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Proceedings of the 10th National Heathland Conference - *Managing Heathlands in the Face of Climate Change*

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Foreword

Natural England commission a range of reports to enhance our evidence base and assist us in delivering our duties. This report contains the conference papers presented at the *10th National Heathland Conference* held in September 2008. The conference was hosted by Natural England with additional support from the Joint Nature Conservation Committee. The views are those of the authors of the individual papers and do not necessarily represent those of Natural England.

Background

The biannual National Heathland conferences are arranged through an informal network of heathland managers and researchers as a forum for the sharing and disseminating heathland research and good practice in the UK.

The theme of the 2008 conference was "Managing Heathlands on the Face of Climate Change". The conference was aimed at those interested in the latest developments in heathland management and science and key themes included:

- climate change
- nutrient management
- fire and management
- housing and development
- heathland interpretation.

Natural England hosted this conference and has published these conference papers to:

- Present the latest research on heathland nutrient budgets, the impacts of climate change on heathland and the effects of human disturbance.
- Share best practice and practical ideas between heathland managers and researchers.
- Provide feedback to enhance the development and implementation of policies, such as the Forestry Commission Open Habitats Policy and the Lowland Heathland Habitat Action Plan.

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Further information
Links to the presentations can be found in **www.keystone-group.co.uk/heathlands/presentations.php**. This report can be downloaded from the Natural England website: **www.naturalengland.org.uk**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

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Introduction

Managing our heathlands has never been so challenging. Climate change could radically alter how heathlands look and will certainly change our approach to heathland management in the coming decades. Furthermore, we are just starting to understand the details of how nutrients and fire affect heathland vegetation.

There has been a lot of work done during the last ten years, especially through the Tomorrow's Heathland Heritage programme (THH). We have to build on this and look for new opportunities to restore and maintain the habitat at a landscape scale. Threats still remain: development, especially in the south due to housing pressures, eg Thames Basin Heaths or Dorset. Also on non-SSSIs, where condition is frequently poor, there are problems with public opposition to change, eg introducing grazing/fencing or cutting trees and the impact of climate change. But there are also new opportunities, such as better targeting of the High Level Scheme or better marketing of heathland products.

The 10th National Heathland Conference, hosted by Natural England and sponsored by the Joint Nature Conservation Committee, was held in September 2008 at the inspirational venue of the National Science Learning Centre at the University of York, on the edge of the historic city.

The conference was aimed at those interested in finding out the latest developments in heathland management and science and key themes included:

- Climate change
- Nutrient management
- Fire and management
- Housing and development
- Heathland interpretation

The three day event included a mix of presentations, workshops and open discussions on Tuesday and Wednesday, featuring practical examples of heathland management techniques. The conference concluded on Thursday with optional guided visits to the inspiring lowland heathlands in the Vale of York.

At this conference there was a great emphasis on networking and the sharing of good practice continued beyond the formal sessions into an informal social evening with Yorkshire beer tasting on Tuesday and a tour of York Minster before the formal conference dinner in York on Wednesday.

The aims of the conference were:

- To present the latest research on heathland nutrient budgets, the impacts of climate change on heathland and the effects of human disturbance;
- To provide a forum for the sharing of practical ideas between heathland managers and researchers;
- To provide feedback to enhance the development and implementation of policy, such as the Forestry Commission Open Habitats Policy and the Lowland Heathland HAP.

These biannual conferences have been arranged through an informal network of heathland managers and researchers and continue to be the premier forum for the sharing and dissemination of heathland research and good practice in the UK.

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Presentations

1 Climate change adaptation of heathland biodiversity

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Summary

Considerable evidence exists which demonstrates that the biodiversity of Britain is responding to climate change, through change in phenology, range, habitat utilisation, community composition and ecosystem processes. Protected areas and other high quality wildlife habitat are the cornerstone of adaptation although they themselves will not be immune from change. Conservation strategies need to conserve the existing range of variation shown by species and habitats as insurance against uncertainty. Landscapes which are varied due to range of altitude, slope, aspect, vegetation structure and other characteristics are likely be most resilient in the short to medium term. However some species with restricted dispersal may require increased landscape connectivity for longer term survival.

Habitat management regimes already need to respond to change in growing season, increased risk of wildfire, flooding and other direct and indirect drivers. Climate change is one of many drivers of heathland change and climate change adaptation needs to be incorporated into integrated conservation planning, as opposed to being seen as a separate activity.

Introduction

Due to its potential adverse impacts upon the environment and society, climate change has become the most prominent environmental concern of the first decade of the 21st century. The reports of the Intergovernmental Panel on Climate Change have received a high level of attention in the media and amongst policy makers (IPCC 2007). Further, there are now vanishingly small numbers in the scientific community who doubt observed and projected climate change is due to release of greenhouse gasses, particularly carbon dioxide, methane and nitrous oxide.

If we are to address the challenge of climate change two types of action are required, *adaptation* and *mitigation*. Adaptation comprises those actions required to minimise the damage caused by climate change, given we are irrevocably committed to further climate change due to lag effects in the climate system. Mitigation actions are those carried to reduce climate change through reducing greenhouse gases in the atmosphere.

UK guidance for conservation practitioners on the adaptation of biodiversity to climate change has been published (Hopkins and others 2007- Box 1) and the main principles behind this guidance are discussed here.

BOX 1 Summary of the UK biodiversity adaptation guidelines (Hopkins and others 2007)

1 Conserve existing biodiversity

- 1a Conserve Protected Areas and other high quality habitats
- 1b Conserve range and ecological variability of habitats and species

2 Reduce sources of harm not linked to climate

3 Develop ecologically resilient and varied landscapes

- 3a Conserve and enhance local variation within sites and habitats
- 3b Make space for the natural development of rivers and coasts

4 Establish ecological networks through habitat protection, restoration and creation

5 Make sound decisions based on analysis

- 5a Thoroughly analyse causes of change
- 5b Respond to changing conservation priorities

6 Integrate adaptation and mitigation measures into conservation management, planning and practice

Observed and projected climate change

One of many reasons for taking the issue of climate change seriously is that significant change to Britain's climate has already been observed. Since 1950 the Central England Temperature (Manley 1974) has risen by 1˚C; 2006 was warmest year in 365 years and 9 of the 15 warmest years have been since 1990 (Jenkins and others 2007). The number of frost free days and hot summer days has increased and the growing season has become longer (Hulme and others 2002). There is no evidence for significant change in annual rainfall in recent decades, although there is evidence of decreasing summer rainfall and increased winter rainfall with rainfall in heavier downpours (Hulme and others 2002; Jenkins and others 2007). Due to thermal expansion of the warming oceans and to a lesser extent melting of ice, sea level rose by 1 mm per year in the 20th century. In the UK this is complicated by the fact that land is falling in the south-east and rising in the north-west so that rates above and below the global average value were encountered (Hulme and others 2002).

Under the United Kingdom Climate Impact Programme (UKCIP) scenarios, which cover a range of future potential greenhouse gas emissions and so several climate projections, a rise in UK temperature of between 2˚C and 3.5˚C is projected before the end of the 21st century, with greater warming in the south-east than in the north-west. By mid century current typical spring temperatures may occur between one and three weeks earlier and onset of winter could be delayed by a similar period, further lengthening the growing season. Annual average precipitation may decrease slightly, winters become wetter and summers drier, particularly in the south-east where summer precipitation may decrease by 50 per cent by the end of the century under the high UKCIP scenario where drought risk will increase most. Periods of heavy winter rainfall may become more frequent. By the end of the century sea levels in Scotland may be between 2cm below and 58cm above current level, with a possible rise of between 26cm and 86cm in south-east England (Hulme and others 2002), and inevitable losses of intertidal and coastal land, including some heathlands, especially on low lying parts of the coast.

Observed biodiversity change

At first sight some of these climate changes may seem slight. For two consecutive days to vary by several degrees in Britain is commonplace. But significant change in biodiversity linked to climate change has already been observed and includes:

Species changes

1 *Phenological change,* ie change to the timing of seasonal events. Across Europe there has been a general trend of spring and summer events taking place earlier in the year (Menzel and others 2006). These include flowering times of plants (Fitter & Fitter 2002); flight times of moths and butterflies (Woiwod 1997; Roy & Sparks 2000); egg-laying dates in birds (Crick and others 1997; Crick & Sparks 1999); first spawning of amphibians (Beebee 1995); first appearance of hoverflies (Morris 2000) and earlier summer fruiting (Menzel and others 2006). Autumn events are more complex (Menzel and others 2006) but delayed migration is reported for some bird species (Sparks 1999). The conservation implications of such changes are starting to emerge. As discussed below they have

implications for timing of management activities. Further some interdependent species no longer have life cycles that are synchronised. Some Dutch populations of the pied flycatcher *Ficedula hypoleuca* are declining because birds are now breeding after the time of peak caterpillar abundance, which has become earlier (Both and others 2006); how widespread such asynchronies might be is unclear.

