Improvement Programme for England's Natura 2000 Sites (IPENS) – Planning for the Future IPENS055

# Burning in the English Uplands - A Review, Reconciliation and Comparison of Results of Natural England's Burn Monitoring: 2005 - 2014

## Multiple Natura 2000 sites within the English Uplands

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*This project is part of the IPENS programme (LIFE11NAT/UK/000384IPENS) which is financially supported by LIFE, a financial instrument of the European Community'.*

# Foreword

The **Improvement Programme for England's Natura 2000 sites (IPENS)**, supported by European Union LIFE+ funding, is a new strategic approach to managing England's Natura 2000 sites. It is enabling Natural England, the Environment Agency, and other key partners to plan what, how, where and when they will target their efforts on Natura 2000 sites and areas surrounding them.

As part of the IPENS programme, we are identifying gaps in our knowledge and, where possible, addressing these through a range of evidence projects. The project findings are being used to help develop our Theme Plans and Site Improvement Plans. This report is one of the evidence project studies we commissioned.

There is a long history of the use of fire as a management tool within the UK uplands and it is supposed that early hunters and farmers used burning to promote fresh growth for the management of prey animals and domesticated livestock. In the last 200 years, fire in the form of rotational burning has mainly been associated with livestock grazing and the management of grouse for shooting. Increasingly, in the English uplands, the emphasis upon burning has been for the management of heather by the grouse shooting industry and in England, this is pronounced in the Pennines, North York Moors and Bowland Fells.

Rotational burning is subject to the guidance set out in the Heather and Grass Burning Code which has been through several revisions over time. Many upland areas in England are designated under domestic and international nature conservation legislation designed to protect their nature conservation interest. As a result, rotational burning is an activity that will often require consent from the statutory nature conservation agency for England (Natural England) and payments are also made through agri-environment schemes so that burning is carried out in ways that are intended to ensure environmental benefits.

Until recently, we did not have the technical capability for monitoring rotational burning but a method has now been developed that makes this possible. This project has allowed the development of GIS products that can be used to implement a programme of monitoring of rotational burning.

This report has two objectives. The first is to provide a summary of the history of rotational burning in the English uplands going back 60 – 70 years. This is to help provide historical context from data on the intensity and scale of rotational burning since World War 2 which can then be compared with rotational burning as is currently practiced. The second objective is to interpret the GIS products from the work and place them in a form that can be readily understood by the non-specialist reader.

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# IPENS 055

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A Review, Reconciliation and Comparison of Results of Natural England's Burn Monitoring : 2005-2014

TECHNICAL REPORT

NATURAL ENGLAND

# IPENS 055

# Burning in the English Uplands

## A Review, Reconciliation and Comparison of Results of Natural England's Burn Monitoring : 2005-2014

### Submission to Natural England – December 2014

This project is part of the IPENS programme (LIFE11NAT/UK/000384IPENS) which is financially supported by LIFE, a financial instrument of the European Community'

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The project was funded under IPENS. The Improvement Programme for England's Natura 2000 Sites (IPENS), supported by EU LIFE+, is a new strategic approach to managing England's Natura 2000 sites. It will enable Natural England, the Environment Agency, and other key partners to plan what, how, where and when they will target their efforts on Natura 2000 sites and areas surrounding them.

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This project was managed by Alistair Crowle at Natural England and we are grateful to him for his comments and guidance throughout this study. Comments on an earlier draft were made by David Glaves at Natural England.

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## Executive Summary

Natura 2000 sites are protected under European legislation and burning on their constituent SSSIs requires consent from Natural England. The 'Heather and Grass Burning Code' also has a presumption against burning on deep or ‘blanket’ peat without the agreement of Natural England. Currently there is no systematic monitoring of moorland burning in upland England and therefore no data on the efficacy of current voluntary and legal controls.

To partly redress this issue, a reconciliation and re-analysis of the results of a series of *ad hoc* moorland burn mapping exercises has been undertaken to provide estimates for the extent of managed burning on blanket peat in England for the first time. Results from a national sample of 2% of the English uplands using historical imagery have also been included to provide a history of changes in burning practices over the second half of the 20th century and the beginning of the 21st.

An area of >33km$^2$ of new burns are executed on heather-dominated upland deep peat soils (bog or degraded bog habitat) annually. This estimate will undoubtedly rise as currently unmapped areas are added.

Contemporary burning regimes on deep peat are essentially as intense as those on other soil types (3.76% yr$^{-1}$ vs 3.99% yr$^{-1}$ respectively) and forty percent of all burning now occurs on deep peat. On average across England fire return times are in the region of twenty times more frequent than evidence suggests is required to permit full ecosystem recovery. In many regions, areas of deep peat are actually more intensively managed by burning than other soils, including the North York Moors, the Yorkshire Dales, the Peak District and Nidderdale AONB.

The extent and intensity of moorland burning has increased markedly since the 1940s. This has in fact occurred to a greater extent on deep peat than on other soil types: from 5.3km$^2$ yr$^{-1}$ in 1945-1959 to 38.9km$^2$ yr$^{-1}$ in 2010. Burning has also expanded from more accessible areas of upland heath on moorland fringes up onto blanket bogs, and in places there is evidence that a combination of artificial drainage and burning has helped to develop heath-type vegetation on deep peat.

The figures presented here show that there is little difference in burning regimes undertaken on areas of deep peat compared to other soil types and indeed recent increases in burn intensity have occurred mainly on deep peat soils. Of the deep peat mapped in the studies summarised here over half is heather-dominated and managed to some degree by burning.

## 1: Introduction

There is currently much debate about the impacts of rotational burning on the biodiversity, nature conservation interest and wider ecosystem services of upland habitats and, in particular, on blanket bog habitats (for reviews see: Tucker, 2003; Stewart et al., 2004; Worrall et al., 2011; IUCN, 2011; Glaves et al., 2013).

Guidance on rotational burning practice is provided by Defra through the ‘The Heather and Grass Burning Code’ (issued previously by MAFF in 1992 and republished in slightly amended form 1994: revised as Defra, 2007). This code has a strong presumption against burning on peat bog and wet heathland, except in special circumstances and as part of a habitat management agreement with Natural England. Blanket bogs are also identified as an Annex 1 habitat of EU 'community interest' under the EU Habitats Directive.

Hitherto however, there have been few data to establish to what extent bog habitat, including that with protected status within Natura 2000 sites and their component SSSIs, is being burned. We therefore have no measure of the effectiveness of current voluntary and/or legal protection.

The national extent and importance of management burning within dwarf-shrub heath (DSH) dominated moorland has been reported previously (Yallop *et al*., 2006a). However, this study made no attempt to differentiate soil types and therefore provided no information as to the extent of burning specifically occurring on deep peat habitats. A further study encompassing the North Pennines AONB (Yallop *et al*. 2006b) did report on the intensity of burning within areas of upland heath and bog habitat as defined by extant vegetation types but not underlying soils. As soil type data were again excluded however there was no opportunity to differentiate burning regimes on deep/blanket peats that should therefore be regarded as bog.

### Managed burning in the English uplands

The use of fire management in the English uplands has an informal history of thousands of years, with a more ‘organized’ adoption of its use dating from the mid- to late- nineteenth century. Burning of dwarf-shrub heath-dominated habitats (DSH: primarily heather *Calluna vulgaris*) removes woody material and litter, and promotes a flush of new growth from rhizomes or stem bases, thus improving grazing for stock. Heather is also an important food for red grouse *Lagopus lagopus scoticus*, so providing areas of pioneer heather may help increase its population density. The mosaic structure of different-aged stands of heather may also benefit grouse by providing more niches for invertebrates, upon which grouse also feed, and by providing cover and nesting sites. Today management for red grouse rearing and shooting is by far the largest driver of moorland burning in England.

### Ecological effects of burning blanket bogs/deep peat soils

Well-managed burning on upland heath habitat contributes to a mosaic of different seral stages of heather growth that will benefit some other wildlife and plants, as well as red grouse. The present balance of evidence however, points to burning of vegetation on bog being detrimental for biodiversity conservation interests (Shaw *et al*., 1996; Tucker, 2003;

Stewart *et al*., 2004; IUCN, 2011; Glaves *et al*. 2013). In addition there is considerable evidence that surface waters draining catchments with a higher intensity of new moorland burns on blanket peat are more highly ‘coloured’ by humic compounds derived from decomposing peat and export larger amounts of dissolved organic carbon (Yallop *et al*., 2008; Yallop & Clutterbuck, 2009). Areas of blanket peat exposed by new burn release 5-15 times more carbon in this form compared to canopied areas (Yallop *et al*. 2010). This phenomenon appears to underlie a large proportion of the increases in humic coloured DOC export from upland peat catchments observed over the recent past (Clutterbuck & Yallop, 2010). Recent work by the EMBER project (Brown, Holden & Palmer, 2014) has shown that burning on moorland causes wide-ranging changes in other aspects of water chemistry and has knock-on effects on ecological assemblages.

Most British blanket bogs are heavily modified by management (c.18,500 $km^2$ of 22,500 $km^2$) according to estimates by Bragg & Tallis (2001); according to Natural England (2010), “*Only 1% of England’s deep peats have been mapped as being in an undamaged state where they remain substantially waterlogged and actively continue to form peat and therefore sequester carbon*.” Blanket bog is a UK BAP priority habitat and active blanket bog is a priority habitat under the EC Habitats Directive. It is likely that the formation of blanket bogs occurred under a low-grazing, infrequent wildfire regime. Pollen studies have shown that bog mosses *Sphagnum* spp. do re-establish after burning in the absence of other impacts (Pitkänen *et al*., 1999) however this may typically require many hundreds of years between fire events and higher-frequency burning may stop peat formation (e.g. Garnett *et al.*, 2000). Wieder *et al.* (2009) found that bogs in Alberta, Canada represent a net carbon source for 13 years after a fire, and become a net sink after that time. Zero net accumulation of carbon would occur with return times (i.e. fire frequencies) of 61 years or less in their study. Lindsay’s (2010) review of British peat bogs suggests c. 200 years are required for bogs to return to carbon balance after a fire and c. 500 years is needed for full ‘ecosystem recovery’.

**Scope and constraints of the project**

The aim of this project is to provide a review of all currently available moorland burn mapping data within NE archives to provide evidence on the extent of management burning in upland England. An important facet of this review is consideration of soil type with a primary interest in burning on 'blanket' or deep peat (see below). Evidence of the extent of burning on non-peat upland soils is also considered to provide an appropriate comparison of extents and trends.

Two major GIS sources of evidence for the extent of blanket bog/peat exist: Natural England's blanket bog habitat inventory version 2.1 (now revised) and the National Soil Research Institute's soil series Winter Hill and Crowdy (1011a, b and 1013a, b). Previous work (Yallop *et al*., *unpublished*) has shown that the blanket bog inventory as it stands has numerous data quality issues with many areas mapped into more than one category. A more major concern is however that as a habitat-based classification it is based on a variety of sources including contemporary vegetation type mapping and may, therefore, exclude severely modified vegetation on deep peat areas, e.g. where heath-type vegetation has developed on degraded deep peat substrates that have been bog in the recent past. Although NSRI soil series has lower spatial resolution than the bog inventory the more inclusive definition of blanket bog it encompasses i.e. all areas where active blanket bog is *or was* present, makes it the dataset preferred here and, as such, it has been used.

Within this review management has been evaluated at several levels of conservation designation: National Parks/Areas of Outstanding Natural Beauty (NPs/AONBs), Natura 2000 sites: Special Areas of Conservation/Special Protection Areas (SACs/SPAs), and Sites of Special Scientific Interest (SSSIs).

To achieve its aim, this review combines and reanalyses, where required, the data collated and presented in:

1: Yallop *et al*., 2005 (A History of Burning as a Management Tool in the English Uplands. English Nature Research Report 667) which assessed the extent of management burning within England by a sample approach using digitisation of burn parcels. This dataset has since been updated to include burning from 1945 to 2010;

2: Yallop *et al*., 2006b (Mapping Extent of Burn Management in the North Pennines: Review of extent Yr. 2001-2003. EN Report 698) which mapped burning across the entirety of the North Pennines AONB using an image sampling approach;

3: Currently unpublished NE data produced between 2009 and 2014 that mapped new moorland burning in a number of areas using image segmentation techniques on 4-band digital aerial imagery acquired by ADS40 sensors.

A full list of datasets available is shown in Table 1.

**Table 1. Datasets of burn mapping analysed in this report.**

| Mapping Project | Undertaken | Comments |
|---|---|---|
| England Sample | 2005 | 2% sample of English uplands for the year 2000. Manual API |
| North Pennines AONB | 2006 | Image sampling approach (point classifier) |
| Peak District NP | 2009 | Image segmentation and automated classification |
| Dartmoor NP | 2009 | Image segmentation and automated classification |
| Exmoor NP | 2009 | Image segmentation and automated classification |
| Quantocks AONB | 2009 | Image segmentation and automated classification |
| North York Moors NP | 2010 | Image segmentation and automated classification |
| England Sample update | 2014 | Manual classification. Widens the original England Sample of five time periods dating back to 1945 |
| North Pennine Moors SAC | 2014 | Image segmentation and automated classification |
| East Lakes | 2014 | Image segmentation and automated classification Includes a small part of the Lake District NP |
| South and West Pennines | 2014 | Image segmentation and automated classification approach. Includes the northern part of the South Pennine Moors SAC |
| Northumberland | 2014 | Image segmentation and automated classification. Includes most of the heather-dominated habitat in the NP, together with large areas outside the NP |
| Forest of Bowland AONB | 2014 | Image segmentation and automated classification |
| Shropshire Hills AONB | 2014 | Image segmentation and automated classification |

## 2: Methods

### 2.1 Data:

**Burning in the English uplands: National sample**

Evidence of burning from a random sample of aerial photography (dating from the year 2000) of the English uplands consisting of 208 1 $km^2$ tiles was collected in an earlier study for English Nature (Yallop *et al.*, 2005). Of these 208 tiles, 106 were identified to contain heather-dominated communities and thus held potential for burning management. Historical aerial photography was sought in relation to these 106 1 $km^2$ tiles, and combined with current digital photography (Table 2).

**Table 2. Periods and availability of aerial photography for the national sample.**

| Period | Source and missing squares |
|---|---|
| 1945-1959 | English Heritage Archive and private holdings; 15 missing squares and 8 partial. |
| 1960-1979 | English Heritage Archive and private holdings; 7 missing squares and 2 partial. |
| 1980-1994 | English Heritage Archive and private holdings; 6 missing squares and 2 partial. |
| 1999-2006 | Digital data available; series complete |
| 2006-2011 | Digital data available; series complete |

Burning was re-mapped for the year 2000 because of the new availability of better imagery than originally used in Yallop *et al.* 2005/2006. Regions were classified into one of the five original categories, with the addition of a null class to represent missing imagery for historical scenes. It was often impractical to distinguish between class 1 and 2 and class 3 and 4 in older, mainly monochrome photography, and for this reason burn classes were simplified into visibly recently burnt (1+2) and not recently burnt (3+4). Details of the categories used in the aerial photographic interpretation (API) can be found in Yallop *et al.* (2006a) and Yallop *et al.* (2006b), but are summarised below for clarity.

**0: No visual presence of ericaceous shrub (DSH)**
Habitat unlikely to be managed by burning e.g. *Eriophorum* dominated bog/moor.
**1: New burn – *within approx. 0-5 years***
**2: Recent burn – *within approx. 4-8 years***
Note: a figure of 7.7 years for the average duration of visibility of a burn is used here, as Yallop et al (2006a).
**3: Visually closed canopy – *estimated age 7-15 years***
**4: Mature, degenerate DSH – *greater than 15-25 years or unmanaged***

The sampled area covers 60.7 $km^2$ of deep peat, or 2.1% of the national total.

### North Pennines AONB (2006)

Details of the original sampled area and protocol can be found in Yallop *et al*. (2006b). The sampled area assessed included all areas of deep peat and ericaceous dominated vegetation on all soils within the AONB. The aerial photography used was taken between 2001 and 2003. Sample points at the same density as in the national sample above were classified into the same five categories. From the total area of the AONB (1985 $km^2$), the sampled area contains 746.3 $km^2$ (25.7%) of the land surface of upland England covered by deep peat.

### Recent mapping

All the remaining regions in Table 1 were mapped from 25 cm resolution 4-band digital ortho-rectified imagery. With reference to historical imagery where available, new burns (typically <3 yrs old) were identified using automated image segmentation and classification procedures. Taken together, these mapping projects cover a large proportion (c. 30%) of England's upland deep and blanket peat.

