in Barber-Lomax and others (2022) to suggest strategic management areas, places where there is potential to interrupt fire highways across the landscape, although it is not clear whether this was done formally. It is worth noting that an “off the shelf” mitigation algorithm is available in FlamMap. The treatment optimisation model (TOM) in FlamMap predicts a modelled fire’s major flow paths. These are quite different in appearance to those in Barber-Lomax and others (2022), because TOM is pixel-based. However, the advantage of polygons in modelling fire behaviour has not been well explained in Barber-Lomax and others (2022). An obvious question is why the widely-used and well understood method available in FlamMap was not chosen in Barber-Lomax and others (2022). A potential reason might be that the fire behaviour polygons are more readily understandable land units for stakeholders. However, if this were the reason, it would still be possible to undertake pixel-based analysis and subsequently present the results in a more interpretable form if required, to in other words simplify the output but not the analysis.

Minor Issues – Tier 3

Weather pattern “A” (Figure 57; p.71) is the same as weather pattern “B” (Figure 58; p.72).

Various units for fireline intensity are shown, some of which are typographical errors. There is “BTR/m-s” (e.g. Figure 65(a) and (b) and Table 21), “BTR/ft-s” (Table 21), “British thermal units per second per feet, which has been converted to metres for easier interpretation” (p.80) and “BUT m-s” (p.87). Outputs from FlamMap and Nexus are available in metric units (i.e. for fireline intensity, kW m^{-1}).

Incidental responses to some in-text comments

As discussed earlier, Barber-Lomax and others (2022) contains a large number of statements, presented as bold fact but with no citation, or reference to data, to support them. To identify them all in such a large document is well beyond the scope of this brief review. However, we include one here which may be falsely interpreted as evidence-based statements.

12.1.2 • Manage fuel complex at high-risk ignition points *pg 96*

“Tier One and Two assessments highlight the areas at highest risk of ignition (based on the level of public access and historic ignitions) being those on the fringes of the moorland. These areas tend to be shallow peat and subject to more intensive management (grazing and controlled burning) than the deeper reaches of the moor. Managing the fuel complex in these areas, to reduce fire behaviour (in particular rate of spread, i.e. reducing fine fuels) provides opportunity to extinguish fires efficiently and reduce the potential of spread”.

Disregarding the inherent problems with the processes of Tier 1 and 2, this makes two strong statements that either need to be supported by evidence or be withdrawn.

i: what evidence is there that controlled burning is less intense on deep peat?

Our own evidence (Thacker and others 2015) is that, up to 2021, there has generally been little difference in the intensity of heather burning on shallow/mineral soils compared to deep peat in England overall: in the Peak District it was, in fact, more intense.

ii: what is the evidence that a: fire behaviour is significantly different on rotationally-burned moorland compared to that not managed in this way, and b: that this translates into improved ability to extinguish wildfires? Holland and others 2022 found a lack of any evidence to support this conjecture.

Concluding observations and remarks

In setting out to provide unbiased evidence about the risk of wildfires in the PDNP, Barber-Lomax and others (2022) has a laudable motive. It represents a significant application of effort towards understanding important issues around wildfire risk and mitigation, with ideas that have potential application on a wider scale. The approach of separating likelihood and hazard in estimating overall risk (although not described in those terms) is useful.

Ultimately though, Barber-Lomax and others (2022) builds to a simple message, that reducing fuel load is the only option to reduce an "*..ever-growing threat"* (pg. 29). Although a number of options to achieve this are listed, writ large within this theme this is that controlled burning is the primary way to achieve this end, and explicit within this message is that management burning regimes on deep peat are essential in reducing wildfire risk. Yet such notions run counter to many observations:

i: 'wildfires' in PDNP have occurred, and have run their course, in past despite intense rotational burning on heather moorland including, over the previous 2 decades, the virtually ubiquitous burning of heather on deep peat over that period.

ii: If managed burning regimes were essential in lowering wildfire risk within the PDNP, it would have been expected to manifest as a rapid decline in wildfire events as controlled-burning regimes on both shallow and deep peat increased precipitously during the late 1990s and early 2000s (Yallop and others 2006[a], 2009). Over the first two decades of this century such management became essentially ubiquitous in heather-dominated deep peat areas of the PDNP (Yallop and others 2006[b]; Thacker and others 2015). Over that time concerns about wildfires have actually increased.

iii: where 'wildfires' occur in the uplands they readily track across areas already managed by controlled burning; running counter to the premise that it provides some 'protection' to these areas. While it can be considered that individual controlled burn scars, when very young, will burn at a different rate and intensity from the surrounding older matrix, there is no evidence that the overall outcome of any particular wildfire event is changed by them.