2 *Range change.* Many species are showing evidence of changes in their range. Non-migratory species which reach a northern limit of distribution in the UK are widely thought to be limited by climate, particularly temperature (Thomas 1993; Thomas and others 1999). This general assumption is unlikely to apply to all species but many southern species at the northern edge of theirs in Britain are expanding their range northwards with increasing temperatures. This general trend can be seen in birds (Thomas & Lennon 1999), butterflies (Warren and others 2001) and dragonflies and damselflies (Hickling and others 2005). A study of 329 southern species (from 16 invertebrate and vertebrate animal groups) which reach their northern limit in Britain (Hickling and others 2006) found average northwards expansion in 279 species, including species from all groups except amphibians and reptiles. Hickling and others (2006) concluded that the average rate of northern expansion for the species they studied is in the range 12.5-19 km per decade, equivalent to a brisk walk every year. Not surprisingly this process has been associated with some continental species extending their range across the English Channel and establishing breeding populations in the UK, as with the bumble bee *Bombus hypnorum* and small red-eyed damselfly *Erythromma viridulum*.

In addition thermophilous species are expanding onto higher ground, including 227 of the 329 species studied by Hickling and others (2006) which increased their range uphill at between 4.7 and 10.7 metres per decade.

A much less studied retreat to the north of cold tolerant species which reach their southern limit in the UK is also occurring (Hickling and others 2005; Franco and others 2006).

3 *Changing habitat preference.* Many UK species, particularly plants and cold blooded animals, occupy a different and wider range of habitat conditions further south in Europe. In many cases this is likely to be due to warmer climates (Perring1960; Thomas 1993; Thomas and others 1999). It can be expected that change to habitat occupation by some species will occur as climate changes. Such change has already been demonstrated in southern England for the silver-spotted skipper butterfly *Hesperia comma.* Previously this species mainly bred in short turf on south facing slopes, where climate conditions are particularly warm. It now breeds in taller, cooler vegetation on slopes with a wider range of aspect and temperature (Davies and others 2006). Climate warming may also account for the shift in larval food plant preference by the brown argus butterfly *Aricia agestis* by making food plants in colder habitats available (Thomas and others 2001).

Species assemblages and habitats

Climate induced changes to species assemblages and habitats are more difficult to detect than for species. This is because factors not linked to climate may also drive ecological change. For example increased nitrogen deposition and decreased level of atmospheric sulphur deposition have occurred in recent decades at the same time as climate has warmed. These have been drivers of significant ecological change, such as increases in soil pH, not apparently linked through causality to climate (Carey and others 2008; NEGTAP 2001).

However long-term monitoring of butterflies (Roy and others 2001; González–Megías and others 2008) and moths (Conrad and others 2004) has detected change in community composition which is correlated with climate. The analysis by González–Megías and others (2008) indicates a c.15% turn over of butterfly species in 25 years, mainly due to the spread of southern and habitat-generalist butterflies. If typical of other insects, the largest animal group on land, this suggests a dramatic change to biodiversity has already occurred.

Much less is known about how climate change is impacting upon plant species and the results of vegetation monitoring have yielded inconsistent results, suggesting that there may be a great deal of context specific change to vegetation. The observational studies of Dunnett and others (1998) and Kirby and others (2005) detected changes in the relative proportions of plant species in road-side grasslands and woodlands correlated with climate change. However the recently reported results of

Countryside Survey 2007, a vegetation monitoring programme for the UK, found no clear signal of climate impact upon vegetation, in part due to the difficulty of separating climate change effects from those caused by other factors (Carey and others 2008).

Experiments which have manipulated climate further illustrate some of the possible complexity of change. After two years of experimental warming and droughting of heathlands at field sites in Spain, The Netherlands, Denmark and North Wales resulted in a 15% increase in productivity due to warming at the temperature limited North Wales site, but reduced productivity at the water limited Spanish site. Complex secondary effects may also come into play. The North Wales warming treatments in the experiment showed an increase in herbivory by heather beetle *Lochmaea suturalis* (Peñuelas and others 2004). Longer term monitoring of the North Wales site has resulted in a decrease in crowberry *Empetrum nigrum* increase in heather *Calluna vulgaris* and little change in the abundance of bilberry *Vaccinium myrtillus* (B. Emmett pers. comm.). In contrast 13 years of simulated temperature and rainfall change in an experiment on long established limestone grasslands in Derbyshire has shown a high stability of these grasslands, suggesting some habitats may be highly resistant to climate change (Grime and others 2008). However similar experimental treatment of grassland on recently established on abandoned arable land showed a more rapid shift in species composition further emphasising the context specificity of change (Grime and others 2000).

Because species respond individualistically to climate change new types of vegetation may emerge unlike any seen today (Williams & Jackson 2007), although available evidence of a relatively slow rate of change suggests strikingly novel vegetation is unlikely to appear in the next few decades.

Uncertainty and new knowledge

Our knowledge about the impacts of climate change on biodiversity has increased dramatically in recent years. None-the-less for the foreseeable future we will only be able to make imprecise projections of how wildlife will be impacted by climate. This is partly because we do not have sufficient knowledge of climate systems to build perfect climate models. Particularly we do not know how much greenhouse gas will be emitted into the atmosphere in future years. Arguably much larger fundamental knowledge gaps exist about how wildlife will respond to climate change, whilst models which explore climate change impacts are at a far earlier stage of development than climate models, and advances are required in their design for them to become fully effective tools (Botkin and others 2007).

The adaptation guidelines of Hopkins and others (2007) therefore make no assumptions about the patterns of change which will occur, but rather aims to increase the inherent adaptive capacity of natural systems and identify no regrets options which will deliver conservation benefit even in the absence of climate change.

The guidelines are also not seen by their authors as a final set of prescriptions. Over many years our knowledge of the most effective ways of increasing the adaptive capacity of our biodiversity will increase. It is foreseen that the guidelines will need to be regularly updated, and expanded to take account of new scientific and practical knowledge.

The role of protected areas and other high quality wildlife habitat

An important focus for UK biodiversity conservation to date has been the establishment of a series of protected areas. Sites of Special Scientific Interest (SSSIs; in Northern Ireland Areas of Special Scientific Interest), are the most extensive type of protected area for wildlife in the UK and cover c.10 per cent of the land surface (JNCC unpublished). This is a significant resource within which there is a strong legal presumption that management and other activities will support biodiversity conservation. Pragmatically, these arrangements may facilitate the implementation within protected areas of plans for adaptation which may be more difficult elsewhere.

Although we can expect the natural spread of species from Continental Europe into Britain as climate changes (Sparks and others 2005), it is a reasonable assumption that for the rest of the 21st century the biodiversity of Britain will consist mainly of species which already occur here. SSSIs are chosen to encompass a wide range of biodiversity and this is especially true for species and habitats with a very restricted range or abundance (NCC 1989). For example all viable breeding sites for species such as the heath fritillary *Melitaea athalia* butterflies qualify for notification as SSSI (NCC 1989) and 72% of the area of lowland heathland in England is within an SSSI (Natural England 2008). In the short and medium term protected areas will therefore play a major role as reservoirs of habitat s and species from which our future biodiversity will develop. Further many retracting cold-tolerant species are likely to have their healthiest populations and most favourable conditions for survival within protected areas. We can expect these to be amongst the last sites from which such species disappear and where some survive despite climate change.