### Reconciliation

There were differences in the reported duration or period of mapped burns in some studies compared to others. For example data for the 2006 North Pennines AONB survey reported all burns of <7.7 yrs owing to difficulties in differentiating between Class 1 (no visible regenerating *Calluna*) and Class 2 (partial canopy of regenerating *Calluna*) because of poor quality imagery, whereas the higher quality imagery available for recent projects (2009-2014) allowed burns less than 3 yrs old to be identified and mapped.

To allow valid comparisons to be made between different areas, all extents of burn mapping have therefore been summarized as annualised rates. Burn rates are reported in two ways: as an absolute figure (area burnt per year in $km^2$) and as burn intensity (% area burnt per year). A notional return period (the length of time, in years, for an entire region of interest to be burnt) is also reported. In all cases burn rates are reported against the heather-dominated habitat in each region.

### Data: Soil data

Soil data were obtained from the digital soil map created by the National Soil Resource Institute (NSRI) as this currently represents the most comprehensive national dataset of soil type. Soil series 1011a, 1011b, 1013a and 1013b (deep and blanket peats) were extracted from this dataset and used for this analysis.

### Data: Conservation designation

Current digital data for English National Parks, AONBs, SACs, SPAs and SSSIs were taken from the Environment Agency's Geostore collection.

### 2.2 Calculation of return periods

A return period, or repeat time, is simply the time taken for an entire area to be burned. It can be calculated easily if a known proportion of the area in question has been burned within a known time period, which in this case is the time taken for burn scars to move into class 3 (see 2.1.1).

$$R = \frac{D_1 + D_2}{C_1 + C_2}$$

where $D_1 + D_2$ is the median time taken for burn scars to become class 3 and $C_1 + C_2$ is their combined area.

The value of $D_1+D_2$ used here has been established observationally over a number of catchments (Yallop *et al*., 2006a) and represents a 'best guess'. Nevertheless, there is the possibility of variation in this figure, whether due to local differences in vegetation recovery or differences in quality of aerial photography. Taken on a broad scale, such a figure is an estimate only, since it obscures spatial variation in the intensity of burning. Also, it should be noted that repeat time figures are "exact" where closely dated (i.e. within the minimum time for a burn to move into class 3) photography is available. The equation above is only needed when a "snapshot" of an area is taken (as, e.g., for the national sample). For most recently mapped burning, there is no uncertainty over the proportion of recent burn, because all burns were dated to <3 years old by the analysis of earlier photography.

#### Statistical analysis of change over time

Changes in burning over time were examined for data from the updated national sample. This was done in R (r-project.org) using a general linear model. Independent variables were time and soil type, with an interaction term. The response variable was untransformed proportion of heather-dominated habitat burnt.

### 2.3 Statement on the overall accuracy of management burn estimates and return periods: Implications for statutory controls and agreements.

It is perhaps obvious that management burns can only be mapped if they are visible and this interacts with the two mapping protocols used to obtain the data reported here in differing ways.

Firstly, manual digitisation using API projects reported here have been executed by defining two 'new burn' classes (i.e. burns < approx. 7.7 yrs *see above*). This is advantageous where older RGB or monochrome imagery is the data source where the subtle distinction between the very new 0-3 yr old burns and older re-vegetating burns may not be clear. In addition the use of a longer time period to average annual burn rates will attenuate the effects of short term inter-year variations in burn rates that sometimes occur through the effects of weather etc.

However, the use of annual estimates derived for this longer period means that in numerous areas older (class 2) burns will be partly over- or cross-burned before assessment i.e. certain patches will have been burned twice within the ≈ 7 yr new burn ‘window’. In such cases however only the newest burn will be mapped, meaning the total burn area in seven years and all derived estimates will be conservative.

The use of automated mapping algorithms applied for many of the areas reported here only derives one new burn class of 0-3 yrs since burn. This makes the mapped burn extent more sensitive to short term variations in burn rates. However, it does ensure that few areas of burn are missed as over-burning will not have had time to occur.

Both protocols are equally sensitive to burning that is undertaken, or allowed to continue into, rapidly growing non DSH-dominated habitat such all grass or sedge dominated moor and bracken *Pteridium* stands. Burning into the latter not uncommon where it is adjacent to management burning. Once such vegetation regrows, i.e. within 6 months usually for bracken, visual evidence of burns, or parts thereof, is ‘lost’ and cannot be mapped. Again this will make estimates of burn area and annualised rates conservative.

A third consideration is that the authors of this report, and the data contained therein, are aware of the potential political sensitivities surrounding moorland burning. Therefore, a working ethos has been adopted which seeks to ensure that mapped burns are definitively identifiable as such. If doubt exists between mapper, reviewer and error assessor burns are not included.

**Overall remarks**

The protocols utilised here will tend to underestimate burning rates. All following reported data should be considered in the light of this fact.

Formal error assessments have been executed for most of the projects reported here. These are based upon variants of secondary manual classification of random points compared to original classification. However, this process *can only* report the accuracy of each project after the above factors are considered as it uses the same imagery and therefore cannot determine over-burned areas or allow identification of management fires occurring in rapidly regenerating vegetation.

## 3: Results

### National Estimates

Nationally an estimated 83.87km$^2$ yr$^{-1}$ of the English uplands are burnt (Table 3). This burning is mostly (60.4%) on shallow peats and other soils with 39.6% on deep peat. This distribution is close to even when one considers the distribution of mapped areas, that is, burning intensity is similar on deep peat and other soils at the national levels. Notional return periods at the national levels are 26.6 years and 25.1 years on deep peat and other soils respectively.

**Table 3. Burning in English uplands, sum of all recent burn mapping projects**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| REGION | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Return period yr |
| England* | Deep Peat | 881.31† | 33.18 | 3.76 | 26.6 |
| | Other | 1270.47 | 50.69 | 3.99 | 25.1 |

* England is incompletely mapped, these figures are based on mapping of approx.80% of DSH-dominated area and will therefore represent an underestimate

† 1612km$^2$ of deep peat has been mapped in total of which 54.7% was DSH-dominated

The remainder of the results section is divided on several levels. First, estimates of burning management are summarised nationally for individual National Parks/AONBs and SACs/SPAs. The next section covers the updated 2% England sample, and considers changes in burning over time. Finally, results are presented on a region-by-region basis. For each region, results are presented in descending size order of the designation envelope. That is, results for each region are first shown at the level of National Park/AONB, then SAC/SPA, and finally at the level of each individual SSSI that has burning.

### Burning in National Parks and AONBs

Recent estimates of burning in National Parks and AONBs are shown in Table 4. Burning management varies widely across suitable habitat, for example from intensive management in the North York Moors NP to very light management in Northumberland and Exmoor NPs.

**Table 4. Recent burning management by National Park and AONB**

| REGION | Soil type | Area km² DSH | Area km² Burnt yr⁻¹ | Burn intensity %burn yr⁻¹ | Burn intensity Rtn period yr |
|---|---|---|---|---|---|
| **National Parks** | | | | | |
| Dartmoor | Deep Peat | 5.28 | 0.05 | 0.95 | >100 |
| *2006-2007*[1] | Other | 60.47 | 1.61 | 2.67 | 37.48 |
| Exmoor | Deep Peat | 0.39 | 0.00 | 0.00 | >100 |
| *2006-2007* | Other | 56.86 | 0.54 | 0.95 | >100 |
| Northumberland* | Deep Peat | 61.05 | 1.07 | 0.44 | >100 |
| *2006-2001* | Other | 120.92 | 1.75 | 0.36 | >100 |
| North York Moors | Deep Peat | 36.76 | 3.22 | 8.76 | 11.4 |
| *2009* | Other | 289.98 | 21.00 | 7.24 | 13.8 |
| Peak District | Deep Peat | 94.24 | 3.98 | 4.22 | 23.7 |
| *2005* | Other | 72.15 | 2.67 | 3.70 | 27.0 |
| Yorkshire Dales* | Deep Peat | 143.46 | 7.23 | 5.04 | 19.8 |
| *2008-2009* | Other | 85.50 | 4.04 | 4.72 | 21.2 |
| **AONBs** | | | | | |
| Forest of Bowland | Deep Peat | 69.85 | 1.83 | 2.62 | 38.2 |
| *2008-2010* | Other | 42.70 | 0.82 | 1.91 | 52.2 |
| Nidderdale* | Deep Peat | 63.77 | 3.59 | 5.62 | 17.8 |
| *2009* | Other | 105.60 | 4.71 | 4.46 | 22.4 |
| North Pennines* | Deep Peat | 274.00 | 9.78 | 3.57 | 28.0 |
| *2006-2010* | Other | 232.41 | 8.83 | 3.80 | 26.3 |
| Quantock Hills | Deep Peat | 0.00 | - | - | - |
| *2006* | Other | 4.23 | 0.17 | 4.06 | 24.6 |
| Shropshire Hills | Deep Peat | 0.00 | - | - | - |
| *2009-2010* | Other | 16.64 | 0.09 | 0.57 | >100 |
| **Outside NPs/AONBs** | | | | | |
| Other regions | Deep Peat | 132.48 | 2.45 | 1.85 | 54.2 |
| | Other | 183.10 | 4.46 | 2.43 | 41.1 |

* Regions marked by an asterisk are incompletely mapped. Only a very small part of the Lake District NP has been mapped and is therefore not shown.

Dates under each region are the year/s of image capture.

### Burning in SACs and SPAs

Recent estimates of burning in SACs are shown in Table 5. As with National Parks and AONBs, there is wide variation in burning intensity across the country. As might be expected by its large shared area with the North York Moors NP, the North York Moors SAC is the most intensively managed SAC. Several SACs with heather-dominated habitats are very lightly managed by fire, including the Border Mires and Exmoor Heaths.

**Table 5. Burning management by SAC and SPA**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SAC | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Asby Complex | Deep Peat | 0.00 | - | - | - |
| | Other | 7.53 | 0.16 | 2.18 | 45.9 |
| Border Mires, Kielder-Butterburn | Deep Peat | 55.54 | 0.03 | 0.02 | >100 |
| | Other | 8.33 | 0.00 | 0.00 | >100 |
| Dartmoor | Deep Peat | 5.26 | 0.05 | 0.94 | >100 |
| | Other | 34.80 | 0.81 | 2.32 | 43.0 |
| Exmoor Heaths | Deep Peat | 0.39 | 0.00 | 0.00 | >100 |
| | Other | 55.89 | 0.54 | 0.96 | >100 |
| Harbottle Moors | Deep Peat | 0.58 | 0.00 | 0.00 | >100 |
| | Other | 8.09 | 0.01 | 0.04 | >100 |
| Moor House-Upper Teesdale* | Deep Peat | 12.69 | 0.45 | 3.56 | 28.1 |
| | Other | 1.34 | 0.02 | 1.45 | 68.8 |
| North Pennine Moors | Deep Peat | 430.67 | 18.77 | 4.36 | 22.9 |
| | Other | 422.03 | 17.92 | 4.25 | 23.5 |
| North York Moors | Deep Peat | 36.76 | 3.22 | 8.77 | 11.4 |
| | Other | 286.00 | 20.88 | 7.30 | 13.7 |
| Simonside Hills | Deep Peat | 0.01 | 0.00 | 0.00 | >100 |
| | Other | 20.10 | 0.66 | 0.82 | >100 |
| South Dartmoor Woods | Deep Peat | 0.00 | - | - | - |
| | Other | 2.23 | 0.05 | 2.34 | 42.7 |
| South Pennine Moors | Deep Peat | 125.18 | 5.73 | 4.58 | 21.9 |
| | Other | 94.57 | 3.54 | 3.74 | 26.7 |
| The Stiperstones & The Hollies | Deep Peat | 0.00 | - | - | - |
| | Other | 3.68 | 0.03 | 0.74 | >100 |
| Outside SACs | Deep Peat | 214.23 | 4.93 | 2.30 | 43.5 |
| | Other | 325.88 | 6.07 | 1.86 | 53.6 |

**Regions marked * are incompletely mapped**

In general SACs and SPAs cover a similar area and identical or almost identical results are obtained for SPAs as for SACs. A notable exception is Bowland Fells SPA (Table 6), which is unusual in this data set in having SPA designation but which is not an SAC. Equivalencies and comparisons of SACs and SPAs in mapped regions are shown in Appendix 1 for convenience.

**Table 6. Burning management in Bowland Fells SPA.**

| | | **Area km$^2$** | | **Burn intensity** | |
|---|---|---|---|---|---|
| SPA | Soil type | DSH | Burnt yr$^{-1}$ | % burn yr$^{-1}$ | Rtn period yr |
| Bowland Fells | Deep Peat | 56.77 | 1.13 | 1.99 | 50.3 |
| | Other | 37.72 | 0.70 | 1.86 | 53.8 |

**England Sample, 1945-2010**

Overall, 74 of the 106 sample square had comprehensive aerial photography coverage for all five time periods. These squares alone are used in the comparative analysis set out below, so that a consistent set of samples is maintained through time. At the time of writing, further historical photography is being sought and it is likely that the situation regarding missing data will be improved.

**Table 7. Distribution of mapped squares in the updated England sample and squares with comprehensive decadal coverage.**

| Region | Mapped squares | Mapped squares with complete decadal coverage and heather |
|---|---|---|
| **National Parks** | | |
| Dartmoor | 2 | 0 |
| Exmoor | 4 | 3 |
| Lake District | 8 | 5 |
| North York Moors | 12 | 12 |
| Northumberland | 4 + 2 partial | 1 |
| Peak District | 5 + 2 partial | 4 |
| Yorkshire Dales | 14 +1 partial | 6 +1 partial |
| **AONBs** | | |
| Forest of Bowland | 5 | 1 |
| Nidderdale | 7 +1 partial | 5 +1 partial |
| North Pennines | 23 +3 partial | 18 |
| Quantocks | 0 | 0 |
| Shropshire Hills | 2 | 2 |
| Other Areas | 12 +7 partial | 6 |
| **Total** | **106** | **64** |

Of the 74 squares with comprehensive photographic coverage, 64 presently have heather-dominated habitat (Table 7). The remainder were probably assessed as containing heather in the original survey due to the poor quality of the imagery used in that project. The average cover of heather-dominated habitat in the 64 squares was c. 46% in the 1945-1959 period and c. 44% in 2010. This difference is due to some loss of heather in early decades, which was estimated by adding in areas of heather to the heather mask that was prepared for the 2010 imagery, although it is not considered that this process was comprehensive. In some areas however the area of heather-dominated area has evidently increased. The former situation may have occurred through heather being grazed out or ‘land improvements’, while the latter appears to have come about via draining and burning (examples: Figure 1 and Figure 2) or conversely may result from some relaxation of grazing pressure.

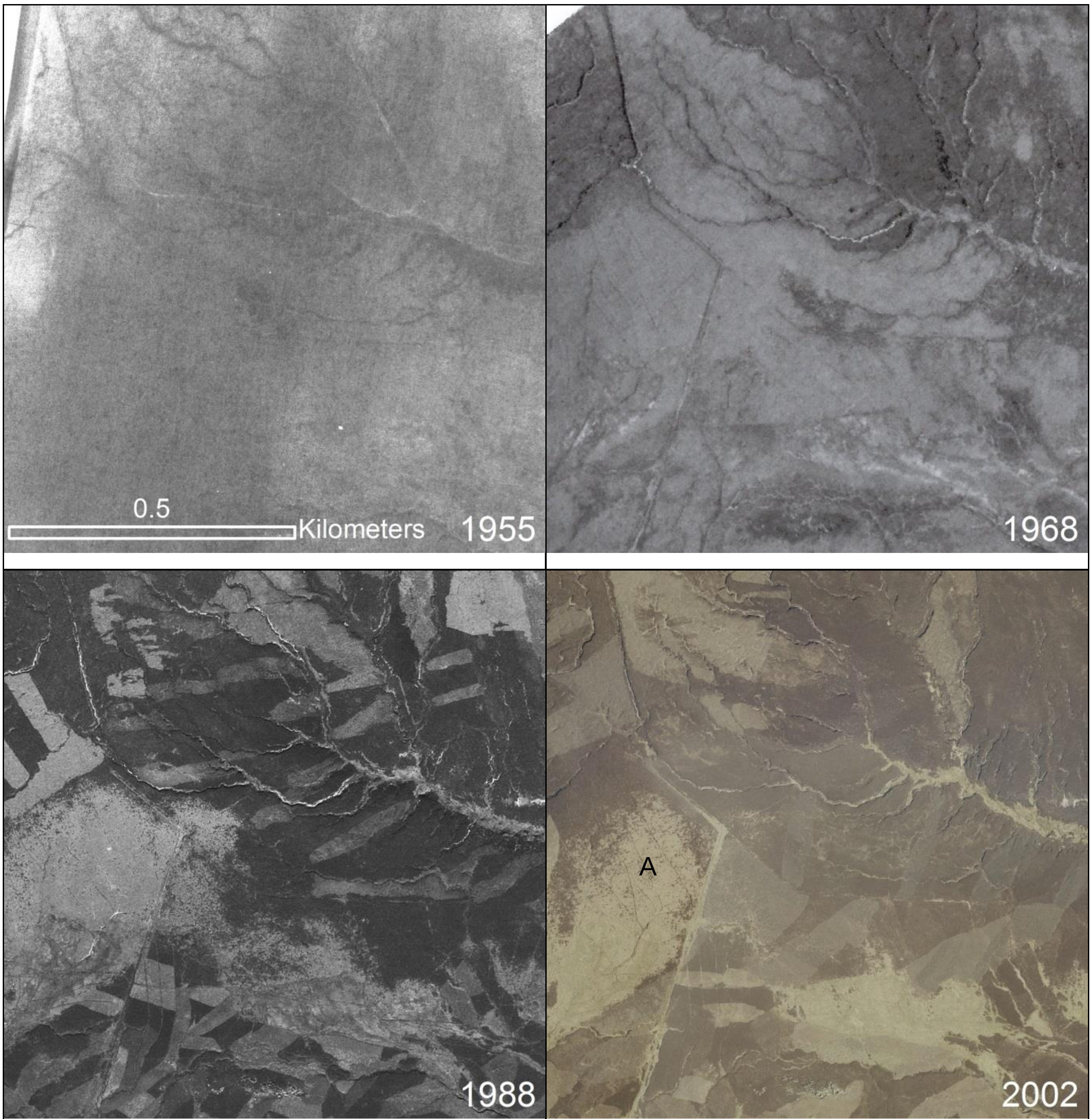



**Figure 1. Burning in SE0767 between 1955 and 2009.**

The region marked ‘A’ in 2002 is gripped deep peat that has seen expansion of heather, perhaps via burning into sparse heather, as have areas to the immediate east.