We would be happy to revise this statement upon seeing evidence of a wildfire stopping as it entered a controlled burned moorland as we have not witnessed this phenomenon in more than 2 decades of mapping moorland burns.

iv: numerous 'wildfire' events have their origins in 'escaped' controlled burns, this will only continue where managed burning continues.

This is evidenced both by our own extensive mapping of controlled-burning in the English uplands and by Holland and others (2022).

iv: large swathes of upland moorland comprise large fuel-loads arising from vegetation types that have not been part of controlled burning regimes within the PDNP for many decades. These include extensive *Molina* swards and areas of *Pteridium* litter. Both are probably the most concerning from the point of view of fire intensity, speed of spread and hence difficulty to control.

We acknowledge, and fully concur with, the observation by Barber-Lomax and others (2022) (14.2 pg 110) “Finer fuels e.g. molinia grass, can support very fast-moving fires that will spread at a speed that will be difficult or impossible to contain”.

There is little to add here. *Molina* swards do indeed give rise to wildfire concern. However, we do not see how controlled burning of heather on deep peat, or any other substratum for that matter, is supposed to play any part in addressing fire risk in other habitats and Barber-Lomax and others (2022) does not explain this.

Conclusion

Barber-Lomax and others (2022) adopts what can be considered inappropriate methods: Tier 1 uses opinion, together with unsuitable area scaling, in lieu of empirical data. Tier 2 adopts data from an earlier study and applies them in an inappropriate way and without apparent appreciation of their derivation and meaning. Even where it adopts long-established fire models (Tier 3) it presents no details as to their parametrisation and execution; how fuel loads were derived from EO imagery, or the error bounds associated with that process. No less important is the absence of either rationale or justification for the process and size used for the extraction of homogenous fire-behaviour polygons. Without these the modelled outcomes lack any real credence. This is particularly critical in this case as such models do not have a history of application in these habitats in the UK.

In conclusion Barber-Lomax and others (2022) lacks any clarity to the methodological approaches it presents, something considered a minimum to be accepted as scientific and objective research suitable for policy guidance.

Recommendations

If fire-modelling is to be considered useful within the PDNP, it requires, as a minimum, rigorous testing in the much finer spatial heterogeneities of fuel load/slope/moisture seen within PDNP moorland, than in the forested/tall dense-scrub environments in which they are more usually deployed. The existing wildfire dataset, combined with meteorological information for the date/time of events, could provide opportunities for some validation of modelled results to take place. However, any future work should also reasonably be expected to include probabilistic analyses of fire occurrences based on past weather/fire data experienced across the PDNP.

The presentation of a suite of scenarios, across a range of meteorological probabilities, would provide information of considerably more use for planning mitigation/response strategies than that provided in the ‘worse-case’ example of Barber-Lomax and others (2022).

However, we would postulate that the need for such non-falsifiable modelled studies remains to be made. It is implausible that they are ever likely to provide the predictive accuracies and spatial resolutions required to either assist significantly for local mitigation and preparation planning or, particularly, in defining tactical responses to active fires. We are not going to prevent wildfires by having models for, as Barber-Lomax and others (2022) points out, wildfires are inevitable events. If this is accepted it would seem more pragmatic and pertinent to improve local plans, equipment, and resource availability now. To facilitate this a number of actions could be considered helpful in improving understanding of wildfire behaviour in the PDNP beyond that gained from mechanistic models.

Wildfire recording

Owing to its historical and evolving nature, the current wildfire recording design is somewhat *ad hoc*. The GIS design should be improved to a full geodatabase (if this has not already been undertaken) and the database kept up to date. This would be assisted if submission of fire records by not only relevant FRS but also private landowners were considered a social responsibility. Attempts to address the current lacunae in the past record (see Titterton & Crouch 2022) should be made and organisations and individuals encourage to contribute. All future recording should include:

i: details of the vegetation in which the fire commenced should be recorded.

ii: mapped fire extents should be contained within the GIS by using UAV or EO imagery, should be considered the minimum standard expected for all large fires of >1 ha.

iii: georeferenced ground, UAV and EO imagery of the fire ‘scar’ should be incorporated into the database.

iv: where it can be established, the source of the ignition should be recorded within the GIS as a point feature.

Research

An historical GIS record of visible wildfire ‘scars’ for the past 2 decades should be created using archive airborne and EO imagery.

Analyses of such mapped fire events, together with other associated data such as topography etc, would provide information regarding which habitats/vegetation communities wildfires occur in, how they spread and, in particular, whether rotationally-managed areas have a lower wildfire risk than unmanaged moorland.

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