In many parts of lowland Britain the protected site series accounts for a high proportion of all high quality wildlife habitat and its role in securing a future biodiversity will be particularly critical. However by no means all high quality habitat is included within protected areas. In the case of lowland heath this unprotected resource is relatively small, 18% of the total area. However 89 % of native broadleaved woodland and wood pasture is outside a protected area in England (Natural England 2008). Linear habitats such as road verges, railways and riverbanks, as well as small fragments of many other habitats are mostly outside the SSSI series, but are important reservoirs of heathland and other species in biologically impoverished landscapes (Smart and others 2006). Action taken to protect and manage such high quality wildlife habitats outside protected areas through for example Local Biodiversity Action Plans and agri-environment schemes is therefore essential. However the collective effectiveness of the full suite of such measures outside protected areas is not well understood. Monitoring of a representative sample of 104 heathlands outside of protected areas found that none was in favourable condition as opposed to 81% in favourable condition within SSSIs (Hewins and others 2007; Natural England 2008)

There are ecological grounds for investing over the long term in protected areas and other high quality wildlife habitats. Such areas have a set of characteristics which make them inherently important for biodiversity. These include low fertility soils (Grime 1973), as well as varied hydrology, soils, geology and landforms which result in high habitat diversity, the main determinant of species richness in many ecosystems (Rosenzweig 1995; Whittaker & Fernández-Palacios 2007). In other cases such areas have features such as high levels of heavy metals or seasonal flooding, which although not associated high species richness, are habitat conditions required by rare and local species narrowly adapted to such harsh or unstable environments, such as in the "*Allium* pans" of The Lizard heathlands, in Cornwall (Rodwell 2000). In addition to retaining higher biodiversity such sites are also likely to provide the conditions most species require as they redistribute themselves in response to climate change.

In contrast, areas of agriculture, forestry and other intensive land uses which dominate our countryside often have modified soils, destroyed seed banks and limited reservoirs of living animals and plants in the vicinity and will typically have very limited potential to develop biodiversity by natural processes (Cramer and others 2008).

Range and ecological variation

Species and habitats are not likely to be at the same climate risk in all the places they occur. The risk of a species becoming extinct will be reduced if as varied a set of locations as possible are conserved over the full geographical range (Saxon 2003). For rare species and habitats it will often be appropriate to include all localities within conservation frameworks, such as action plans. For more widespread species, given some may become rare, and vulnerable to extinction (Gaston & Fuller 2008) sites with large populations appear most important.

Not all species populations may be sustainable as climate changes and those at the southern edge of range and so likely to be at the limit of thermal tolerance may be most vulnerable as temperature increases (Crawford 2008). Conversely localities with small populations at the northern or altitudinal edge of range, which we today see as curiosities (such as horseshoe vetch *Hippocrepis comosa* in Upper Teesdale), may become the species' stronghold in the future.

The maintenance of all occurrences for a species should not be automatically set as long-term conservation targets. Over time, where decline is unavoidably due to climate change we should prepare ourselves to lose some populations and even species. For example modelling of change in available climate space for Norwegian mugwort *Artemisia norvegica* suggests that by the end of this century there could no longer be areas with suitable climate (Walmsley and others 2007).

However at the current time of uncertain confidence in such projections embracing geographical range and ecological variation in conservation plans is a strategy for reducing the risk of extinction by spreading conservation investment, until we know more about the climatic winners and losers.

This issue is not just about geography. Species populations and habitat patches across the range of ecological situations in which they occur should be included, not just the typical. For example the marsh fritillary butterfly *Euphydryas aurinia* occurs in several different habitats, ie damp grasslands, wet heath, mires, chalk downlands and temporary woodland clearings (Asher and others 2001). It is not difficult to imagine that changing rainfall patterns might have different impacts on these habitats although we lack the science to make predictions, and are therefore wise to keep the full habitat range until we learn more.

Other sources of harm

Climate change is only one of many factors which impacts on biodiversity in the UK (Carey and others 2008; Hopkins 2003; Hopkins & Kirby 2007; NEGTAP 2001; Smart and others 2005). As with climate change, many of these other sources of harm have gradual but persistent impacts upon wildlife. Action taken to reduce the impact of climate change only makes sense if these other causes of damage are also reduced. This is illustrated in the case of recent concern about decline of farmland birds which have been the subject of possibly the most rigorous conservation research programme ever undertaken, but which has revealed change in farming practices not climate change as the cause of declines (Grice and others 2004).

Of course the sources of damage to wildlife are many and various, but some are widespread and account for a high proportion of loss of biodiversity, including:

- Abandonment of management leading to more closed vegetation
- Over grazing of uplands by livestock, and of woods in the lowlands by deer
- Nutrient enrichment
- Introductions of invasive non-native species or new plant and animal diseases
- Aerial pollutants
- Past habitat loss meaning that many populations are now too small and isolated to be viable.

Ecological heterogeneity in the landscape

To wildlife the environment is a complex mosaic of habitat patches. Suitable patches are surrounded by varying amounts of habitat offering dispersal but not long-term survival or which are hostile or lethal. Each species requires a specific range of habitat-patch characteristics, including suitable climatic conditions, which allow it to establish, survive and reproduce. The size of habitat patch required to support a population of a given species varies enormously from a single leaf to many square kilometres. Within this ecological mosaic, climate can vary over very short distances – even two sides of a boulder can have very different microclimates – and many species are highly sensitive to these very small differences, which are not readily perceived by humans nor reflected in climate models which are based upon air temperatures in cells of many kilometres.

Where there is wide diversity of habitat patches at a given locality species are more likely to be able to respond to climate change by finding newly suitable patches nearby to relocate to. As in these cases only short-distance dispersal may be necessary, this gives a higher probability that a population will be maintained than if long-distance dispersal is required to reach a suitable new location.

As a very general guide to this diversity, as discussed above, those landscapes which are richest in terms of their current biodiversity are also more likely to be most varied in terms of their habitat mosaic and thereby most likely to allow some species to adapt to a changing climate by dispersing to nearby habitat patches in the future. The following characteristics are worth maintaining and enhancing:

a) *Diverse and structurally varied vegetation*. Different types of vegetation have different microclimates and some species may be able to adjust to climate change by expanding the range of vegetation types they occupy, or by moving from one type of vegetation to another. For example Thomas (1990) found that swards of hoseshoe vetch *Hippocrepis comosa* from 1 cm to 10 cm in height differed by 8°C in July day time temperature.

b) *Semi-natural habitat on a range of slope and aspect*. Microclimate varies considerably with slope and aspect. North and south facing hill slopes measured in Germany had day time temperatures which varied by 3.5°C (Bonan 2008). At sites with varied topography species adversely affected by higher temperature and summer drought on south-facing slopes may be able to move locally to cooler, more humid north-facing slopes.

c) *Uninterrupted semi-natural vegetation over a range of altitude*. For some species the response to climate change will be to move to higher areas, where climate is generally cooler and wetter. According to Hopkins' Bioclimatic Law (Kerr & Kharounba 2007) a 130m increase in altitude is associated with 1°C cooling, whereas on flat ground a movement of 100 km is required to achieve this difference, ie c.1,000 times shorter distance involved in adaptation by uphill movement. Uninterrupted habitat within mountains and hills will allow the dispersal of species but montane species on the highest peaks are likely to be left with nowhere to go.

d) *Uninterrupted semi-natural habitat across coastal zones*. Although much less studied coastal areas have complex microclimates compared to inland areas and there is large climate variation over distances of less than one kilometre at the coast, meaning species may find suitable nearby habitat patches as climate changes (Malloch & Okusanya 1979).

e) *Diverse water regimes*. Climate change is likely to have a complex effect upon water regimes. Summers are expected to become drier, winters are likely to become wetter and rainfall may become less evenly distributed, with more heavy rainfall events and flooding. The most complex range of habitats, and therefore the most aquatic and wetland species, are likely to survive in landscapes where there is variation from open water to dry land. A diversity of wetland conditions is most likely to persist where the open waters and wetlands are fed by a combination of surface drainage, ground water and aquifers.

In the light of these general patterns of heterogeneity it is possible to identify a number of measure which can be taken to increase local heterogeneity:

- Designing engineered land forms such as quarries and roads to add or reinforce local topographic diversity
- Removing or fragmenting blanket forests on hill slopes to allow valley species to spread gradually onto high ground through zones with intermediate climate properties
- Restoring habitats in topographically complex system, such as valleys, to create habitat patches over a more complete microclimate range
- Managing habitat to create a wider range of vegetation structure and so microclimate variation.

Ecological networks

In the uplands, along our least developed coasts and at extensive lowland sites such as The New Forest, relatively large expanses of continuous habitat survive. However over large parts of lowland Britain, habitat is much more fragmented than in the past. We can expect that many species with poor dispersal and ecological requirements which are not found in the surrounding countryside, are now trapped on these habitat fragments. This has been shown for a range of "specialist" butterfly species and amphibians and reptiles which, despite being at the northern edge of their range, are not spreading despite climate change making conditions more favourable for them (Warren and others 2001; Hickling and others 2006).