This kilometre square is part of an area of deep peat in West Nidderdale, Barden and Blubber-houses Moors SSSI in the North Pennine Moors SAC and shows an apparent increase in burning.


**Figure 2. Changes in SD6094 between 1945 and 2009.**

This square is between the Lake District NP and the Yorkshire Dales NP. Note the loss of heather between 1973 and 1989.

Evidence of burning increased through time in the sampled squares. Of the 64 squares with no gaps in photography and heather-dominated habitat, a third showed burning in the 1945-1959 period, and two-thirds showed burning in 2000 and 2010 (Table 8).

**Table 8. Sample squares with evidence of burning, by period.**

| Period | Squares with burning (squares with comprehensive photographic record only) |
|---|---|
| 1945-1959 | 22 |
| 1960-1979 | 36 |
| 1980-1994 | 43 |
| 1999-2006 | 49 |
| 2006-2011 | 47 |

As well as becoming more widespread over time, burning has also become more intensive (Figure 3).

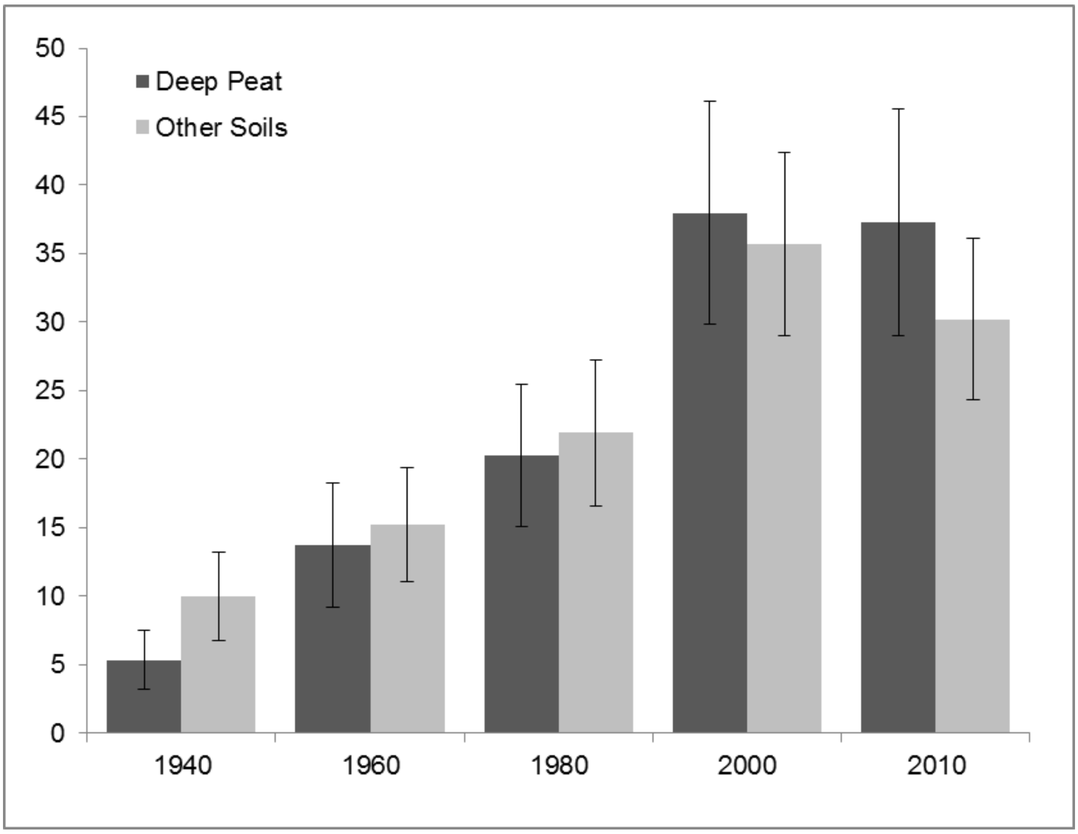


**Figure 3. Estimated changes in annual burning on deep peat and other soils, England, 1945-2010.**

Figures are in $km^2$ and are based on 74 sample squares for which imagery was available for all decades. Estimated burn visibility duration of 7.7 years. Error bars +/- 1 leave-one-out Jackknife standard error.

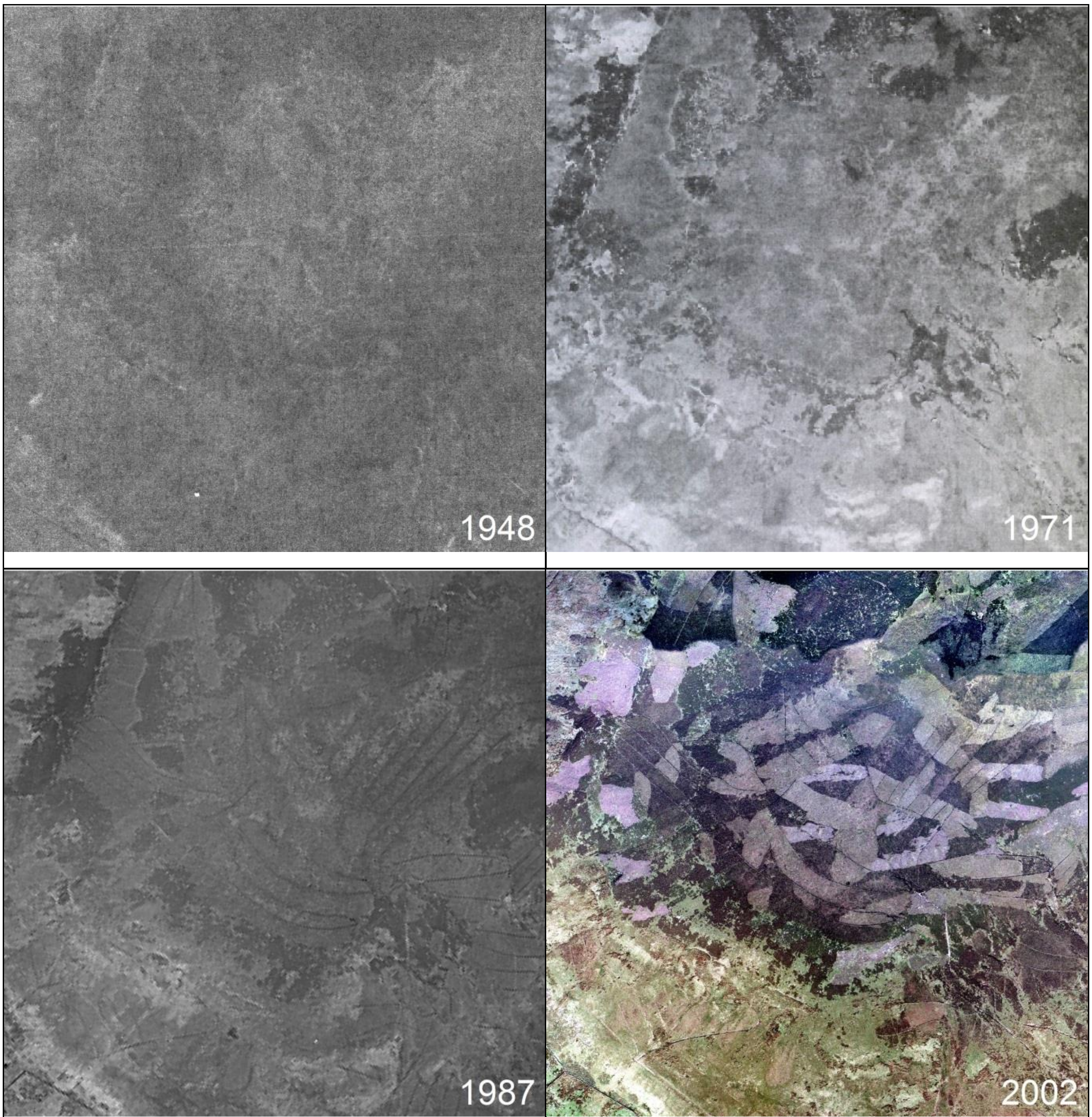



**Figure 4. Burning in NY9707 between 1948 and 2009.**

The square is entirely deep peat except for the extreme south west. Gripping and burning seems to have resulted in an expansion of heather, which is now heavily managed.

The square is outside statutory areas and is close to the North Pennines SAC.

The average percentage of heather-dominated habitat burnt increased from 5.6% in 1945-1959 to a maximum of 27.9% in 2000, before decreasing slightly to 25.5% in 2010. Based on an estimate for the duration of visibility of class 1 and 2 burns of 7.7 years, per Yallop *et al* (2006a), the 2000 figure provides an estimate for national burning of 74.6 $km^2 yr^{-1}$.

It should be noted this figure is less than the 114$km^2$ $yr^{-1}$ reported for the same sample squares using 2000 imagery (Yallop et al 2006a). It is difficult to reconcile these two estimates as a number of factors varied between projects. Firstly, the original survey utilised imagery from one year whereas the second sourced a range of dates from 1999-2006. Secondly, it based the estimate on class one burns alone making it sensitive to difference in annual burn rates whereas the latter survey is based on class 1 and 2 burns i.e. an estimate based on a longer period and re-analysing the original survey using class 1 & 2 burns does give a lower estimate of 99.75 $km^2$ $yr^{-1}$. However this is still markedly higher than that from the new review and cannot therefore account for all the difference. Perhaps more importantly it should be acknowledged that imagery used for the earlier review was of lower quality and this may have led to higher error rates meaning the new lower figure should be treated as more reliable.

It is evident that the distribution of burning is uneven across England, there being a combination of large areas of lightly-managed heather-dominated habitat and other, more intensively managed areas.

Burning has increased more on deep peat than on other soils, as seen in Figure 3. This interaction between soil type and time is significant ($n=534$, $t=2.687$, $P<0.01$). The distribution of burning changes from more burning overall on other soils from 1945-1994, to more burning on deep peat from 2000-2010. Burning on deep peat has increased from 5.3$km^2$ $yr^{-1}$ in 1945-1959 to 38.9$km^2$ $yr^{-1}$ in 2010. For other soils the figures are 9.8$km^2$ $yr^{-1}$ in 1945-1959 and 28.9$km^2$ $yr^{-1}$ in 2010. In both cases the 2010 figure is slightly lower than that for the year 2000. Examples of burning spreading into, or increasing on, deep peat areas are shown in Figure 4 and Figure 6-8.

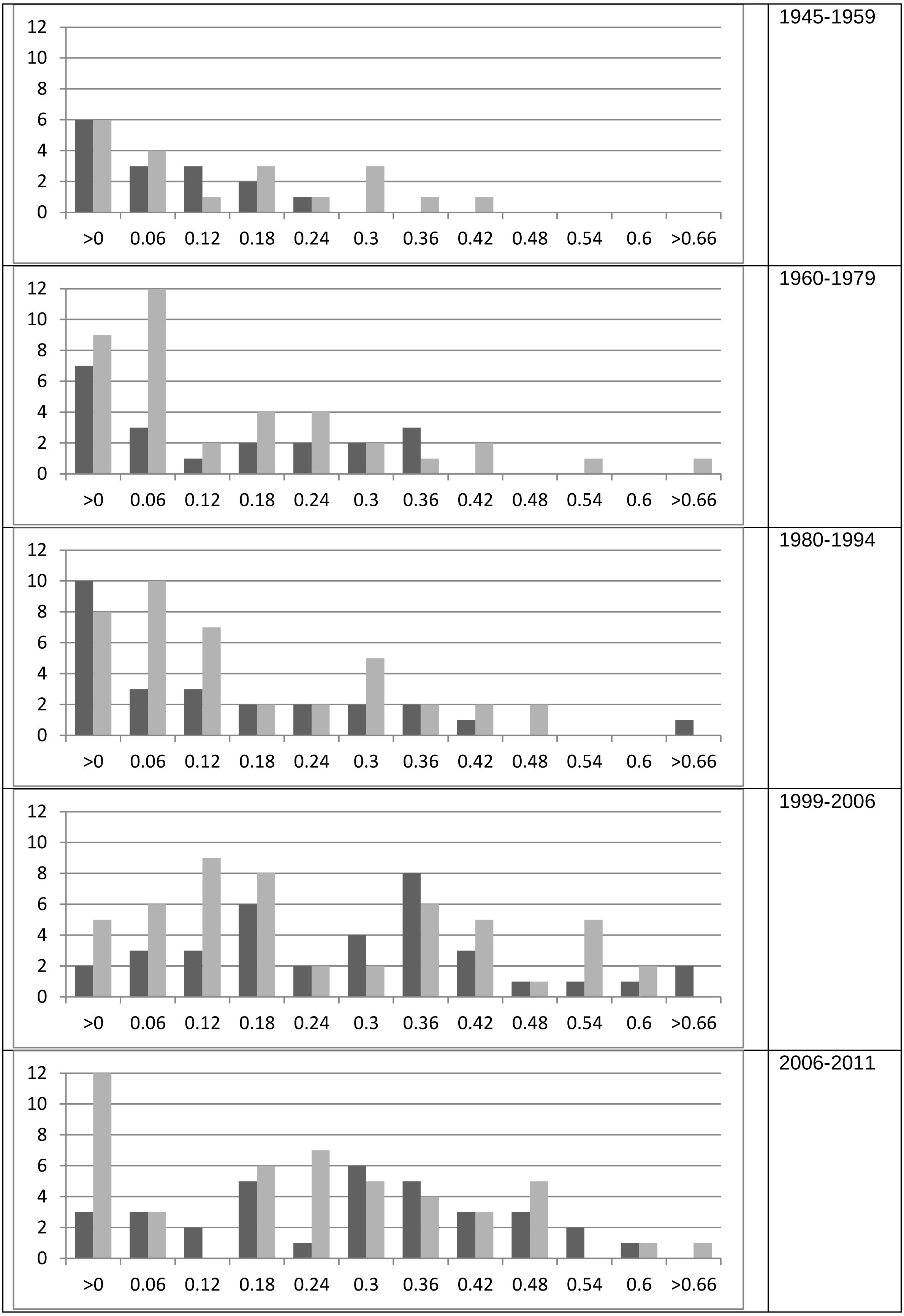


**Figure 5. Histograms of burning intensity, by period.**

Figures represent the proportion of a sample classified as burnt. Deep grey: deep peat; pale grey: other soils. n=106; only squares with burning are shown; squares with regions of deep peat and other soils appear twice.

Examples of changes over time in the England sample squares are shown in Figures 1, 2, 4, and 6-8. The general pattern is one of the extension of burning from shallow peat areas into deep peat areas, often with the inclusion of gripping.

It is difficult in most cases to make definite statistical statements about changes in burning at the regional level, as most areas have insufficient sample squares in them. The two regions (North Pennines AONB/ North Pennine Moors SAC and North York Moors NP/SAC) with sufficient sample squares (18/19 and 12 respectively with comprehensive coverage and heather) both show a similar pattern to that seen overall, i.e. an extension of burning, particularly onto deep peat areas.