At particular risk are species at sites which are small, lack variation in slope, aspect, altitude and vegetation structure and are a long distance from favourable sites. Such species may not be able to move inside or outside the site to find habitat patches with suitable climate if their current habitat becomes uninhabitable (Travis 2003). There is then a need in fragmented parts of our countryside to conserve and develop ecological networks, that is, groups of sites linked by inter change of species.

Most often it is assumed that this is done by producing "wildlife corridors", physically continuous linear habitats linking larger habitat patches. However the evidence for the effectiveness of wildlife corridors is mixed and they are likely to be used by only a relatively small proportion of species (Watkinson & Gill 2002). In practice most species do not need this continuity of habitat to spread. For virtually all species the world consists of discrete patches of suitable habitat separated by varying amounts of inhospitable habitat. They have evolved to disperse to move through the landscape by "jump dispersal" which means that the ecological networks can consists of habitat patches in close proximity, which are not necessarily continuous (Watkinson & Gill 2002). In recent years there has been significant research into ecological network design (eg Opdam & Wascher 2004) and a number of networks have been set up (eg Ministry of Agriculture, Nature and Food Quality 2005) or are planned (eg Watts and others 2005). It will however be some years before we understand the design principles which work and the issue of landscape connectivity, how it should be measured and managed remains one of the most contested aspects of landscape ecology (Lindenmayer and others 2007).

Critical to the development of ecological networks is the conservation of protected areas and existing areas of high-quality wildlife habitat discussed above. These will form the *core areas*, rich in biodiversity which the network is intended to conserve, and which will hopefully populate the rest of the network once connectivity is improved.

Further complementary types of activity are required, firstly to restore habitat that has become degraded due to inappropriate management or abandonment and secondly to create new habitat, targeting it where there are greatest concentrations of existing semi-natural habitats.

A further option, but one which is as yet not well researched is that of increasing species movement in the landscape by reducing intensity of land use between habitat patches.

Both restoration and creation are more resource intensive than conservation of existing high-quality wildlife habitat. Furthermore, in most landscapes relatively small areas contain the combinations of land use, land ownership and environmental characteristics that will permit habitat restoration and creation which is sustainable in the long term. Given the establishment of ecological networks is intended as a long term conservation strategy and has little benefit as a short term measure careful planning involving a range of relevant expertise is needed.

Adaptation of land management practices

The timing of a range of farming operations across Europe has already changed in response to climate (Menzel and others 2006) and the way in which habitats are managed for biodiversity will also need to be modified, indeed some land management has already changed.

Earlier flowering of plants and breeding of animals is occurring and changes to the timing of heathland management in The New Forest has already been implemented to avoid disturbance to birds which now nest earlier (David Morris, pers. comm.)

More frequent summer drought may require a planned removal of livestock in summer from some areas due to lack of vegetation. Additional water supplies may be needed where ponds and streams are relied upon for watering of stock. Change of livestock breeds to ones better adapted to new climates may also become appropriate.

In low lying areas both inland and on the coast planning to accommodate more frequent flooding may be needed.

Of course one consequences of a projected increase in drought frequency would be a greater risk of summer wildfire and this could particularly impact upon heathlands, where fire risk is already a significant management consideration. In addition to the requirement for additional infrastructure to fight fire, strategic land management options include grazing to prevent litter build-up, firebreak construction and the planting of belts of less fire prone species.

Undocumented a*d hoc* decisions to accommodate climate induced change may already have been taken by many conservation managers, and would be helped by further research on this topic.

Understanding and guiding change

Possibly the most demanding task of all will be to understand how wildlife is being affected by climate change. As discussed above many factors affect wildlife, not just climate, and careful analysis will be required to separate the various causes of change. Where change is due to climate and unlikely to be reversible there is the potential to invest large resources in trying to maintain the *status quo*, which will ultimately be domed to failure. Conversely in some cases change may be addressed by the sort of activity outlined above , or be due to factors not linked to climate which can be addressed, such as lack of management. Much further monitoring and research will be needed to guide such decisions.

We will also need to adapt our conservation targets. Otherwise we run the risk of investing conservation effort in species whose future cannot be secured or putting unnecessary effort into species which previously struggled in the British climate (Thomas 1993), but are now increasing as climate changes. Ultimately we will need to learn how to guide change in ways which maximises diversity and have only just begun.

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2 Predicting ecosystem responses to multiple drivers – application and relevance to Dwarf Shrub Heath and Bog

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Summary

A range of approaches to quantify and predict responses of ecosystems, including heathlands, to multiple drivers is ongoing in CEH. This paper present results from our long term climate change experiments, surveys and new modelling initiatives to illustrate how these may be used to forecast potential outcomes of future changes in air pollution, climate and management.

Multiple drivers of global change

The most important human drivers of change in global biodiversity in the next 100 years are estimated to be land use, climate change, nitrogen deposition, biotic exchange (species compositional turnover particularly including non-native species) and atmospheric CO_2 (Sala and others 2000). All these drivers pose known or potential threats to heath and bog in NW Europe by affecting the interest and fabric of the site itself or by indirect effects. For example land-use change around a protected site acts as a filter on the local species pool. This alters the abundance of potential colonists that could disperse into and establish in response to change in conditions within the site driven by management, pollutants and climate change. More generally, land-use change will also affect the favourability of the habitat matrix, altering prospects for species to move in response to climate change (Vos and others 2008). Predicting these scale- and driver-dependent effects is a challenge for a number of reasons. A particularly important issue is that drivers act simultaneously in space and at the same time. This can result in effects that are substantially different from their separate impacts (Table 1). This happens because the response of an ecosystem compartment or biota to one effect can be conditional on the impact of another (Emmett and others 2004; Smart and others 2006).

Table 1 Examples of interacting effects of land use and ecosystem state on British heathlands.

Habitat type	Interaction
Upland heath	Increased N deposition and sheep grazing interact in upland heath (Van der Wal and others 2003)
Upland heath	N deposition, fire and grazing interact in alpine heath (Britton & Fisher 2007)

Lowland heath	Land use context as a source of propagules interacts with heathland management in lowland heath (Manning and others 2004)

Why models?

Since these multiple drivers are expected to increase in intensity over the next 100 years, we need to develop ways of reliably forecasting their impact including the interactions between them. The severity and spatial scale of impacts resulting from these drivers have, in many cases, been quantified using model predictions (Kooistra and others 2008; Britton and others 2001; Terry and others 2004; DeVries and others, in press; Bakkenes and others 2002). Ensuring good model performance will often rely on observations from monitoring time series and experiments during development, modification and testing (Moorcroft 2006).

A simple definition of a model is ‘a representation of reality’. What criteria are needed though to discriminate good from bad representations of reality? Three offer a starting point;

- Model adequately separates the independent and interacting effects of multiple drivers
- Model reproduces observations
- Model represents patterns and processes not amenable to experimentation because of scale and cost

These criteria all apply within the constraint imposed by a decision about the scale at which the model should apply and whether general applicability to all examples of a habitat type or all places in a landscape or biome is emphasised over the realism of any one set of predictions in a specific place within the region. The generality-realism continuum is a trade-off because high local realism and accuracy requires lots of data and knowledge to effectively capture the importance of local conditions be they the dynamics of particular subordinate and dominant species or other local issues such as disease, land-use history, climate interactions or specialised forms of management. Time and resources simply prohibit accumulation of this level of detail over most occurrences of an ecosystem type so that it may be unrealistic to expect a generally applicable ecosystem model to yield high local realism measured in terms of accurate reproduction of observed dynamics on any specific site (Moorcroft 2006).

Models should separate the effects of multiple drivers

We assume this is a basic though far from simple requirement. Environmental change is a reflection of human drivers interacting with each other as well as background random and cyclic changes in ecosystems and climate. A good illustration of the importance of separating these effects comes from the development of General Circulation Models of global climate change that could firstly reproduce the variation in historical temperature records attributable to natural factors such as solar variation and volcanic eruptions. Further model development then showed that recent climate warming was best explained by a model that allowed for both natural and anthropogenic effects (IPCC 2001).

Models should reproduce observations

This is basic requirement. Even if it is acceptable that a model often gets things wrong but still acts as a useful null model and generator of falsifiable hypotheses, it seems essential that a model is seen to reproduce observations to some acceptable extent. This is especially important if a model is to win credibility as a useful tool among users who may be focussed on the predictions made and therefore on the model as a means to an end rather than appreciating it as an elegantly constructed, theoretically sound end in itself (Clark & Gelfand 2006). Practical difficulties can however arise in model testing. A model may make predictions at scales at which it is impossible to realistically measure paired observations.

Examples include any time in the future or at large spatial scales such as grid squares where the prediction might be an average constrained to the occurrence of a certain soil type in a 1 or 5km grid square. In the latter case, the growing number of large-scale observational datasets has allowed large-scale model testing in some cases (eg ECOSSE 2007). Also, such issues are considered less problematic if the emphasis is on the generality of the model and its application at large spatial scales rather than on accurate prediction of the fine detail in a specific area. Hence, it is not so much that the fine detail is ignored but that in larger scale applications the test is whether the overall variation between regions or grid squares is being adequately predicted given the uncertainty around the average predictions within each region or grid square (Meir and others 2006).

Models should adequately represent process and pattern

A major challenge for ecosystem modelling is incorporating sufficient detail to account for the dynamic interplay between ecosystem attributes of interest. This again depends upon the level of generality or realism that is acceptable to those building and using the model. Knowing where the acceptable limits of model realism are may itself only emerge from iterating rounds of model development, testing and application (Meir and others 2006; Moorcroft 2006). Since no model will ever be perfect there is perhaps an inevitable sense in which reality is incrementally approached by successions of better models but where some level of detail will always be missing and some level of uncertainty always present. The levels of detail and uncertainty deemed acceptable will be a matter of ongoing negotiation that reflect the question and scale of concern. For example, the outputs of global vegetation dynamic models are judged acceptable because the small-scale variation that would be accounted for by incorporating species-specific responses is considered less important relative to between region variation and the need to model at the global scale. At this scale species-specific responses are assumed to be adequately summarised by the coarser response of few plant functional types that can be modelled on a global scale while individual species could not (Sitch and others 2003). This is a pragmatic decision based on the need for global generality but the impossibility of building this on a foundation of species-specific local realism. Such constraints can restrict the choices available for inclusion of process detail. In some cases the omission of vital detail can profoundly affect predicted outcomes. For example, excluding the role of above-ground net primary production on carbon sequestration in grasslands in response to climate change alters model predictions from net gain in soil and vegetation to net loss in soil only (Smith and others 2005).

Modelling the impacts of multiple drivers on heathland and bog

The ecosystem attributes to be modelled in British bog and heath can be divided into those that relate to quality or conservation value and those that are indicators of change in condition or the impact of particular drivers but that are not valued in their own right. For example, the distinction could be between site interest, where changes in particular species and habitats will be modelled because these have UK Biodiversity Action Plan targets (Smart and others 2005), versus site fabric, for example represented by soil C/N ratio and nitrate leaching (Evans and others 2008), versus extrinsic site factors such as likely changes in the availability of invasive plants in the local species pool as a result of changes in surrounding land use. These groups can overlap. For example, a subset of Common Standards Monitoring indicators in heathland have also been shown to be potential indicators of the atmospheric N deposition gradient across Britain (Stevens and others this volume). While the species and habitats to be modelled are largely clear because they are defined by policies such as the UK BAP and Public Service Agreement targets for SSSI condition (www.defra.gov.uk/wildlife-countryside/protected-areas/sssi/psa.htm), the scientific evidence base that highlights attributes and indicators for the impact of the entire range of multiple drivers is perhaps less comprehensive although a wide range of associated indicators have been developed and are operational (www.defra.gov.uk/wildlife-countryside/biodiversity/indicator.htm).

The modelling challenge is therefore to develop an integrated forecasting capability for a wide range of attributes of interest at policy-relevant scales plus conveying the uncertainty in the forecasts. Integration refers to the need to dynamically model the processes of ecosystem development such as nutrient cycling, biomass growth and decomposition and the feedback loops between these that underpin the ability of ecosystems to bounce back or withstand perturbation (Chapin and others 2006; Folke and others 2004). Such a dynamic capability ought then to provide a way of testing scenarios of interest such as multiple perturbation, post-disturbance recovery and protection as a result of applying mitigation options (eg Wamelink and others 2003).

Approaches to modelling multiple drivers on heathland and bog

Four approaches are briefly described each differing in complexity, extent to which they trade-off local realism against regional generality, and the extent to which they are dynamic in the sense that new ecosystem states can be predicted that do not just depend on static relationships between environment, biota and the likely impact of driving variables at one point in time.

Risk Assessment (RA)

Simple yet powerful, RA approaches do not include a dynamic modelling component but instead use a simple scoring of threats to a site to assess risk of change due to various drivers. Probably the most well-developed of these approaches applies local information to derive site-based empirical Critical Loads (CL) for nitrogen deposition (Achermann & Bobbink 2002) but where the published CL for the habitat is adjusted according to local risk factors including soil moisture and nitrogen status, and to variation in vulnerability, for example where rare species are present with small population sizes (Ashmore & Hicks 2007; Wadsworth & Hall 2007). The RA approach is locally realistic in that it explicitly weights the information that applies at a specific site. Site scoring is also simple and transparent and perhaps more readily reality-checked than forecasts based on models or model chains that can carry high uncertainty and whose complexity makes it difficult for the lay-person to verify the origins and plausibility of the prediction. While locally realistic, the ease with which risk factors can be accumulated for a site series also makes it feasible to generate a regional or national classification of site risk in terms of the risk factors responsible (Smart and others 2005). The disadvantage of RA approaches are that there simplicity means that species or habitat specific thresholds may not exist or maybe crudely defined although critical limits for species could be included where they exist (eg van Dobben and others 2006). The lack of a dynamic process basis also means that RA approaches do not have the ability to predict the kind of surprise outcomes that can emerge from negative and positive feedbacks between processes and interacting drivers (Strengbom and others 2001; Folke and others 2004).

Habitat-specific models

Heathland ecosystems have benefited particularly from detailed modelling of the competitive interactions between dominant plant species and the response of the mixed species assemblage to natural and human-induced perturbations that are a particular issue in temperate heathland. These include N deposition, grazing, fire, drought, mowing and heather beetle attack plus interactions between these. Because heathlands are typically dominated by a small number of plant species, the cost of measuring detailed parameter information on growth rates for these, as well as the size of soil nutrient pools and rates of nutrient cycling processes, has not been prohibitive. This has resulted in the development of locally realistic models that can be generally applied to the same species and ecosystem type in the Netherlands (Bakema and others 1994) and Britain (Terry and others 2004). Since these models are based on a specific habitat and small pool of species, model testing is highly feasible because observations of species dynamics can be easily recorded at the modelled scale. This builds confidence in model simulations. Terry and others (2004) showed for example, that model predictions were comparable with experimental observations and then went onto illustrate the impacts of multiple and interacting factors on heathland dynamics up to 2150. Important conclusions were that a) *Calluna* recovery from high N deposition was predicted between 20 and 30 years but only with high intensity management, and in 50 years with low intensity management, b) The probability of Heather beetle attack was highly sensitive to variation in growth and mortality rates of *Calluna*, c) High N deposition actually increased *Calluna* growth initially but ultimately resulted in grass dominance.

Linked soil and vegetation models

Recently, groups in Sweden, Germany, UK, America and the Netherlands have been developing models that attempt to strike a useful balance between local realism and cross-scale generality (De Vries and others in press). Stimulated by the need for dynamic modelling of critical loads for acidity and nitrogen on waters and soils (eg Evans and others 1998), this international research effort has built on the development of dynamic models such as SMART, MAGIC, VSD and SAFE. The models have undergone rounds of simplification or increasing complexity (Cosby and others 2001). For example the requirement to predict Critical Load exceedance across Europe (increasing generality) led to the simplified Very Simple Dynamic (VSD) model for which reduced numbers of parameters were required leading to less burdensome data collection but inevitably less realism in the predictions made at smaller scales (Posch & Reinds 2008). This model is now undergoing a round of additional development to add in greater process-based sensitivity to above-ground vegetation growth (Mol-Dijkstra, J. pers.com.). In general, the trend has been toward greater model complexity in an effort to better simulate soil and vegetation processes and the dynamic feedbacks between soil and biomass growth and decomposition. To achieve general applicability, vegetation is modelled as competitive interactions between plant functional types given the differential response of each type to available nutrients, light, water and management regime (Chapin 2003). Thus models such as FORSAFE and SMART2-SUMO occupy the middle ground between the highly simplified treatment of vegetation that allows global scale modelling within Global Dynamic Vegetation Models such as LPJ-GUESS (Sitch and others 2003) and the highly species-specific parameterisation of models such as HEATHSOL that allow greater local realism but only for a small number of dominants within one habitat type. FORSAFE and SMART2-SUMO are parameterised for national ecosystem mosaics in Scandinavia and the Netherlands respectively and therefore work across national landscapes. They also include greater detail in terms of the number of plant functional types and individual species for which separate parameters are available. Their construction also reflects phenomena and issues of regional importance such as wind-tatter in FORSAFE, which predicts ecosystem change in the Swedish tundra as well as in the more climatically benign south, or the inclusion in SUMO of the impact of turf-stripping as a management intervention in Dutch heaths and bogs.