**Regional Summaries**

**Dartmoor**

Dartmoor NP was mapped in 2009 using imagery dated from 2006-2007. A total of 956 $km^2$ was mapped, and comprised the entirety of Dartmoor NP. Three SACs were included in the mapping: Dartmoor, South Dartmoor Woods, and a small part of South Hams. Of these, both Dartmoor and South Dartmoor Woods showed evidence of burning (Table 11).

The mapped area includes all or part of 42 SSSIs, eleven of which had some heather-dominated areas. Of these, seven showed evidence of burning (Table 9).

| **Table 9. Dartmoor SSSIs with burning** |
|---|
| Blackslade Mire |
| East Dartmoor |
| Holne Woodlands |
| North Dartmoor |
| South Dartmoor |
| Tor Royal Bog |
| Yarner Wood & Trendlebere Down |

Dartmoor is lightly managed by burning. Averaged across the National Park there is a return period of >100 years on the relatively small area of heather-dominated deep peat and 37.5 years on other soils. Note this excludes burning of areas of non-DSH habitat e.g. purple moor grass which is not identifiable in summer acquired aerial photography.

**Table 10. Burning in Dartmoor (DSH dominated areas)**

| | | **Area $km^2$** | | **Burn intensity** | |
|---|---|---|---|---|---|
| National Park | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| Dartmoor | Deep Peat | 5.28 | 0.05 | 0.95 | >100 |
| | Other | 60.47 | 1.61 | 2.67 | 37.5 |

Almost all of the heather-dominated deep peat on Dartmoor is within Dartmoor SAC, so it is not surprising that figures for burning this habitat are similar to those for the NP. For other soils, a little over half of the burnable habitat in the NP is within the SAC, and this region is slightly less intensively managed than the whole (return period of 43 years vs 37.5 years).

**Table 11. Burning in Dartmoor SACs (DSH dominated areas)**

| | | Area $km^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SAC | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| Dartmoor | Deep Peat | 5.26 | 0.05 | 0.94 | >100 |
| | Other | 34.80 | 0.81 | 2.32 | 43.0 |
| South Dartmoor Woods | Deep Peat | 0.00 | - | - | - |
| | Other | 2.23 | 0.05 | 2.34 | 42.7 |

For individual SSSIs there is a range of burning intensities. In some cases (eg. Blackslade Mire), the calculated return period is short owing to the tiny amount of burnable area involved in the calculation. Return periods for Tor Royal Bog are not given for this reason.

**Table 12. Burning in Dartmoor SSSIs (DSH dominated areas)**

| | | Area $km^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SSSI | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| Blackslade Mire | Deep Peat | 0.00 | - | - | - |
| | Other | 0.10 | 0.02 | 18.24 | 5.5 |
| East Dartmoor | Deep Peat | 0.00 | - | - | - |
| | Other | 12.21 | 0.46 | 3.78 | 26.5 |
| Holne Woodlands | Deep Peat | 0.00 | - | - | - |
| | Other | 0.84 | 0.01 | 0.62 | >100 |
| North Dartmoor | Deep Peat | 3.69 | 0.00 | 0.00 | - |
| | Other | 17.99 | 0.27 | 1.50 | 66.8 |
| South Dartmoor | Deep Peat | 1.43 | 0.00 | 0.00 | - |
| | Other | 4.50 | 0.08 | 1.72 | 58.0 |
| Tor Royal Bog | Deep Peat | 0.15 | 0.05 | 34.00 | - |
| | Other | <0.01 | <0.01 | 48.33 | - |
| Yarner Wood & Trendlebere Down | Deep Peat | 0.00 | - | - | - |
| | Other | 1.39 | 0.05 | 3.39 | 29.5 |

**Exmoor**

Exmoor National Park was mapped in 2009 from imagery dated 2006-2007. The mapped area was 694 $km^2$, including all of Exmoor NP. Two SACs were included in the mapping, Exmoor Heaths and Exmoor/Quantock Oakwoods. Of these only Exmoor Heaths showed any management by burning. The mapped area included 14 SSSIs, three of which included heather-dominated areas, all with signs of burning (Table 13).

| **Table 13. Exmoor SSSIs with burning** |
|---|
| Exmoor Coastal Heaths |
| North Exmoor |
| South Exmoor |

As with Dartmoor, Exmoor NP is lightly managed by burning. Return periods are greater than 100 years for burnable habitat both on deep peat and other soils (Table 14).

**Table 14. Burning in Exmoor**

| | | **Area $km^2$** | | **Burn intensity** | |
|---|---|---|---|---|---|
| National Park | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| Exmoor | Deep Peat | 0.39 | 0.00 | 0.00 | >100 |
| | Other | 56.86 | 0.54 | | >100 |

Exmoor Heaths SAC covers much of the burnable habitat present in the NP, and has a similarly long return period of more than 100 years (Table 15).

**Table 15. Burning in Exmoor SACs**

| | | **Area $km^2$** | | **Burn intensity** | |
|---|---|---|---|---|---|
| SAC | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| Exmoor Heaths | Deep Peat | 0.39 | 0.00 | 0.00 | >100 |
| | Other | 55.89 | 0.54 | 0.96 | >100 |

Of the three SSSIs with burning in Exmoor, none has an intense regime, the shortest return period being of the order of 60 years. In general there is too little heather-dominated area on deep peat to draw any conclusions about burning regimes on such habitats (Table 16).

| Table 16. Burning in Exmoor SSSIs | | | | | |
|---|---|---|---|---|---|
| | | Area km$^2$ | | Burn intensity | |
| SAC | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Exmoor Coastal Heaths SSSI | Deep Peat | 0.00 | - | - | - |
| | Other | 6.86 | 0.11 | 1.61 | 61.9 |
| North Exmoor | Deep Peat | 0.39 | 0.00 | 0.00 | - |
| | Other | 34.48 | 0.26 | 0.74 | >100 |
| South Exmoor | Deep Peat | 0.00 | - | - | - |
| | Other | 14.62 | 0.18 | 1.20 | 83.3 |

**North York Moors**

The North York Moors NP was mapped in 2010 from imagery dated 2009. The mapped area was 1441 km$^2$, and covered the entire NP. Five SACs were included, but only North York Moors SAC itself showed burning management. Mapping included all or part of 39 SSSIs. Nine of these SSSIs included heather-dominated habitat, of which four showed management by burning, although only Newtondale SSSI and North York Moors SSSI contained a significant amount (more than a hectare) of burning (Table 17).

| Table 17. North York Moors SSSIs with burning |
|---|
| Newtondale |
| North York Moors |

The North York Moors NP is intensively managed by burning, having return periods of 11.4 years on deep peat and 13.8 years on other soils (Table 18).

| Table 18. Burning in the North York Moors | | | | | |
|---|---|---|---|---|---|
| | | Area km$^2$ | | Burn intensity | |
| National Park | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| North York Moors | Deep Peat | 36.76 | 3.22 | 8.76 | 11.4 |
| | Other | 289.98 | 21.00 | 7.24 | 13.8 |

The North York Moors SAC covers a very similar area to the NP, and the figures arrived at for its burning regime are nearly identical (Table 19). The North York Moors SSSI covers an identical area to the SAC and therefore has an identical burning regime. The only other SSSI in the North York Moors NP with burning is Newtondale, which has a very small area of burnable habitat (Table 20).

**Table 19. Burning in North York Moors SACs**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SAC | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| North York Moors | Deep Peat | 36.76 | 3.22 | 8.77 | 11.4 |
| | Other | 286.00 | 20.88 | 7.30 | 13.7 |

**Table 20. Burning in North York Moors SSSIs**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SSSI | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Newtondale | Deep Peat | 0.00 | - | - | - |
| | Other | 0.28 | 0.01 | 3.10 | 32.2 |
| North York Moors | Deep Peat | 36.76 | 3.22 | 8.77 | 11.4 |
| | Other | 286.00 | 20.88 | 7.30 | 13.7 |

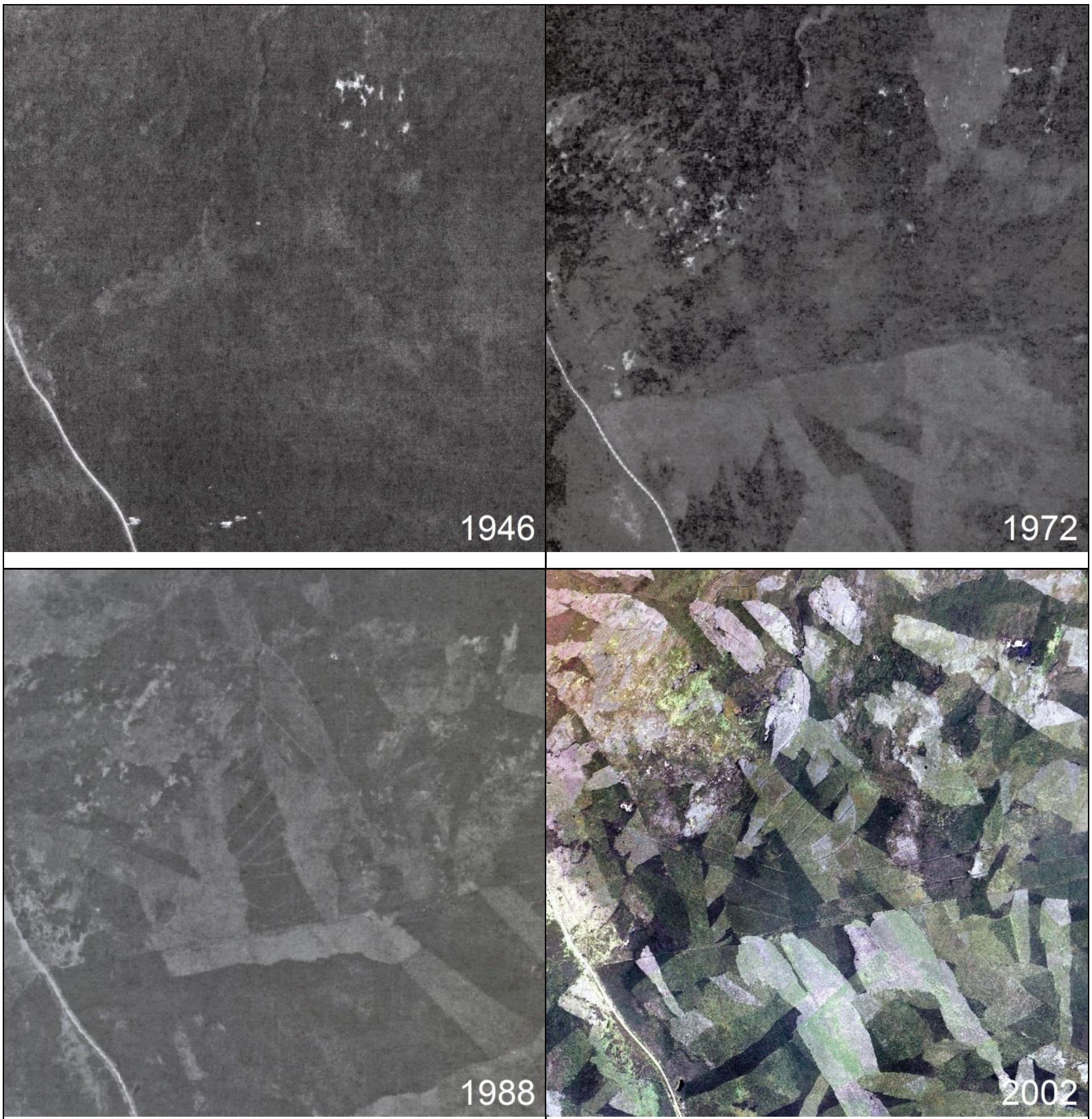


**Figure 6. Burning in NZ6102 between 1946 and 2009.**

This is an area of deep peat within the North York Moors NP/SAC/SSSI. A comprehensive expansion of burning is visible, coupled with gripping.

**Northumberland**

Burning in Northumberland National Park and nearby was mapped in 2014 using imagery dating from 2006 to 2011. The mapped area was 1125 $km^2$.

Most of the burnable habitat within Northumberland NP was mapped, although several small areas of heather with evidence of burning activity remain unmapped (probably <10$km^2$ of heather in all).

SACs mapped included Harbottle Moors and Simonside Hills in their entirety, together with about 70% of Kielder-Butterburn Border Mires, all three of which showed evidence of burning management (Table 21). The missing section of Kielder-Butterburn Border Mires appears to have some heather-dominated areas, but a brief inspection suggests that there is no burning management in the unmapped part.

The mapped area includes all or part of 29 SSSIs, of which 15 include some areas that are heather-dominated. Eight SSSIs have significant levels of burning (Table 22).
The mapped area also includes significant areas of managed moorland without statutory designation.

| **Table 21. Northumberland SACs with burning** |
|---|
| Harbottle Moors<br>Simonside Hills<br>Kielder-Butterburn Border Mires |

| **Table 22. Northumberland SSSIs with burning** |
|---|
| Bewick and Beanley Moors<br>Harbottle Moors<br>Humbleton Hill and The Trows<br>Kielder Mires<br>Kielderhead and Emblehope Moors<br>Otterburn Mires<br>Simonside Hills<br>The Cheviot |

Burning regimes are light in Northumberland SACs, and all three have return periods in excess of 100 years (Table 23). The situation is similar for the SSSIs managed by burning (Table 24). No SSSI has a burning regime with a return period of less than 100 years on deep peat or other soils.

**Table 23. Burning in Northumberland SACs**

| SAC | Soil type | Area km² DSH | Area km² Burnt yr⁻¹ | Burn intensity %burn yr⁻¹ | Burn intensity Rtn period yr |
|---|---|---|---|---|---|
| Border Mires, | Deep Peat | 55.54 | 0.03 | 0.02 | >100 |
| Kielder-Butterburn | Other | 8.33 | 0.00 | 0.00 | >100 |
| Harbottle Moors | Deep Peat | 0.58 | 0.00 | 0.00 | >100 |
| | Other | 8.09 | 0.01 | 0.04 | >100 |
| Simonside Hills | Deep Peat | 0.01 | 0.00 | 0.00 | >100 |
| | Other | 20.10 | 0.66 | 0.82 | >100 |

**Table 24. Burning in Northumberland SSSIs**

| SSSI | Soil type | Area km² DSH | Area km² Burnt yr⁻¹ | Burn intensity %burn yr⁻¹ | Burn intensity Rt period yr |
|---|---|---|---|---|---|
| Bewick and | Deep Peat | 0.00 | - | - | - |
| Beanley Moors | Other | 28.08 | 0.31 | 0.28 | >100 |
| Harbottle Moors | Deep Peat | 0.58 | 0.00 | 0.00 | >100 |
| | Other | 8.08 | 0.01 | 0.04 | >100 |
| Humbleton Hill | Deep Peat | 0.00 | - | - | - |
| and The Trows | Other | 1.29 | 0.03 | 0.68 | >100 |
| Kielder Mires | Deep Peat | 29.17 | 0.03 | 0.03 | >100 |
| | Other | 0.35 | 0.00 | 0.00 | >100 |
| Kielderhead & | Deep Peat | 45.85 | 0.03 | 0.01 | >100 |
| Emblehope | Other | 14.67 | 0.02 | 0.03 | >100 |
| Otterburn Mires | Deep Peat | 1.53 | 0.01 | 0.14 | >100 |
| | Other | 0.35 | 0.00 | 0.00 | >100 |
| Simonside Hills | Deep Peat | 0.01 | 0.00 | 0.00 | >100 |
| | Other | 20.10 | 0.66 | 0.82 | >100 |
| The Cheviot | Deep Peat | 12.55 | 0.22 | 0.43 | >100 |
| | Other | 7.66 | 0.05 | 0.16 | >100 |

**South Pennine Moors SAC**

Combining the mapping of the Peak District and South and West Pennines shows the overall level of burning in the South Pennine Moors overall (Table 25). Burning in the SAC is more intense on deep peat than on other soils, with return periods of 21.9 years and 26.7 years respectively.

**Table 25. Burning in the South Pennine Moors SAC**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| Mapping Project | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Peak District NP | Deep Peat | 88.70 | 3.64 | 4.11 | 24.3 |
| | Other | 64.87 | 2.43 | 3.75 | 26.7 |
| South & West Pennines | Deep Peat | 36.48 | 2.08 | 5.71 | 17.5 |
| | Other | 29.70 | 1.11 | 3.73 | 26.8 |
| South Pennine Moors SAC Overall | Deep Peat | 125.18 | 5.73 | 4.58 | 21.9 |
| | Other | 94.57 | 3.54 | 3.74 | 26.7 |

**Peak District**

The Peak District was mapped in 2009 from imagery dated 2005. The mapped area slightly exceeded that of the Peak District NP (1438 km$^2$) because a few small regions of managed heather adjacent to the National Park were also mapped.

Mapping covered South Pennine Moors SAC and Peak District Dales SAC, although burning only occurred in the former. Coverage of South Pennine Moors SAC is partial and was completed by mapping of the South West Pennines, below.