Because these models are constrained to operate within national territories where large databases of species occurrence data have been accumulated, the outputs of soil and biomass growth modules can also be used to solve empirical realised niche models that predict how changes in abiotic conditions alter the favourability of a particular locus over a particular time-step for all species that have such models. The development of these species niche models and their linkage to soil and vegetation dynamic models is particularly well developed in the Netherlands and the UK (De Vries and others in press; Smart and others 2005) where the goal has been to achieve an integrated modelling capability for predicting the effects of multiple drivers on a large number of individual species across a range of habitat types – see below.

Modelling Natural Resource Responses to Climate Change (MONARCH)

This seven-year long UK program ended in 2008 (www.ukcip.org.uk). It sought to assess impacts of climate change on a range of animal and plant species in Britain and Ireland. The modelling approach combined empirical climate envelope modelling, similar in aim and methods to the production of static empirical realised niche models for plants, with a dynamic component that allowed repeated phases of dispersal, reproduction and repeated dispersal to occur within the constraints of the favourable climate and land-cover space for each species.

Hence MONARCH could simulate the separate and combined effects of climate and land-cover change on the distribution of favourable climate space, and did this to provide scenario tests for a final group of 32 BAP species comprising birds, butterflies and plants. Key differences from the modelling approaches considered above were as follows;

- The inclusion of animals, although the Dutch Natuurplanner modelling has a butterfly distribution module (www.rivm.nl/bibliotheek/rapporten/500002001.html).
- The ultimately large-scale of model predictions (50km^2). This is an interesting outcome of the project since the resolution was deliberately coarsened to reduce the interpretation of model outputs as realistic expectations of species occupancy and change in occupancy at small scales. While local realism is an ambitious target and tends to trade-off against larger-scale generality, an outcome of coarsening model resolution is that this tends to reduce the range and variability of the values of driving variables such as climate and pollutant deposition. This can result in favourable niche space being underestimated for species whose optima is within the range of values that are omitted when such averaging truncates the extremes (Trivedi and others 2008).
- The use of artificial neural networks to train the envelope models.
- No inclusion of process-based soil and vegetation modelling to allow mitigation scenarios or interactions with other global change phenomena to be explored.
- Process-based dispersal modelling was included such that reproduction, dispersal and establishment were explicitly parameterised (Vos and others 2008). In the other approaches this has either been omitted or achieved using static informatics-based approaches that combine contextual local land-cover maps and databases of species occupancy in large grid squares around targeted sites to define local species pools from which potential immigrants could be drawn assuming dispersal is possible (Smart and others 2005).

Quantifying the impact of multiple drivers on CSM indicators; an example application of linked soil and plant species niche models

Linking the models

In Britain, both the MAGIC and VSD models have been used to simulate the impacts of atmospheric sulphur and nitrogen deposition on the acidification and eutrophication of UK soils and waters. The results have been used to map critical load exceedances across British 1km squares (www.critloads.ceh.ac.uk/reports.htm) and more recently to develop and test ways of simulating change in the suitability of habitats for a range of plant species.

Empirical niche models for a large number of British higher and lower plants have been recently completed (Smart and others 2005; De Vries and others in press). These are based on explanatory variables that express favourable realised niche space for each species as an index of habitat suitability along the principal gradients that constrain plant growth. These gradients are described by explanatory variables that quantify species' responses to climate, nutrient availability, light, pH and soil moisture. All that is required to solve these models are values of the explanatory variables for a particular place and time. The soil models generate time series of soil pH, %C and %N, whose values can be used to solve the part of each regression model that quantifies response to soil pH and nutrient availability. Cover-weighted canopy height and soil moisture values are also explanatory variables that indicate position on additional niche axes; the first representing response to light availability and hence successional status and managed biomass removal, and the second indicating position on the continuum form dry to wetter soils. All these variables can be made available for a habitat patch, a site or as averages for the occurrence of a particular habitat and soil type in a UK grid square. Since soil models such as VSD and MAGIC can be run at the national scale for all 1km square, projected time series of soil variables can also be combined with national scale climate change scenarios for 50km or 5km grid squares (www.ukcip.org.uk) and used to test the expected separate or combined impact of atmospheric pollutant deposition and climate change on species of biodiversity importance (Fig 1). At present 78% of CSM indicator species have niche models. For about half of these, climate variables were also significant in addition to soil variables and canopy height (Smart and others 2005). Rare species are poorly covered by available niche models because so little data is available on their environmental preferences. However, a method has been recently developed to predict likely impacts on habitat suitability for rare species by quantifying their association with the more common species with which they typically grow (Smart and others 2005).

Trialling national scale predictions of change in Common Standards Monitoring indicator species

The steps involved in producing national scale predictions of change in habitat suitability for particular CSM indicators are outlined in Figure 1 and described in more detail below:

A) A dynamic soil model such as VSD or MAGIC is calibrated against soil parameter values for a particular soil type in 1km squares across GB. Because measured observations are not available for every location, necessary simplifying assumptions are made so that parameter values can be set to an acceptable average or range of values. The soil model predicts changes in Carbon, Nitrogen and pH in response to modelled trajectories of change in Nitrogen and Sulphur deposition.

B) Annual time series of change in climate variables are then produced based on the current UKCIP02 forecast for a particular emissions scenario. For example, medium to high GHG emissions for 1990 to 2020 are expected to give…

- 5% reduction or no change in rainfall
- 0.5-0.75 deg C increase in Summer temperature
- 0.5 deg C increase or no change in Winter temperature

C) The time series of change in C, N and pH from the soil model are then combined with observed or modelled cover-weighted vegetation height, observed mean or modelled soil moisture and the time series of change in the climate variables. This information constitutes all the values of the explanatory variables needed to solve each species niche model equation at each at each yearly time step for each 1km square for each species of interest.

D) The outputs from the model chain are time series of predicted change in habitat suitability for each species in each 1km square. These can be summarised as graphs of average change for all the examples of a habitat and soil type in a region or for a specific site if the model chain was applied at that more detailed scale.

E) The model chain produces a national dataset of 1km square predictions. However, lack of predictive accuracy in each 1km square will be expected because of important sources of insensitivity to local conditions. For example, the final predictions will reflect the coarse scale of deposition estimates input to the soil model and the coarse scale outputs of the climate model –both 5 or 50km^2. A challenge is to express these sources of uncertainty to qualify the apparent accuracy conveyed by powerful products such as GB-scale maps of model outputs. Mapping the predictions themselves is a straightforward task (Fig 2).

Figure 1 Simulating the impact of climate change and atmospheric pollutant deposition on British plant species. A) A dynamic soil model (VSD or MAGIC) is used to simulate the impact of atmospheric sulphur and nitrogen deposition on %C, %N and pH. B) Climate change scenarios for different emission regimes provide projected change in rainfall, summer and winter temperature. C) Soil model outputs and UKCIP outputs can then be used to solve niche regression models at annual time steps for CSM indicator species. D) These results can be summarised as trajectories over time (vertical lines indicate the timing of two GB Countryside Surveys, which can provide observations to test the model predictions). E) Impacts on biodiversity can be summarised as maps of predicted change in habitat suitability across Britain.