In terms of SPAs, the 2009 mapping covered the Peak District Moors SPA (South Pennine Moors Phase 1) and a small section of South Pennine Moors Phase 2. Sixty-three SSSIs were included in the mapping, nine of which included heather-dominated habitats. Five SSSIs showed evidence of burning (Table 26).

| Table 26. Peak District SSSIs with burning |
|---|
| Canyards Hills |
| Dark Peak |
| Eastern Peak District Moors |
| Goyt Valley |
| Leek Moors |

The most intensely-managed SSSI in the Peak District NP is the Dark Peak, with return periods of 22.0 and 22.9 years on deep peat and other soils respectively (Table 27).

| Table 27. Burning in Peak District SSSIs | | | | | |
|---|---|---|---|---|---|
| | | Area km$^2$ | | Burn intensity | |
| SSSI | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Canyards Hills | Deep Peat | 0.00 | - | - | - |
| | Other | 0.27 | <0.01 | 1.27 | 78.7 |
| Dark Peak | Deep Peat | 66.58 | 3.03 | 4.55 | 22.0 |
| | Other | 33.05 | 1.44 | 4.36 | 22.9 |
| Eastern Peak District Moors | Deep Peat | 10.48 | 0.29 | 2.80 | 35.7 |
| | Other | 24.61 | 0.90 | 3.66 | 27.3 |
| Goyt Valley | Deep Peat | 4.83 | 0.12 | 2.38 | 42.0 |
| | Other | 0.53 | 0.01 | 1.14 | 88.0 |
| Leek Moors | Deep Peat | 6.83 | 0.21 | 3.02 | 33.1 |
| | Other | 6.89 | 0.08 | 1.20 | 83.1 |

**South and West Pennines**

The South and West Pennines were mapped in 2014 from imagery dated 2008-2010. The area mapped was 542 km$^2$. The mapped area included the part of the South Pennine Moors SAC that was not mapped in the study of the Peak District NP. The mapping covers the South Pennine Moors Phase 2 SPA. A small area of heather-dominated habitat that lies within the South Pennine Moors SAC/SPAs has not been mapped but does not appear to be managed by burning. Six SSSIs are covered by the mapping, two of which contain heather-dominated areas. Of these, only the South Pennine Moors shows burning management (Table 28).

| Table 28. South and West Pennines SSSIs with burning |
|---|
| South Pennine Moors |

Burning on deep peat in the South Pennine Moors SSSI is more intense than on other soils (Table 29), with return periods of 17.5 and 26.8 years respectively.

| Table 29. Burning in South and West Pennines SSSIs | | | | | |
|---|---|---|---|---|---|
| | | Area km$^2$ | | Burn intensity | |
| SSSI | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| South Pennine Moors | Deep Peat | 36.48 | 2.08 | 5.71 | 17.5 |
| | Other | 29.70 | 1.11 | 3.73 | 26.8 |

**North Pennines SAC**

Overall levels of burning in the North Pennine Moors SAC are shown in Table 30. Burning in Moor House – Upper Teesdale SAC is also shown, but only a small proportion of this SAC has been recently mapped.

**Table 30. Burning in the North Pennines**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SAC | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Moor House-Upper Teesdale* | Deep Peat | 12.69 | 0.45 | 3.56 | 28.1 |
| | Other | 1.34 | 0.02 | 1.45 | 68.8 |
| North Pennine Moors | Deep Peat | 430.67 | 18.77 | 4.36 | 22.9 |
| | Other | 422.03 | 17.92 | 4.25 | 23.5 |

*Only a small proportion of Moor House-Upper Teesdale has been mapped as of October 2014

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**Yorkshire Dales National Park**

Parts of the Yorkshire Dales National Park were mapped in 2014 from imagery dated 2008-2009. The area mapped was 415km$^2$ as a subset of the North Pennines SAC mapping (which also included North Pennines AONB and Nidderdale AONB). The mapped area included all the North Pennines SAC enclosed by the National Park (about 288km$^2$). The area mapped included 25 SSSIs, of which five contained significant areas of heather-dominated habitat. All five showed burning (Tables 31, 33). Note that mapping in the Yorkshire Dales NP is not comprehensive and is largely restricted to the North Pennines SAC region, so the list of SSSIs with burning in the NP may be incomplete.

Large sections of heather-dominated habitats in the Yorkshire Dales NP have not been mapped, amounting to about 100km$^2$, most of which is managed by burning.

| Table 31. Yorkshire Dales NP SSSIs with burning |
|---|
| Arkengarthdale, Gunnerside and Reeth Moors |
| East Nidderdale Moors (Flamstone Pin - High Ruckles) |
| Lovely Seat - Stainton Moor |
| Mallerstang-Swaledale Head |
| West Nidderdale, Barden and Blubberhouses Moors |

| Table 32. Burning in the Yorkshire Dales NP | | | | | |
|---|---|---|---|---|---|
| | | Area km$^2$ | | Burn intensity | |
| National Park | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Yorkshire Dales* | Deep Peat | 143.46 | 7.23 | 5.04 | 19.8 |
| | Other | 85.50 | 4.04 | 4.72 | 21.2 |

*Mapping is not comprehensive, and is largely restricted to the North Pennines SAC region.

Return periods for the mapped part of the Yorkshire Dales NP are of the order of 20 years for both deep peat and other soils. The distribution of burning among SSSIs is uneven, with return periods ranging from 14 years to more than 30 (Table 33). The most heavily burnt SSSI on deep peat in the Yorkshire Dales NP is East Nidderdale Moors, although it should be noted that most of this SSSI is mapped under Nidderdale AONB itself (below). The Nidderdale part of East Nidderdale Moors has a slightly longer return period on deep peat, 18.6 years.

| Table 33. Burning in Yorkshire Dales NP SSSIs. | | | | | |
|---|---|---|---|---|---|
| | | Area km$^2$ | | Burn intensity | |
| SSSI | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rt period yr |
| Arkengarthdale, Gunner-side and Reeth Moors | Deep Peat | 39.83 | 1.77 | 4.44 | 22.5 |
| | Other | 19.43 | 0.60 | 3.10 | 32.3 |
| East Nidderdale Moors (Flamstone Pin-High Ruckles)† | Deep Peat | 3.40 | 0.24 | 6.98 | 14.3 |
| | Other | 8.60 | 0.42 | 4.86 | 20.6 |
| Lovely Seat – Stainton Moor | Deep Peat | 43.23 | 2.65 | 6.13 | 16.3 |
| | Other | 25.56 | 1.29 | 5.05 | 19.8 |
| Mallerstang – Swaledale Head | Deep Peat | 26.03 | 0.83 | 3.19 | 31.3 |
| | Other | 2.39 | 0.07 | 2.96 | 33.8 |
| West Nidderdale, Barden and Blubberhouses Moors† | Deep Peat | 27.88 | 1.67 | 5.99 | 16.7 |
| | Other | 28.26 | 1.64 | 5.81 | 17.2 |

†Also partly within Nidderdale AONB (see Table 36)

**Nidderdale AONB**

Parts of Nidderdale AONB were mapped in 2014 from imagery dated 2009. The mapped area was 267km$^2$, and included all the North Pennine Moors SAC within the AONB

(168km$^2$). Mapping included six SSSIs, of which two have heather-dominated habitats, both of which are managed by burning (Table 34).

Nidderdale AONB is incompletely mapped, with perhaps 50km$^2$ of unmapped heather-dominated habitat managed by burning remaining.

| **Table 34. Nidderdale AONB SSSIs with burning** |
|---|
| East Nidderdale Moors (Flamstone Pin - High Ruckles)<br>West Nidderdale, Barden and Blubberhouses Moors |

**Table 35. Burning in Nidderdale AONB.**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| AONB | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rt period yr |
| Nidderdale* | Deep Peat | 63.77 | 3.59 | 5.62 | 17.8 |
| | Other | 105.60 | 4.71 | 4.46 | 22.4 |

*Mapping is not comprehensive, and is largely restricted to the North Pennines SAC region

Burning in Nidderdale is relatively intense, with return periods of 17.8 years on deep peat and 22.4 years on other soils. Of the two SSSIs burnt, West Nidderdale has the most intense regime with return periods of 16.1 and 19.4 years on deep peat and other soils respectively (Table 36). It is noteworthy that deep peat is more intensively managed than other soils.

**Table 36. Burning in Nidderdale AONB SSSIs.**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SSSI | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| East Nidderdale Moors (Flamstone Pin - High Ruckles) † | Deep Peat | 29.92 | 1.61 | 5.39 | 18.6 |
| | Other | 61.43 | 2.57 | 4.18 | 23.9 |
| West Nidderdale Barden & Blubberhouses Moors† | Deep Peat | 28.28 | 1.76 | 6.21 | 16.1 |
| | Other | 39.97 | 2.06 | 5.15 | 19.4 |

†Also partly within the Yorkshire Dales NP (see Table 33).

### North Pennines AONB

Parts of the North Pennines AONB were mapped in 2014 from imagery dated from 2006 to 2010. The entire AONB was also mapped using a point-sampling method in 2006 using imagery from 2001-2003 (mapping was updated in 2010 to add a few missing areas).

The area mapped in 2014 comprised 817 $km^2$, including all of the North Pennine Moors SAC falling within the AONB (544$km^2$) and a small section of Moor House-Upper Teesdale SAC (19$km^2$). About 400$km^2$ of the AONB remains to be mapped, which comprises the vast majority of Moor House-Upper Teesdale SAC. The North Pennine Moors SPA includes both the North Pennine Moors SAC and Moor House-Upper Teesdale SAC, so a large section of the SPA remains to be mapped in the AONB.

Mapping includes 37 SSSIs. Fourteen SSSIs have significant areas of heather-dominated habitat, twelve of them with significant areas of burning (Table 37).

**Table 37. North Pennines SSSIs with significant burning**

| |
|---|
| Allendale Moors |
| Appleby Fells |
| Bollihope, Pikestone, Eggleston and Woodland Fells |
| Bowes Moor |
| Cotherstone Moor |
| Geltsdale & Glendue Fells |
| Hexhamshire Moors |
| Lune Forest |
| Muggleswick,Stanhope & Edmundbyers Commons & Blanchland Moor |
| Teesdale Allotments |
| Upper Teesdale |
| Whitfield Moor, Plenmeller and Ashholme Commons |

**Table 38. Burning in North Pennines AONB**

| | | Area $km^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| AONB | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| North Pennines AONB* | Deep Peat | 274.00 | 9.78 | 3.57 | 28.0 |
| | Other | 232.41 | 8.83 | 3.80 | 26.3 |

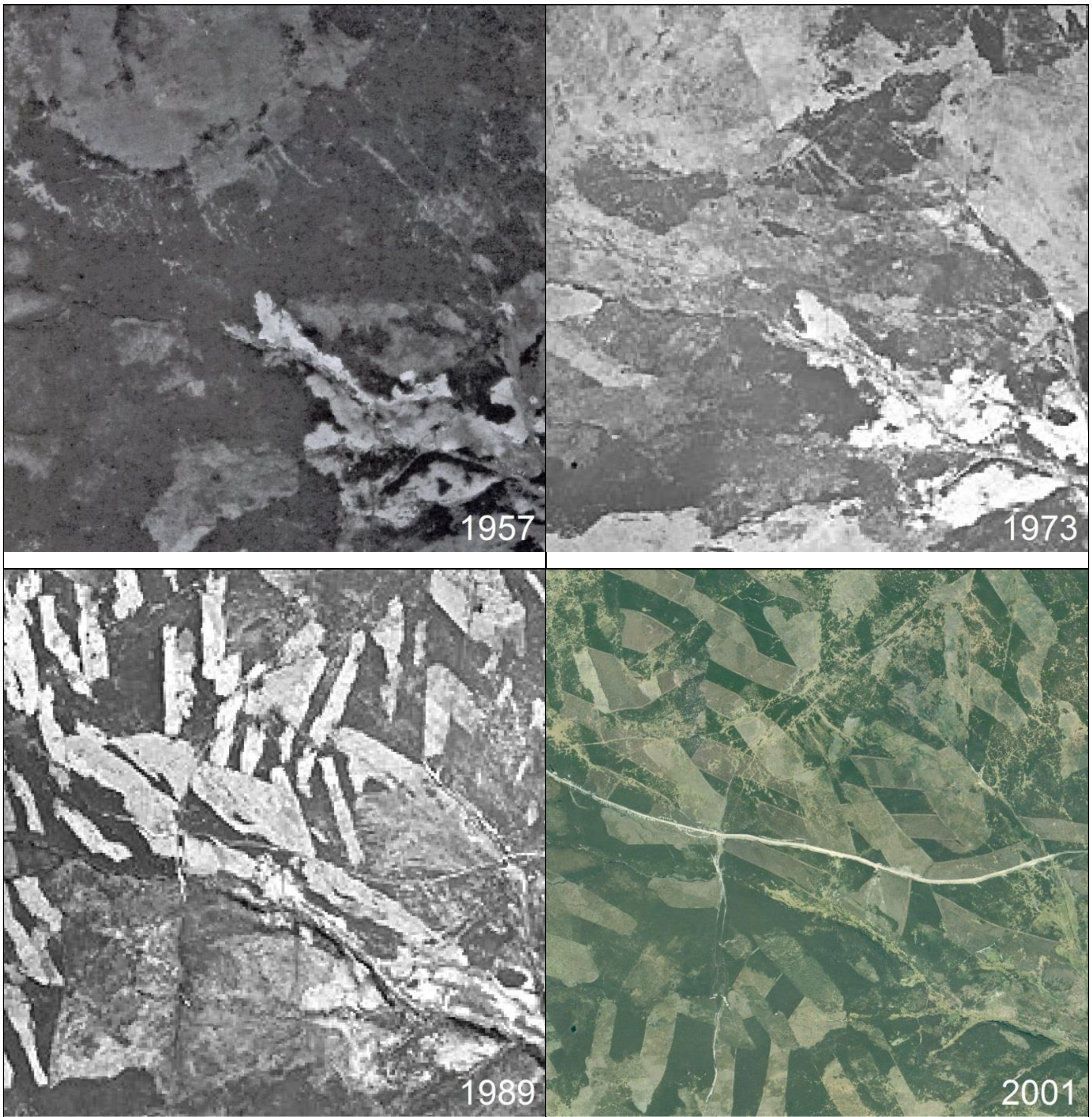
*Mapping is not comprehensive, and is largely restricted to the North Pennines SAC region

Burning in the North Pennines AONB is not as intense as in the Yorkshire Dales NP and Nidderdale (Table 38; see also Tables 32, 35). Among SSSIs, Muggleswick has the most intense management regime on deep peat, with a return period of 12.7 years (although this is based on a relatively small area of deep peat). Some SSSIs have very low-intensity regimes, with return periods of more than 70 years for Geltsdale and Glendue Fells SSSI, for example (Table 39).

**Table 39. Burning in SSSIs in the North Pennines AONB**

| SSSI | Soil type | Area $km^2$ DSH | Area $km^2$ Burnt $yr^{-1}$ | Burn intensity %burn $yr^{-1}$ | Burn intensity Rtn period yr |
|---|---|---|---|---|---|
| Allendale Moors | Deep Peat | 15.72 | 0.37 | 2.35 | 42.5 |
| | Other | 10.47 | 0.22 | 2.07 | 48.3 |
| Appleby Fells* | Deep Peat | 2.83 | 0.11 | 3.72 | 26.9 |
| | Other | 0.01 | 0.00 | 0.00 | - |
| Bollihope, Pikestone, Eggleston and Woodland Fells | Deep Peat | 17.57 | 1.06 | 6.03 | 16.6 |
| | Other | 45.06 | 1.69 | 3.76 | 26.6 |
| Bowes Moor | Deep Peat | 35.28 | 0.94 | 2.65 | 37.7 |
| | Other | 4.16 | 0.11 | 2.59 | 38.6 |
| Cotherstone Moor | Deep Peat | 7.80 | 0.56 | 7.17 | 14.0 |
| | Other | 3.85 | 0.03 | 0.87 | >100 |
| Geltsdale & Glendue Fells | Deep Peat | 51.68 | 0.71 | 1.37 | 72.9 |
| | Other | 10.16 | 0.14 | 1.33 | 74.9 |
| Hexhamshire Moors | Deep Peat | 28.58 | 1.43 | 5.01 | 20.0 |
| | Other | 50.42 | 2.11 | 4.18 | 23.9 |
| Lune Forest | Deep Peat | 43.89 | 1.49 | 3.40 | 29.4 |
| | Other | 4.98 | 0.11 | 2.17 | 46.0 |
| Muggleswick, Stanhope & Edmundbyers Commons & Blanchland Moor | Deep Peat | 7.28 | 0.57 | 7.86 | 12.7 |
| | Other | 73.33 | 3.47 | 4.73 | 21.2 |
| Teesdale Allotments* | Deep Peat | 0.00 | - | - | - |
| | Other | 0.22 | <0.01 | 1.20 | 83.6 |
| Upper Teesdale* | Deep Peat | 9.83 | 0.35 | 3.53 | 28.4 |
| | Other | 1.33 | 0.02 | 1.46 | 68.4 |
| Whitfield Moor, Plenmeller and Ashholme Commons | Deep Peat | 23.25 | 1.02 | 4.39 | 22.8 |
| | Other | 23.09 | 0.84 | 3.64 | 27.4 |

***Mapping is not comprehensive.**



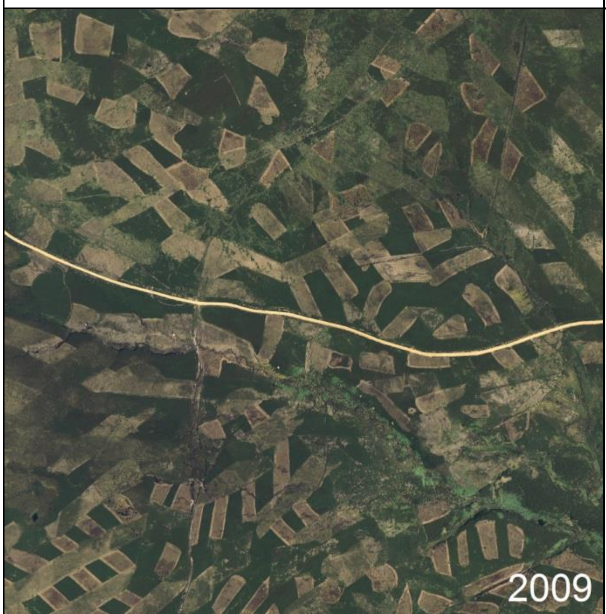




**Figure 7. Burning in NZ0132 between 1957 and 2009.**

This square is in Bollihope, Pikestone, Eggleston and Woodland Fells SSSI in the North Pennine Moors SAC.

The area is entirely deep peat.

Of note is an apparent intensification of burning and a shift between occasional large burns to regular small burns. The bright area to the south east along the creek is an area that is apparently bracken-dominated in early decades, but is presently mostly heather.

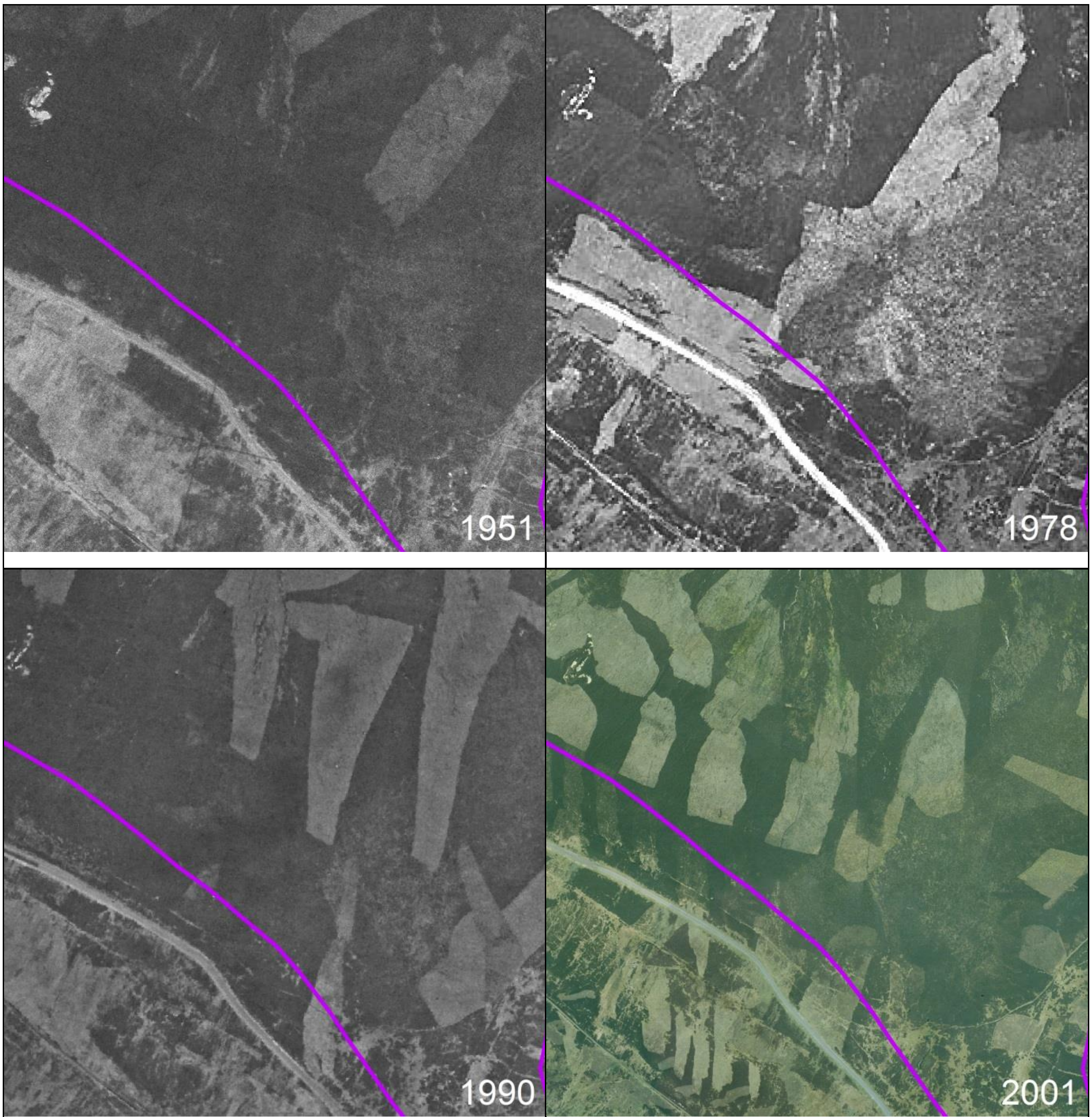




**Figure 8. Burning in NY9944 between 1951 and 2009.**

Square in Muggleswick, Stanhope & Edmundbyers Commons & Blanchland Moor SSSI in the North Pennine Moors SAC.

The region to the north of the purple line is deep peat, while the area to the south is shallow peat. There is an expansion of burning on the deep peat area over the five decades.

**Comparison of burning: North Pennines AONB 2001-3 and 2006-10**

The 2014 mapping project shows return periods in the North Pennines AONB to be 28.0 years on deep peat and 26.3 years on other soils. However, not all the AONB was mapped in 2014; considering only the area mapped in 2006 *and* 2014 (565 $km^2$), these figures are 28.0 years and 24.9 years. In contrast, the 2006 mapping project found return periods of 17.1 years for other soils and 15.2 years on deep peat; for the overlapping area, these figures are 16.9 years and 13.9 years (Table 40). Are these differences real, or an artefact of the methodology used?

**Table 40. Comparison of mapping results in the North Pennines AONB for the 2006 and 2014 projects**

| Mapping project | Soil type | Burnable Habitat in common area ($km^2$) | Return period in common area (yrs) | Notes |
|---|---|---|---|---|
| 2006, with imagery from 2001-3 | Deep Peat<br>Other | 172.09<br>129.00 | 13.9<br>16.9 | Uses class 1 and 2 burns with estimated duration of 7.7 yr |
| 2014, with imagery from 2006-10 | Deep Peat<br>Other | 266.52<br>211.14 | 28.0<br>24.9 | Uses class 1 burns only with a duration of 4 yr |

There are a series of differences in the methods used to arrive at return periods in the two studies. The 2006 study calculated return periods using class 1 and class 2 burns with an estimated duration of 7.7 years, whereas the 2014 study considered only class 1 burns and estimated their lifetime to be 4 years. However, the most important difference between the two measurements is that the first study mapped habitats and burns using a point-sampling technique, while the newer study used polygons to map habitats and burns. The practical result of this difference can be clearly seen in Table 40: the point sampling technique arrives at a far lower estimate for burnable habitat than the version which has a hand-drawn burnable habitat map. This is because, even within areas of habitat that are dominated by heather, there will always be areas of non-heather: tracks, creeks, eroded peat, flushes, areas of bracken, etc. These features will be too small to be excluded from the burnable habitat mask, but when point samples are dropped within the burnable habitat mask, inevitably many points will miss heather and will therefore be categorised as class 0, i.e. non-burnable habitat. Note that this difference does not affect the absolute level of burning measured (as $km^2$/yr); it only shortens the apparent return period of point-sampled regions compared to polygon-mapped regions. This issue had not been foreseen and highlights the importance of consistent methodology in comparing return periods.

Table 41 shows the estimated return period, for the common area of the two mapping studies, using the methodology of both studies. It was possible to 'back-calculate' the effect of using the 2006 methodology on the 2014 data by using the 2006 point data and intersecting it with the 2014 classification. As can be seen, a slightly different interpretation of return periods is arrived at according to whether only class 1 or both class 1 and 2 are used with the 2006 data. In the future it will be unnecessary to consider class 2 burns, provided that a suitable frequency of aerial photography is available. Given that the estimated return period in the newer study falls between the two estimates of return period for the earlier study (26.5 vs 23.9 - 34.3), it is unlikely that there is a systematic difference in burning intensity between the two studies. Estimates for annual burning in the overlapping area range from 18.02 $km^2$/yr (new mapping) to 13.92-20.00 $km^2$/yr (2006 mapping).

**Table 41. Return periods (years) for the common area in the 2006 and 2014 North Pennines mapping projects calculated using 2006 and 2014 methodologies**

| Mapping Project | Method used | |
|---|---|---|
| | 2006 (point-sampling) | 2014 (polygon mapping) |
| 2006 (Class 1 only) | 21.6 | 34.3 |
| 2006 (Class 1 and 2) | 15.1 | 23.9 |
| 2014 (Class 1 only) | 16.7 | 26.5 |

**East Lakes**

The East Lakes region was mapped in 2014 from imagery dated 2009-2010. The mapped area totalled 140$km^2$, and includes most of Asby Complex SAC. The area is largely outside National Parks or AONBs, having only a small area within the Lake District NP (<2$km^2$ heather-dominated habitat). Because only a very small amount of the Lake District NP has been mapped, this National Park is not included in the national summary table. Besides Asby Complex, one other SAC with heather-dominated habitat was included in the mapping: a small part of Lake District High Fells. Burning occurred in both SACs. The East Lakes region included eight SSSIs with heather-dominated habitat, four of which also had significant levels of burning (Table 42).

| **Table 42. East Lakes SSSIs with burning** |
|---|
| Ash Fell |
| Crosby Ravensworth Fell |
| Shap Fells |
| Sunbiggin Tarn & Moors and Little Asby Scar |

Burning in Asby Complex SAC is relatively light, with a return period of more than forty years. It is similarly light in the small part of Lake District High Fells to have been mapped (Table 43). The most intensively burnt SSSI in the region is Ash Fell, with a return period of 35.8 years. However, this figure is based on a very small area of burnable habitat (3.75$km^2$; Table 44).

**Table 43. Burning in East Lakes SACs**

| SAC | Soil type | Area km² DSH | Burnt yr⁻¹ | Burn intensity %burn yr⁻¹ | Rtn period yr |
|---|---|---|---|---|---|
| Asby Complex | Deep Peat | 0.00 | - | - | - |
| | Other | 7.53 | 0.16 | 2.18 | 45.9 |
| Lake District High Fells* | Deep Peat | 0.95 | 0.02 | 1.58 | 63.3 |
| | Other | 0.83 | <0.01 | 0.19 | >100 |

***Only a small proportion of Lake District High Fells SAC has been mapped.**

**Table 44. Burning in East Lakes SSSIs.**

| SSSI | Soil type | Area km² DSH | Burnt yr⁻¹ | Burn intensity %burn yr⁻¹ | Rtn period yr |
|---|---|---|---|---|---|
| Ash Fell | Deep Peat | 0.00 | - | - | - |
| | Other | 3.75 | 0.10 | 2.79 | 35.8 |
| Crosby Ravensworth Fell | Deep Peat | 0.00 | - | - | - |
| | Other | 4.57 | 0.09 | 1.92 | 52.0 |
| Shap Fells* | Deep Peat | 0.95 | 0.02 | 1.58 | 63.3 |
| | Other | 0.83 | <0.01 | 0.19 | >100 |
| Sunbiggin Tarn & Moors and Little Asby Scar | Deep Peat | 0.00 | - | - | - |
| | Other | 2.84 | 0.08 | 2.69 | 37.1 |

*Incompletely mapped.

**Forest of Bowland**

The Forest of Bowland AONB was mapped in 2014 from imagery dating from 2008-2010. Mapping covered 334 km$^2$, 329 km$^2$ of which is within the Forest of Bowland AONB. The mapped area included the entirety of Bowland Fells SPA (160 km$^2$). Three SSSIs were in the mapped area, but only one, Bowland Fells SSSI itself, included heather-dominated habitat and burning management (Table 45).

**Table 45. Forest of Bowland SSSIs with burning**

| |
|---|
| Bowland Fells |

Bowland Fells is an SPA with c. 80km$^2$ of burnable habitat. Burning management is light, with return periods of more than 50 years on both deep peat and other soils (Table 46). Bowland Fells SSSI occupies the same space as the SPA, and burn statistics are identical.

**Table 46. Burning in Bowland Fells SPA/SSSI**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| Region | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| Bowland Fells SPA/SSSI | Deep Peat | 56.77 | 1.13 | 1.99 | 50.3 |
| | Other | 37.72 | 0.70 | 1.86 | 53.8 |

## Shropshire Hills AONB

Shropshire Hills AONB was mapped in 2014 from imagery dated 2009 to 2010. 933km$^2$ were mapped in total, which included 776 km$^2$ of Shropshire Hills AONB the rest being undesignated.

Mapping included the entirety of The Stiperstones and The Hollies SAC (6km$^2$). Fifty SSSIs were included in the mapped area, four with significant areas of heather-dominated habitat. Three of these were managed by burning (Table 47). Current mapping shows no upland deep peat in the Shropshire Hills.

Note that The Stiperstones and The Hollies SSSI is slightly larger than The Stiperstones and The Hollies SAC.

**Table 47. Shropshire Hills SSSIs with burning**

| |
|---|
| Catherton Common |
| Long Mynd |
| The Stiperstones & The Hollies |

Burning is light in The Stiperstones and The Hollies SAC, with a return period estimated of over 100 years (Table 48). Burning is also light in all three SSSIs in which it occurs in the Shropshire Hills, the shortest return period being 83.4 years for Catherton Common (Table 49).

**Table 48. Burning in Shropshire Hills SAC**

| | | Area km$^2$ | | Burn intensity | |
|---|---|---|---|---|---|
| SAC | Soil type | DSH | Burnt yr$^{-1}$ | %burn yr$^{-1}$ | Rtn period yr |
| The Stiperstones & The Hollies SAC | Deep Peat | 0.00 | - | - | - |
| | Other | 3.68 | 0.03 | 0.74 | >100 |

| Table 49. Burning in Shropshire Hills SSSIs. | | | | | |
|---|---|---|---|---|---|
| | | Area $km^2$ | | Burn intensity | |
| SSSI | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| Catherton Common SSSI | Other | 0.76 | 0.01 | 1.20 | 83.44 |
| Long Mynd | Other | 9.87 | 0.06 | 0.59 | >100 |
| The Stiperstones & The Hollies | Other | 3.68 | 0.03 | 0.74 | >100 |

**Quantocks**

The Quantocks AONB was mapped in 2009 from imagery dated 2006. The mapped area was $99km^2$, comprising the entire AONB. Mapping included $3km^2$ of Exmoor and Quantock Oakwoods SAC, but there was no significant DSH or burning in this SAC. Three SSSIs were mapped, only one of which had significant heather-dominated habitat and burning management (Table 50).

| Table 50. Quantocks SSSIs with burning |
|---|
| The Quantocks |

There is little DSH-dominated habitat in The Quantocks, and as a consequence a very small area of it is burnt in absolute terms. In terms of intensity, the calculated return period for the AONB is 24.6 years on other soils (there is no DSH-dominated deep peat) (Table 51). The relatively short return period in this instance is likely due to the small absolute area of DSH-dominated habitat, because of which a few burns might make up a relatively large proportion of the total area. The figures for the AONB are identical to the figures for The Quantocks SSSI, because both regions include all heather-dominated habitat mapped.

| Table 51. Burning in the Quantocks. | | | | | |
|---|---|---|---|---|---|
| | | Area $km^2$ | | Burn intensity | |
| Region | Soil type | DSH | Burnt $yr^{-1}$ | %burn $yr^{-1}$ | Rtn period yr |
| The Quantocks AONB/SSSI | Deep Peat | 0.00 | - | - | - |
| | Other | 4.23 | 0.17 | 4.06 | 24.6 |

## 4: Discussion

### The spatial distribution and intensity of burning management in the English Uplands

Burning is very unevenly distributed in the English uplands. In some areas, although burning is used, return periods are of the order of a century (Northumberland for example; Table 23). Conversely, some areas are intensively managed (e.g., North York Moors (Table 18)), with return periods of little over a decade on both soil types. In terms of NPs/AONBs, burning management is concentrated in three areas: the larger North Pennines, comprising North Pennines AONB, Yorkshire Dales NP and Nidderdale AONB, the North York Moors NP, and the Peak District NP. Because all these are closely related to SACs of the same name, the situation for SACs/SPAs is very similar, although the South Pennine Moors SAC has significant burning that is outside NPs/AONBs (Table 25). Areas outside NPs/AONBs and SACs/SPAs are burnt less intensively than areas within those designations. In part this is probably due to the fact that large and contiguous blocks of moorland tend to have been placed within conservation designations, so that remaining areas may be small, fragmented and less suitable for burning.