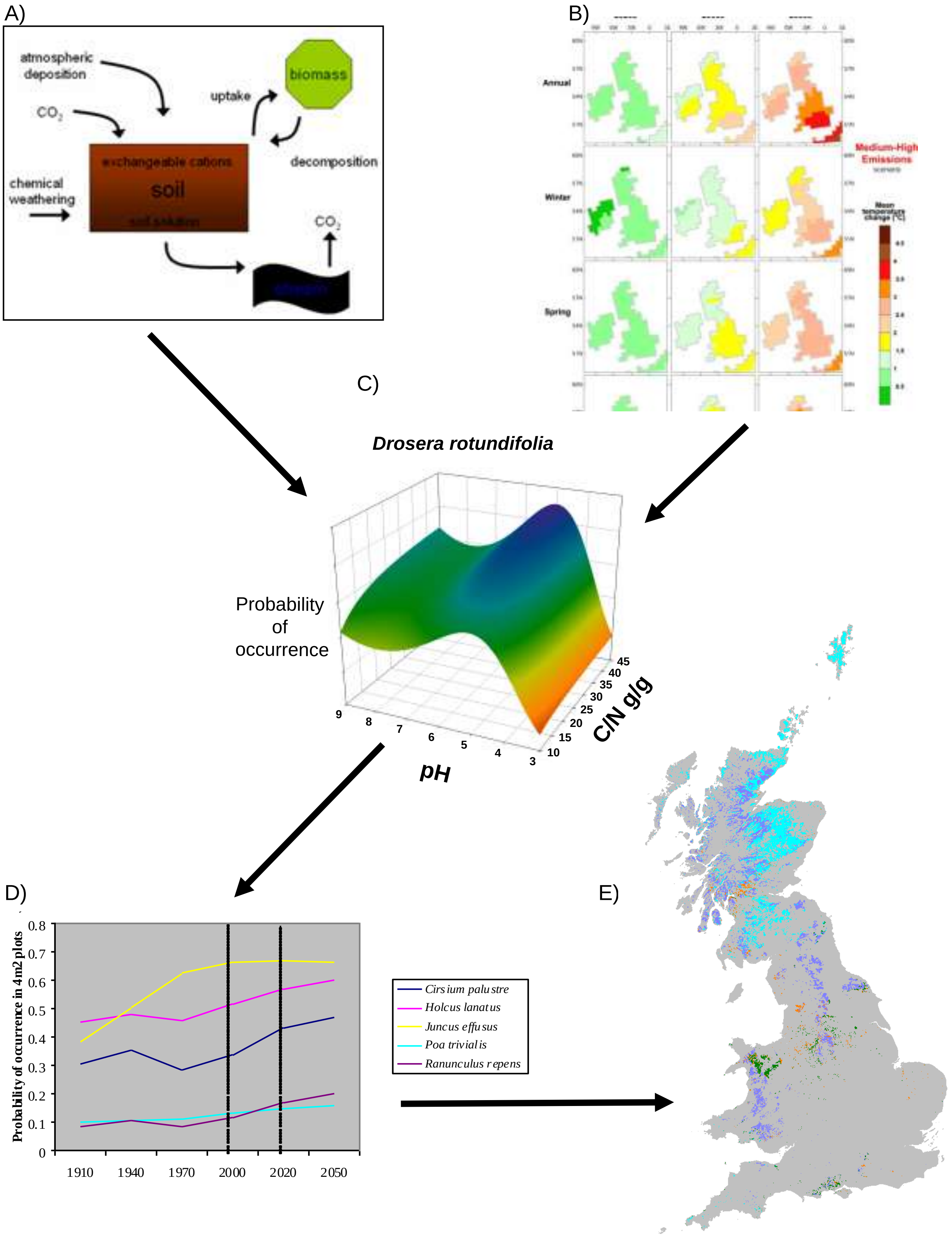
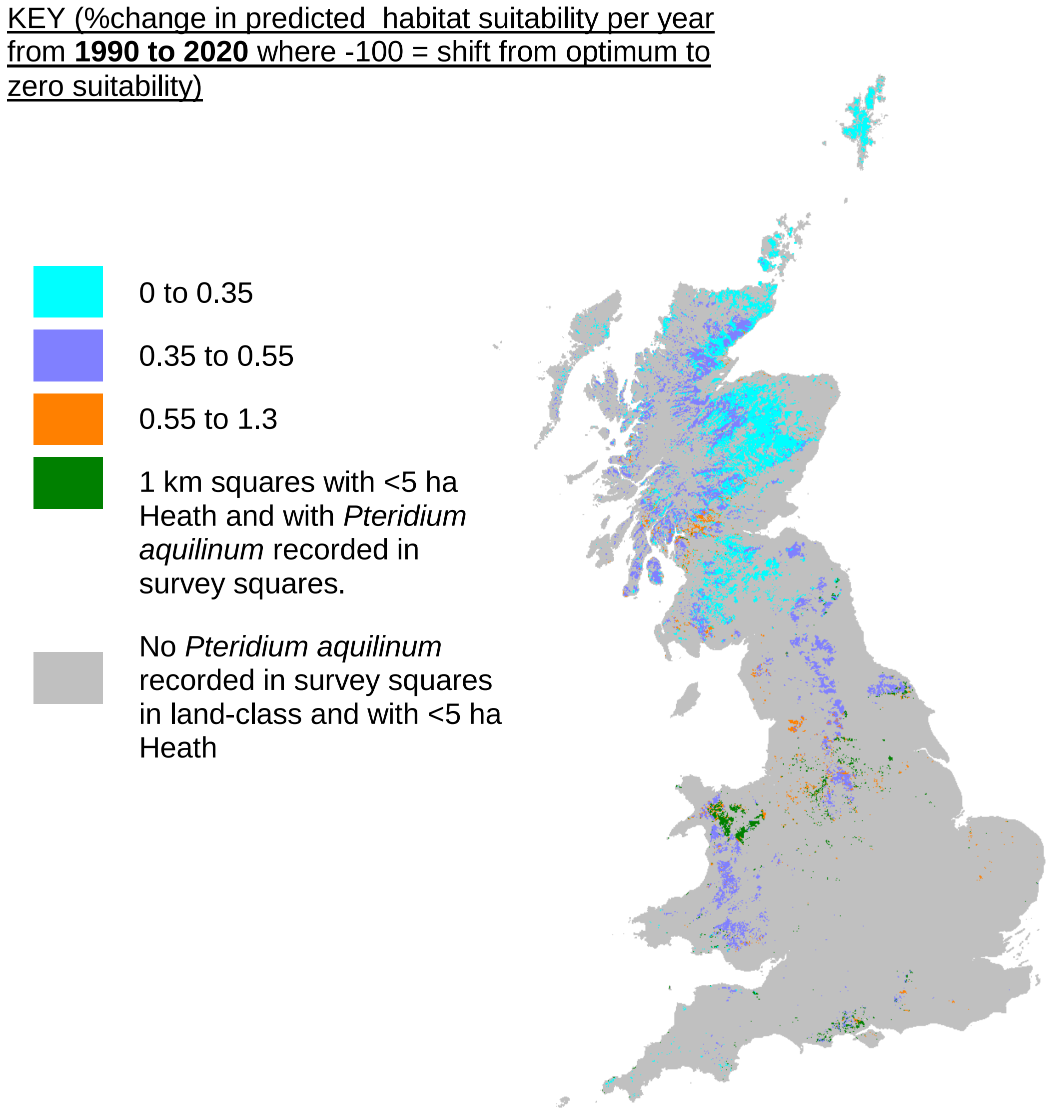


Figure 2 A provisional map of predicted change in habitat suitability for *Pteridium aquilinum* in response to EMEP N and S deposition trajectories and UKCIP02 medium to high emissions scenario (both at $50km^2$ scale). Habitat suitability (Hs) was defined as probability of occurrence output from species niche models rescaled by the niche space maximum. Change in Hs was defined as the linear slope coefficient of the 30 year time series of Hs indices predicted for each 1km square and summarised as ITE Land Class averages (Bunce and others 1996). These were overlaid with the occurrence of Dwarf Shrub Heath (>5ha extent in each $1km^2$) in Britain according to the satellite Land Cover Map 2000 (Fuller and others 2002). This gives a more spatially explicit rendering of the response of the species over the specified time interval. Results are provisional because the uncertainty around the predictions are not quantified. The results indicate little change in the north and most change in the English lowland heaths (16.5 to 39% total increase in Hs).



Current directions for further UK soil-vegetation model development

Quantifying uncertainty

Lack of detailed knowledge about the appropriateness of different parameter values in different places leads to uncertainty which must be expressed in the model output if users are to understand the robustness of model predictions and developers are to identify model components and parameters that contribute the greatest uncertainty (Schouwenburg and others 2001). Uncertainty and sensitivity analyses of complex models and chained models is a challenging but essential undertaking and further work is underway.