Burning intensity is similar on deep peat and other soils (Table 3). From the estimates obtained here, burning of heather on deep peat occurs at a rate of 3.76%/yr, only slightly less than that of heather on other soils (3.99%/yr). In absolute terms, for the areas recently mapped, around 33km$^2$/yr of heather is burnt on deep peat a year and 51km$^2$/yr on other soils. These figures are derived from mapping of c. 2150km$^2$ of DSH-dominated habitat, which exclude several important statutory regions, as well as areas with no formal conservation designation. The figures therefore represent an under-estimate of national burning of the order of 20% based on a brief assessment of unmapped areas (the precise figure is not known).

Although the absolute area of burning on deep peat is lower than for other soils, this does not represent a lower intensity of management on deep peat. In many areas, indeed, burning is in fact more intense on deep peat than on other soils (Tables 4,5). These areas include all of the important centres of burning mentioned above; nationally this difference is counterbalanced by burning in areas where there is no or little deep peat. It may be that divisions between soil types are not obvious on the ground, especially where heath-type vegetation has developed on deep peat, and that a single burning prescription is being carried out which more suits heath than bog.

It is interesting to note that of the c. 2,900km$^2$ of deep and blanket peat in England, recent mapping projects have identified 880km$^2$ to be DSH-dominated. Other areas of DSH-dominated deep peat remain unmapped, but it is already clear that a large proportion of blanket bog or former blanket bog has developed heath-type vegetation (Table 3).

As noted, the current blanket bog habitat map has a number of weaknesses, which is why deep peat has been used here as a measure of blanket bog and former blanket bog. When an accurate inventory of blanket bog is established, this should also include an inventory of the historic extent of blanket bog. The uplands of England have been affected by a range of impacts over the last century, including pollution, artificial drainage, grazing and burning

(Appendix 2). The general trend is that these impacts are now weakening. The apparent exception is that of managed burning (as measured here in the national historical survey, and via the proxy of historic grouse bags (Appendix 2; Figure 1).

**Changes in burning management, 1945-2009**

Burning increased over the latter half of the twentieth century (Figure 1). The change was more pronounced on deep peat (a seven-fold increase) than other soils (three-fold). There seems to have been an expansion of burning from more accessible areas of upland heath on moorland fringes onto blanket bogs (typically on the plateaus), perhaps because more suitable areas were already in use so that natural expansion would tend to extend burning onto the higher, flatter, deep peat areas of moorland. This expansion has been aided by provision of gripping in many areas, which, in consort with burning, appears to have allowed heather to spread into areas it was previously not a dominant feature of. It is not known to what extent this increase in burning was driven by sheep farming or grouse rearing, but it is noticeable in many sample squares that burn sizes have declined in recent decades (eg NZ0132; Figure 7) perhaps reflecting a change in the purpose of burning from improvement of sheep grazing to improvement of grouse rearing. Additionally, grants were available for agricultural improvements including provision of artificial drainage for much of the latter half of the twentieth century, and these must have contributed towards the general intensification in burning as well. Sheep numbers in England and Wales apparently peaked around 1999, but grouse bags have risen since that date (Appendix 2).

The general picture then is of sparse, large, infrequent burns more prevalent on other soils than deep peat becoming small, regular and frequent burns on heath-type communities regardless of whether on deep peat or other soils.

It should be noted that burn scars are difficult to see when non-DSH-dominated communities are burnt, particularly in poor-quality imagery. It is though possible to see burns into sparse heather (eg, SE0767; Figure 1), showing that to some extent the increase in burning on deep peat must have come about by burning such habitats, the effect of which was to promote more burnable, heath-type communities. It has been argued that burning is a necessity to prevent wildfire in many situations. However, it is equally arguable that burning has, by promoting wildfire-prone heather, itself necessitated further burning.

The possibility must be mentioned that burns might fade into the background faster in earlier imagery, which, particularly for the period 1945-1959 is both of poor quality and black and white. This would have the effect of artificially decreasing estimates of burning in the early decades of the sampling relative to the later decades with better photography. However, bearing in mind the size of the difference measured (15.1 $km^2$/yr burning in 1945-1959 vs 68.74 $km^2$/yr in 2010), it would require burns in new imagery to be visible for four times as long as in 1945-1959 imagery for the intensity of burning to be the same. Even allowing the caveat that burning is probably less visible in 1945-1959 imagery, there is little doubt that burning is more intense now.

It may be argued that burning in the years following World War 2 had declined from a higher level in the decades preceding for socio-economic reasons, but there is of course no documentary photographic evidence to assess that view (but see Figure 1, Appendix 2, which shows low levels of grouse shooting and/or low grouse populations during World War 2 and the years after).

#### Considerations for measuring, analysing and interpreting burning management

The notional return period for a given area under management is calculated as the time it would take for the entirety of that area to undergo management *if it was burned evenly* i.e. if 5% of an area is burnt each year then the notional return period will be 20 years.

This is an intuitive measure of management intensity, and enables comparisons between sites and through time. In addition return periods are invariably used in management agreements. However, the measurement and interpretation of return periods is not without problems and these need consideration. Primary amongst these is that is incorrect to interpret a return period of, for example, 20 years as implying every part of the area of interest is burned once in 20 yrs. This is not the nature of moorland burn management. In reality many parts of the area will probably not be burned at all and others burned more than once i.e. a notional return period is simply an *average* of the management burn intensity within a given area. At its simplest this means that rotations prescribed within management agreements designed to minimise damage to vegetation communities are unlikely to have the desired outcome over large parts of a protected area.

#### Measuring return periods: Point sampling vs polygon mapping

Return periods are also defined against burnable habitat, i.e. the subset of an area of interest that is likely to be subject to burning management (usually heather-dominated habitat). But the envelope of land defined as burnable is bound to overestimate the area of land that is available to burn. Unless heather forms a seamless monoculture, there will always patches of other habitat within the heather-dominated area: grass, sedge or bracken-dominated habitat, or bare eroding peat, rock or creeks. Comparison of estimates of heather-dominated habitat in the North Pennines AONB showed that more than 30% of sample points within a well-defined burnable habitat envelope may not intersect with heather. Taken together, there are a significant number of small (unmappable) areas of non-heather within a larger region defined as a whole as burnable. Some of these areas may be burnable in the sense that a fire could pass over them; some may not be. Even the ‘burnable’ non-heather will not be likely to show a burn signature for anything longer than a single year.

Bearing in mind the large difference between the results of point-sampling and polygon-based mapping, which method should be considered the most accurate? Given the above discussion it is evident that the point-sampling method will always produce a shorter (i.e. more intense) estimate of return period than polygon mapping will. While creeks, flushes, tracks etc occupy a surprisingly large area within heather-dominated habitat, it is inarguable that they should not be included when calculating a burning rotation, since they are not a burning target and will, or should, never be burned. This means that estimates of return period based on polygon mapping in a heather-dominated habitat mask will underestimate burning intensity. The point-sampling method is ‘pedantically accurate’. Because it more accurately captures the proportion of heather-dominated habitat in a scene, the point-sampling method defines a lower burnable habitat area than when a heather-dominated mask is used. As noted, this does not affect *absolute* burning estimates, only return periods, via the difference in burnable habitat. Bearing in mind the difficulties of point-sampling and the speed and accuracy obtained with automated classification within a heather-dominated habitat mask, there is no case for using point-sampling methods for anything other than error checking. However, it should be borne in mind always that estimates of return period will depend heavily on the nature of the habitat in study, because of the occurrence of non-heather habitat within heather-dominated areas but at a non-mappable scale. The conclusion to be drawn from these observations is that an individual patch of heather will, on average, probably be burnt more than once within the length of time defined as 'return period'.

Return periods reported here, then, are an upper estimate. It appears from the headline figures reported in Table 4 and Table 5 that in many areas burning is not very intensive. However, as noted, there are limitations to this interpretation. Return periods are specified in management prescriptions that generally do not include fine-scale maps, so the polygon method largely used in the studies summarised here is an appropriate important metric of burn intensity despite the caveats acknowledged above.

#### Measuring return periods: Duration of burn scar visibility

The results of the extended English Sample reported here found rates of burning 25% lower than the original sample for the year 2000. There are several possible reasons for this difference, the most obvious being the quality of the original imagery used and the fact that it lacked the context of images of different dates. With one-off images, features that resemble burns may be present, but these may represent 'permanent' patches of non-heather communities; with a time series of images, it is easy to determine features that are transient and are therefore more likely to be burns. On this basis, the figure arrived at by the extended English sample of $74.60km^2/yr$ is more likely to be closer to the true number than the original figure of $99.75km^2/yr$.

However, both these figures rely upon the duration of visibility of burns to be approximately 7.7 years. This figure was based on an empirical analysis of 88 burns in Yallop et al (2006a), but is likely to vary regionally and even on a very small scale depending on the age of heather being burnt, since it has been known for a long time that mature heather regenerates more slowly than younger stands. Anecdotally (pers. obs.) it is clear that many burns have a visible lifetime very much shorter than 7.7 years, while it is equally clear that the outline of some burns persist for more than 7.7 years, and may in fact become 'permanent' features where heather effectively never regains dominance. Many variables contribute to these different lifetimes, including the community composition, the time since that community was last burnt, the intensity of the burn, substrate, latitude and altitude.

It was possible to compare the use of a snapshot of one image with an estimated 7.7 years for burn visibility with a more intensive approach mapping each new burn with a series of images using one particular square kilometre (SD9433) that was both part of the England sample and had also been studied exhaustively for another project (Table 52).

**Table 52. Comparison of estimates of burning for a single kilometre square in the English uplands, SD9433.**

This square was both part of the National sample and studied more intensively for another project. The data for the intensive study come from a series of four images, and that for the National sample from a single image.

| Burn date | Burning ($m^2$) | Burn $yr^{-1}$ ($m^2$) |
|---|---|---|
| **Intensive study, 2003-2010** | | |
| Oct 2003-Apr 2006 | 86,508 | 14,915 |
| Oct 2006-Apr 2008 | 8,725 | |
| Oct 2009-Apr 2010 | 9,173 | |
| **National Sample** | | |
| 2003-2010 (7.7 yr assumed window, photograph 2010) | 75,129 | 9,757 |

Data on burning covers 7 years for the intensive study and is assumed to cover 7.7 years in the National sample.

As can be seen, the use of 7.7 years in this instance underestimates burning rates. Evidently some burning that occurred from 2003-6 is no longer visible in 2010, which leads to the difference. In fact, in order to get an estimate from this square of the National sample to equate to the more accurate figure derived from the intensive study, it would be necessary to use an estimated duration of burn visibility of between 5.0 and 5.1 years rather than 7.7 years. It must be emphasised that this is only a comparison based on a single available sample square, but it is suggestive that the period of 7.7 years is too conservative. Further evidence to support this is that summing the annual burning in the regions that have been mapped completely gives a figure of 83.87 $km^2$/yr, which exceeds the estimate obtained by the National sample (74.60 $km^2$/yr) despite the fact that several large areas managed by burning are not included in the former total (principally parts of the Dales and Nidderdale). If the figure of 5.0-5.1 years for the duration of visibility was used to produce the national estimate of burning, then the estimate of burning would rise to c.110$km^2$/yr.

This problem only arises when one wishes to place a figure for the rate of burning on the National sample, i.e. it is due to selecting a figure for burn visibility duration to divide the visible burning by. If instead the quantity of burning mapped is used as a raw figure, there are fewer questions over accuracy.

Where scene length is open-ended, and depends upon measured estimates of burn visibility duration (as for the England sample), there is an unavoidable assumption that all mapped burns will not have been burnt more than once in the preceding 7.7 years. The necessary assumption that burns are visible for a uniform length of time wherever they are in the country, on whatever habitat, and however intense they may be, adds a potential source of variability to accurate estimates of return periods.

There are a number of ways of minimising the variability in estimates of return periods. The most obvious of these is to map new burns only using multispectral imagery. This has been done for the recent mapping projects summarised here. Additionally, high-frequency, regular monitoring would decrease the likelihood that burns would be missed. It should be possible to develop digital products that map all burning over an extended period of time and show the number of times each part of the area of interest has been burnt. Unburnt areas on such maps would show both non-burnable habitat and mature unburnt heather.

**Summary and concluding remarks**

- In England as a whole, the intensity of burning has increased approximately five-fold from the 1940s to the present.

- The increase in burning from 1940s to 2000s was more pronounced in areas of deep peat (blanket bog and former blanket bog). The trend was for management to move from moorland edges onto the flatter tops, often accompanied by artificial drainage.

- Nationally, the intensity of burning on deep peat is now similar to that on other substrates, with average return periods of 25-27 years. Although bogs are able to tolerate wildfire events and recover this has only been shown to occur at fire frequencies or return periods of perhaps 1/20$^{th}$ of that currently seen in England The distribution of return periods is right-skewed with much shorter rotations in most places combined with essentially unburned regions.

- Regional variation in burning intensity is striking. The North York Moors is the most heavily managed National Park, with return periods of 11-14 years. Other National Parks, including Northumberland and Exmoor have relatively little burning.

- In the North Pennines AONB, Yorkshire Dales NP, Nidderdale AONB, North York Moors NP and elsewhere the burning of deep peat is occurring at a greater intensity than on other soils.

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## 6: Appendices

## Appendix 1

### Equivalencies and comparisons of SACs and SPAs in mapped regions

SACs and SPAs are European level conservation designations. Some areas classified under this scheme are designated as solely SACs or SPAs. Other areas have joint SAC/SPA status; in this situation SPAs frequently extend over a larger area than the equivalent SAC. For convenience in interpretation of management data, a table of these distinctions for the relevant SACs and SPAs is given here.

| SAC | SPA | Notes |
|---|---|---|
| Border Mires, Kielder-Butterburn SAC | No SPA | |
| Dartmoor SAC | No SPA | |
| Exmoor Heaths SAC | No SPA | |
| No SAC | Forest of Bowland SPA | |
| Harbottle Moors SAC | No SPA | |
| Moor House-Upper Teesdale SAC* | Part of North Pennine Moors SPA | North Pennine Moors SPA is slightly larger than Moor House-Upper Teesdale SAC and North Pennine Moors SAC combined |
| North Pennine Moors SAC | Part of North Pennine Moors SPA | |
| North York Moors SAC | North York Moors SPA | SAC and SPA cover identical areas |
| Simonside Hills SAC | No SPA | |
| South Dartmoor Woods SAC | No SPA | |
| South Pennine Moors SAC | Peak District Moors SPA (South Pennine Moors Phase 1)<br>AND<br>South Pennine Moors Phase 2 | Peak District Moors SPA is slightly larger than the relevant part of South Pennine Moors SAC. South Pennine Moors Phase 2 covers an identical area. |
| The Stiperstones & The Hollies SAC | No SPA | |

## Appendix 2

Impacts on upland England in the twentieth century and early twenty first century

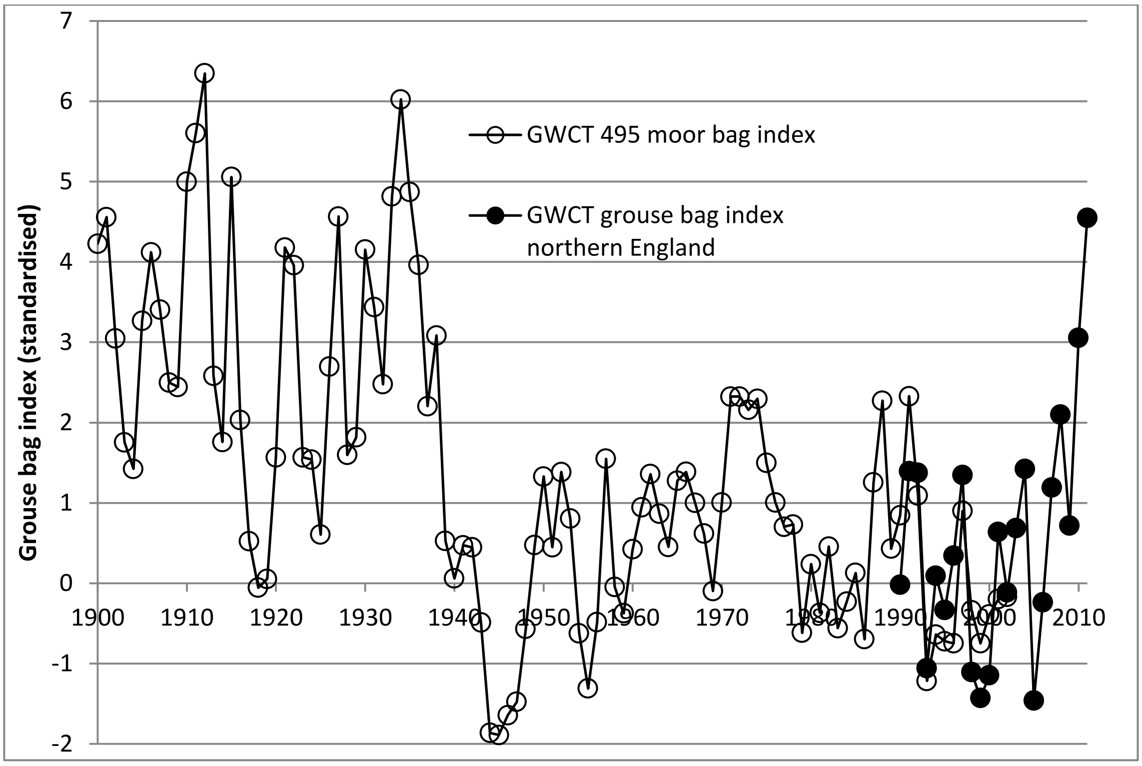


**Figure A1. Grouse bags and survey data: data from Game and Wildlife Conservation Trust.**
Open circles: 1900-2002 data on grouse bags for 495 moors; closed circles: 1990-2011 population survey data for northern England only. Series standardised based on period of overlap (1990-2002).

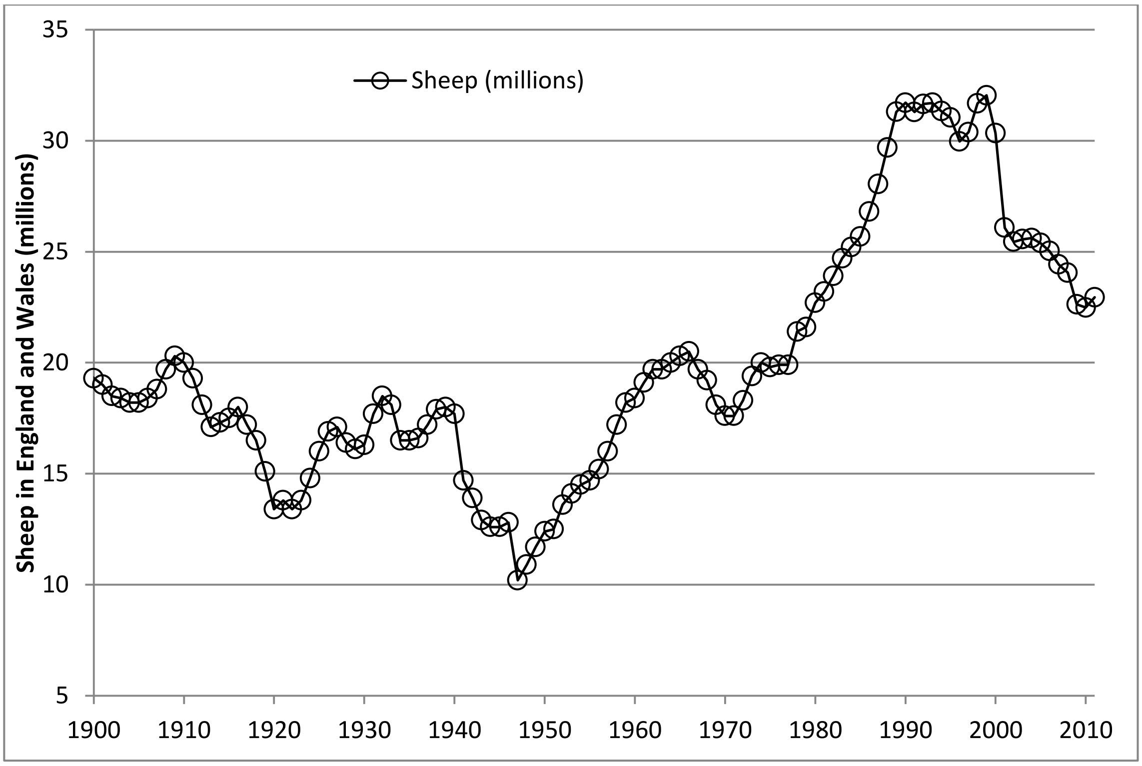


**Figure A2. Number of sheep in England and Wales, 1900-2011.**

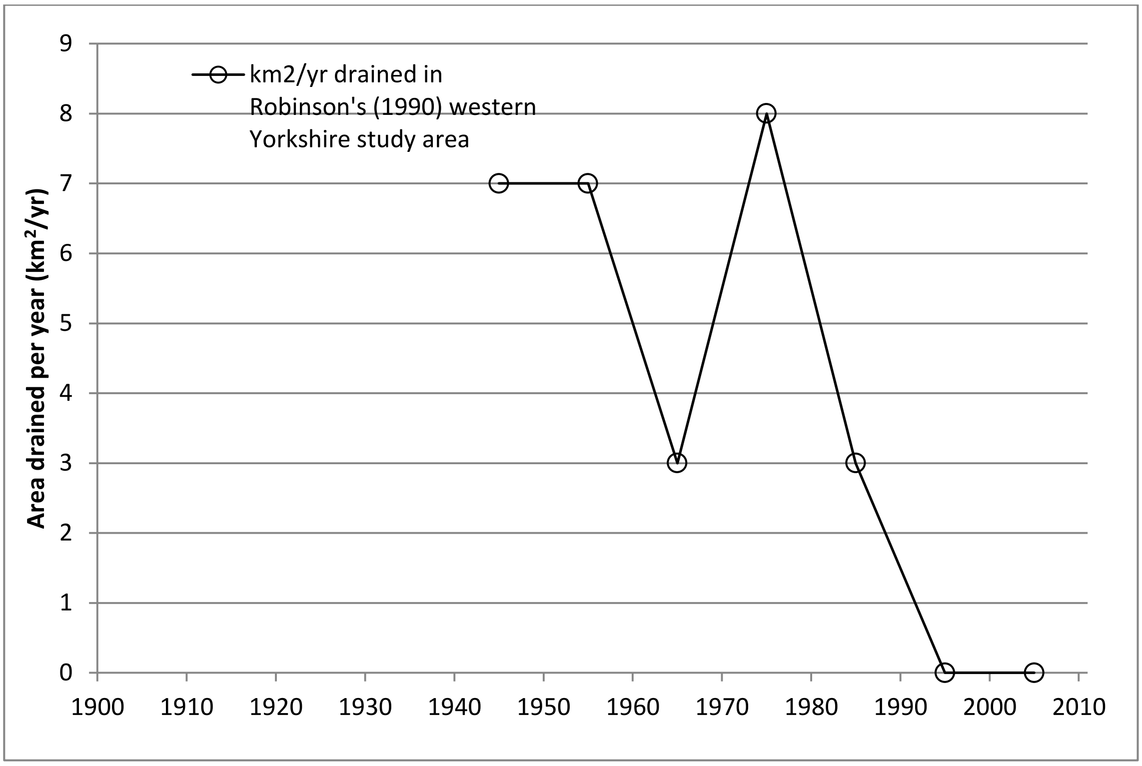


**Figure A3. Area of drainage (km$^2$) installed in an area of western Yorkshire in the 1940s to 1980s.**
Value of 0 for 1990s and 2000s is inferred; values before the 1940s are unknown. Data covers Ribblesdale, Wharfedale, Nidderdale, Wensleydale and Swaledale (Robinson, 1990).

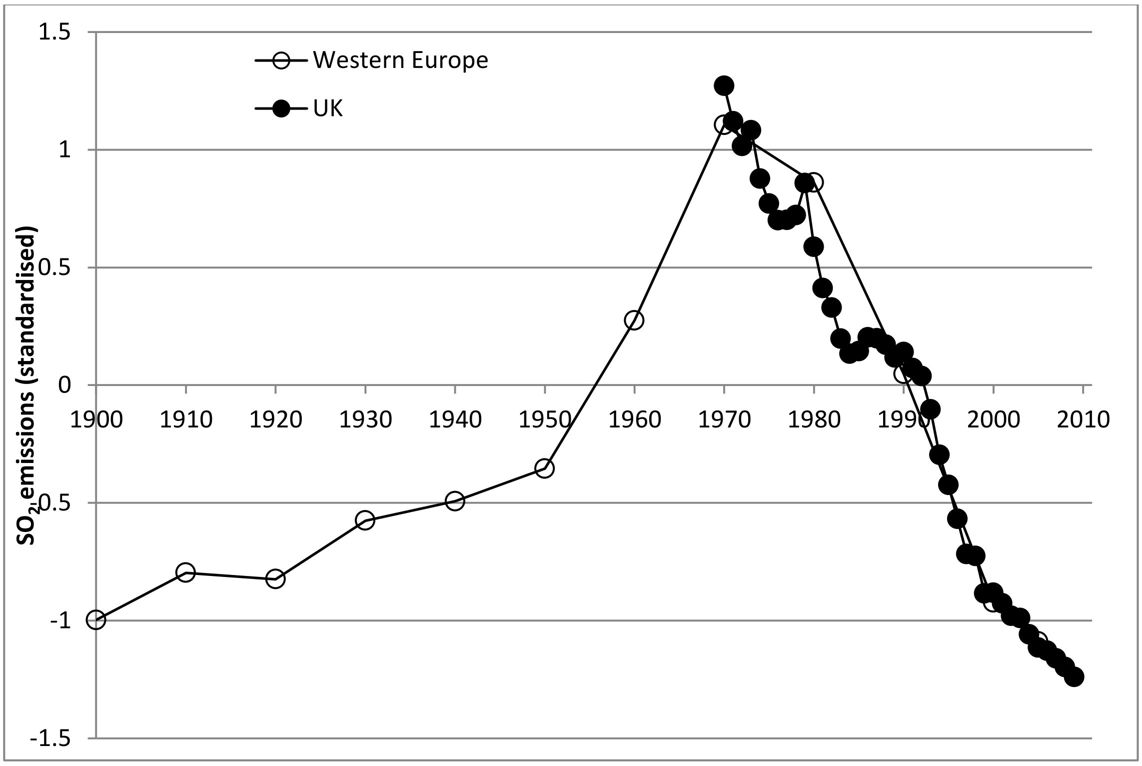


**Figure A4. Standardised SO2 emissions for western Europe and the UK.**
Western Europe 1900-2005: Smith et al (2011). UK 1970-2009: Defra. Values standardised based on overlapping data points in the two series.

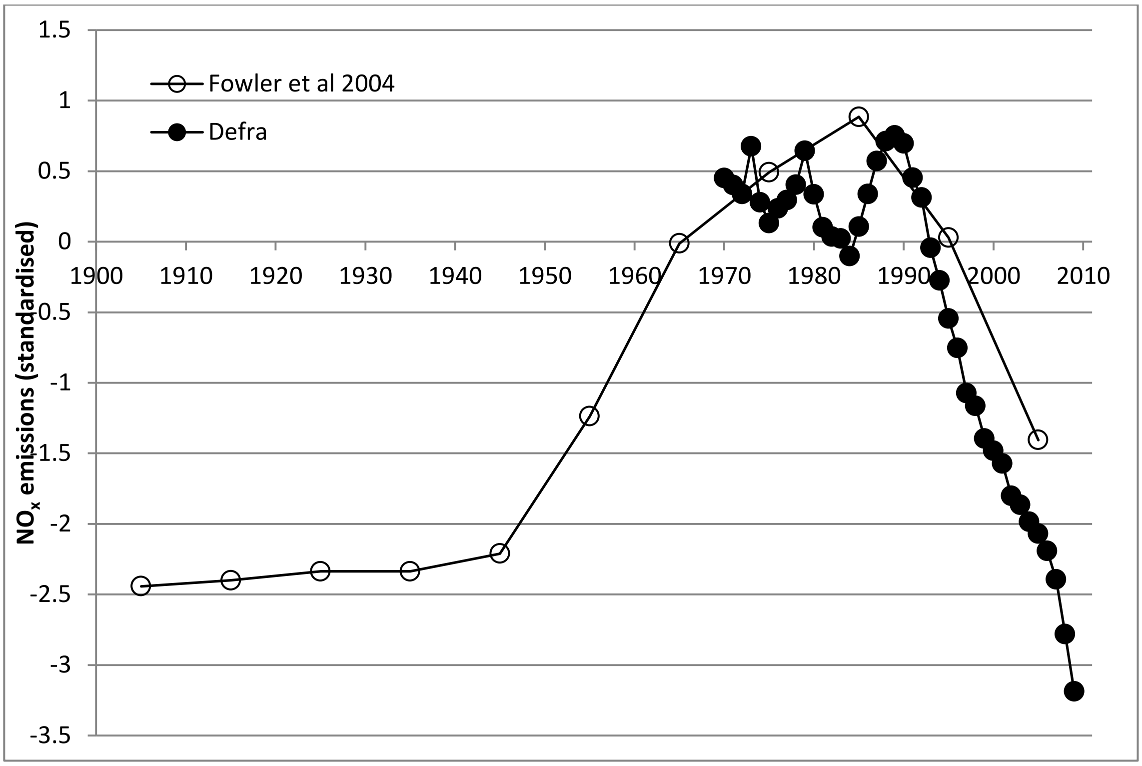


**Figure A5. Standardised $NO_x$ emissions for the UK. Decades from 1900s-2000s.**
Fowler et al (2004); UK 1970-2009: Defra. Values standardised based on the overlapping data points in the two series.

Data sources:
Grouse bags, 1900-2011
1900-2002: Available at:
http://www.gwct.org.uk/research__surveys/wildlife_surveys_and_ngc/national_gamebag_census_ngc/birds__summary_trends/233.asp [last accessed 17.iv.2012]
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Grazing
1900-2011:
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http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-landuselivestock-june-results-uklivestock-111222.xls [last accessed 17.iv.2012]

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$SO_2$
1850-2005:

Smith S. J., van Aardenne J., Klimont Z., Andres R. J., Volke A., & Delgado Arias S. (2011). Anthropogenic sulfur dioxide emissions: 1850–2005. Atmospheric Chemistry and Physics 11, 1101-1116.
1970-2009:
Available at: http://data.defra.gov.uk/env/aqfg20-soet-201112.csv [last accessed 17.iv.2012]

$NO_x$
1900-2000:
Fowler D., O'Donoghue M., Muller J. B. A., Smith R. I., Dragosits U., Skiba U., Sutton M. A. & Brimblecombe P. (2004). A chronology of nitrogen deposition in the uk between 1900 and 2000. Water, air, and soil pollution: focus 4: 9-23.
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## Appendix 3

### Recommendations for further work

#### General

Map outstanding areas of heather-dominated habitats in NPs and AONBs.

Assess the quantity of unmapped heather-dominated habitats outside statutory areas and determine which areas need to be mapped, with the ultimate aim of making the mapping of burning in the English uplands comprehensive.

Re-map areas managed by burning at regular intervals. Ensure an archive of aerial photography is available at three year intervals for any future mapping requirements.

#### National Sample

For the national sample, data and photography should be archived. Where historical photography is unavailable, sample squares could be moved to adjacent or nearby sample squares where there is available. It would also be worth considering improving the quality of digitised historical photography by manually re-scanning the original prints or negatives at the English Heritage Archive.

The sample should be re-mapped every decade.

For the national sample, obtain historical aerial photography for areas without heather in recent times (i.e. complete the remainder of the original 208 kilometre squares for the period 1945-2010). There are two reasons for this: first, some areas may have lost heather in the period before the year 2000: such squares might contain burning in the early decades of the sample that therefore not have been mapped in the present series; second, the completed sample would be a valuable, more wide-ranging survey of changes in the uplands, and would include information on enclosure of lower moors, artificial drainage, changes in plant communities and forestry. Such a set of time series of aerial photographs would be a unique, landmark dataset and research tool.