Ensemble forecasting

There are now a wide range of methods for modelling species' niche distributions and applying these models to simulate the impact of a range of drivers. In the most comprehensive test to date, Elith and others (2006) found that a number of newer techniques consistently outperformed older and simpler environmental envelope-based methods. Conceptually simpler models such as GLM and GAM still performed well however. Certain techniques are also known to perform better when particular applications are required (Randin & Dirnbock 2006). Given the plurality of modelling methods, the ease with which they can be built and applied but the lack of a clear front-runner, a new approach called ensemble forecasting is being increasingly recommended (Araújo & New 2006). This involves building and running models using a range of different techniques and then deriving a consensus based on the range of predicted values from each type of model. The more the different models agree then the greater the confidence in the forecast (eg. Broennimann and others 2007; Beale and others 2008). Building an ensemble forecasting capability for British plant species is underway based on three techniques GLM, GAM and MARS.

Model development and testing

Despite considerable validation and testing of the soil and plant species niche models (De Vries and others in press; Smart and others 2005) a species by species campaign of long-term testing must take place to continually build credibility and explore the performance of each niche model. Further model development is also underway to better simulate the impact of multiple drivers on key processes. In Britain this is focussed particularly on developing a biomass growth module that will dynamically interact with the soil model in a similar fashion to FORSAFE and SMART2-SUMO. More generally, there is a need to better accommodate climate change effects on key processes such as biomass growth rate and the different components of nutrient cycling.

Communicating the results

The emphasis at present is on achieving ways of simplifying multi-species predictions of change in habitat suitability in ways that provides users with a single, simple metric for evaluating expected change in positive and negative indicators.

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3 Restoration of open habitats from woods and forests in England: developing Government policy

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Summary

The Forestry Commission (FC) is leading development of Government policy on restoration of open habitats from woods and forests in England. The policy will apply to all open habitats restorable from woods and forests but lowland heathland is the most testing. Open habitats are valuable for public benefit as is the land use from which they would be created: woodland and forestry. The policy must help to generate a landscape with greater public benefit in the long-term with reasonable burdens for Government and others.

Proposed desired outcomes relate to: habitats, species, quality of life and landscape, heritage, and preservation of historic features.

All of the Government's objectives for woods and forests in England will be taken into account, proposed additional issues relate to: financial viability, water quality and yield, woodland cover, local community and other user concerns, carbon balance, access and recreation, native or ancient woodland, timber, and woodland biodiversity, rationalisation of low benefit forestry.

The FC has outlined several policy options. These will be adjusted following appraisal: The policy may have implications for several of the Government's delivery mechanisms but one of the most significant is land managed by the FC. The FC is studying the potential for open habitats on this land and a strategy will be developed following the policy.

A public consultation on the policy is planned for launch in early in 2009. Intermediate stages are being published at www.forestry.gov.uk/england-openhabitats

Background

Through the England Biodiversity Strategy (Defra 2006) and A Strategy for England's Trees Woods and Forests (ETWF) (Defra 2007) the Government has committed to developing and delivering a policy on restoration of open habitats from woods and forests and a restoration strategy for the Forestry Commission (FC) estate.

ETWF states that "...our policy for creating, expanding and maintaining the network of sustainably managed trees, woods and forests will be to: … Develop a clear rationale to guide removal of inappropriate plantations and woodland where other key [Biodiversity Action Plan] habitats (eg lowland heathland and bog) can be restored and where the benefits of doing so outweigh the environmental and social costs".

The Forestry Commission is leading a process to develop this policy working closely with Defra and Natural England. The policy will apply to all open habitats restorable from woods and forests but lowland heathland is the most testing. This is because of its extent, biodiversity value, value of timber grown on some former heath, proximity to populations and discrepancy between hectares of extant and potential habitat, much of which is on publicly owned land.

The problem

It is important that we get this policy right. Open habitats are valuable for their biodiversity, contribution to the landscape and cultural heritage. Many are also vulnerable and have declined significantly over the past few hundred years.

However, the land use from which open habitats would be converted under this policy, woods and forests, is itself valued for the benefits it provides and contributes to several Government objectives. Get it wrong and we could end up with a landscape that makes a lower net contribution to public benefit and a process that generates conflict over decisions about removal of woodland.

Get it right and decisions about restoration of open habitats from woodland would be made according to a clear policy and desired changes in key species, habitat quality, landscape, and cultural heritage would be delivered. The process would contribute to a landscape that delivers greater public benefit now and in the long-term.

Our approach

To resolve this challenge we are taking an approach based on a cycle for effective policy making. In essence this involves being focussed on the changes in the real world (outcomes) that the policy should deliver, planning for evaluation early in the process, and developing options which we then use evidence to choose between.

We have published a nine-step process (Table 1). We are taking an open approach encouraging participation by stakeholders, running a formal public consultation and publishing intermediate steps at www.forestry.gov.uk/england-openhabitats.

Table 1 Summary of policy development process.

	Step	**Timescale**
1	Fit progress to date into a policy cycle	June 08
2	Workout implications, collate evidence	August 08
3	Plan evaluation	September 08
4	Appraise options	
5	Consult	Oct 08 to Jan 09
6	Make a decision	February 09
7	Produce policy document	March 09
8	Set up delivery mechanisms	Depends on policy
9	Launch policy	

This paper presents progress to Step 1 only. Note that in the process turbulence is allowed so elements may have changed since this paper was written[1].

Factors to be taken into account

There are a number of factors that need to be taken into account during the process. These are divided into desired outcomes and other issues.

[1] As at 20th February 2009 FC anticipate launching the consultation in February 2009 with the policy decision in July 2009.

Proposed desired outcomes are:

- **Habitats:** Ecologically robust open habitats with secure long-term management regimes in place.
- **Species:** The declining trend in populations of key open habitat species is reversed.
- **Quality of life and landscape:** Changes in landscape due to restoration of open habitats from woods or forests improve the quality of life of people who experience that landscape.
- **Heritage:** People now and in the future can learn through direct enjoyment of the outdoors how history has shaped the landscape.
- **Preservation of historic features:** The condition of historic features in open habitats restored from woods and forests improves and key cultural and designed landscapes are retained.

Proposed issues that need to be taken into account along with financial and administrative burden are (organised according to ETWF aims):

Sustainable resource

- **Financial viability:** Would management of the landscapes that result from restoration of open habitats be financially viable in the long-term, including open habitats, associated woodland, and remaining woodland elsewhere?
- **Woodland cover:** What are the implications for our international commitments to sustainable forest management including maintaining net woodland cover?

Climate change

- **Carbon:** What would be the effect on Government targets for reducing carbon emissions as part of combating climate change?

Natural environment

- **Native and/or ancient woodland:** What would be the effect on our ability to keep to commitments in Keepers of Time[2] on area of native and/or ancient woodland?
- **Woodland biodiversity:** What would be the effect on priority species associated with native and non-native woodland habitats?
- **Water quality and yield:** Is there any potential significant effect on nitrate run-off, scavenging of airborne pollution, water yields, flooding, or other water quality factors?

Quality of life

- **Local community and other user concerns:** What would be the effect on the level of people's positive engagement in woods and forests (including the effect on woodland owners and those working in forestry)?
- **Access and recreation:** What would be the effect on rates of use and benefits received by users?

Business and markets

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[2] Keepers of Time is the Government's statement of policy on ancient and native woodland, see http://www.forestry.gov.uk/forestry/infd-6h3fvs.

- **Timber:** What would be the effect of changes in timber production on stability of timber supply, confidence in the timber producing and processing sectors, and ultimately on economic activity in the timber producing and processing sectors?

- **Rationalisation of low public and private benefit forestry:** Are there opportunities to help woodland owners remove forests that they no longer want to have on their land that have low public benefit and replace them with higher public benefit land uses of equal or greater use to the landowner?

Policy options

We have developed a range of possible policy options to take forward into the rest of the process. Policy options exist along several gradients. The most significant of these are amount of open habitat restored and extent to which activity is centrally directed at a national level (Figure 1). The options are therefore about different approaches and means of decision making, rather than simply different amounts of open habitat restored. However, an indication of the likely amount of open habitat restored is given in relative terms.

At this stage, the options represent a reasonable range of possibilities. They are not a set of rigid policy statements from which we will choose the best but a basis for moving the process forward towards rational appraisal of policy on which we can consult. The process may include amending, combining, or dropping options or developing new ones.

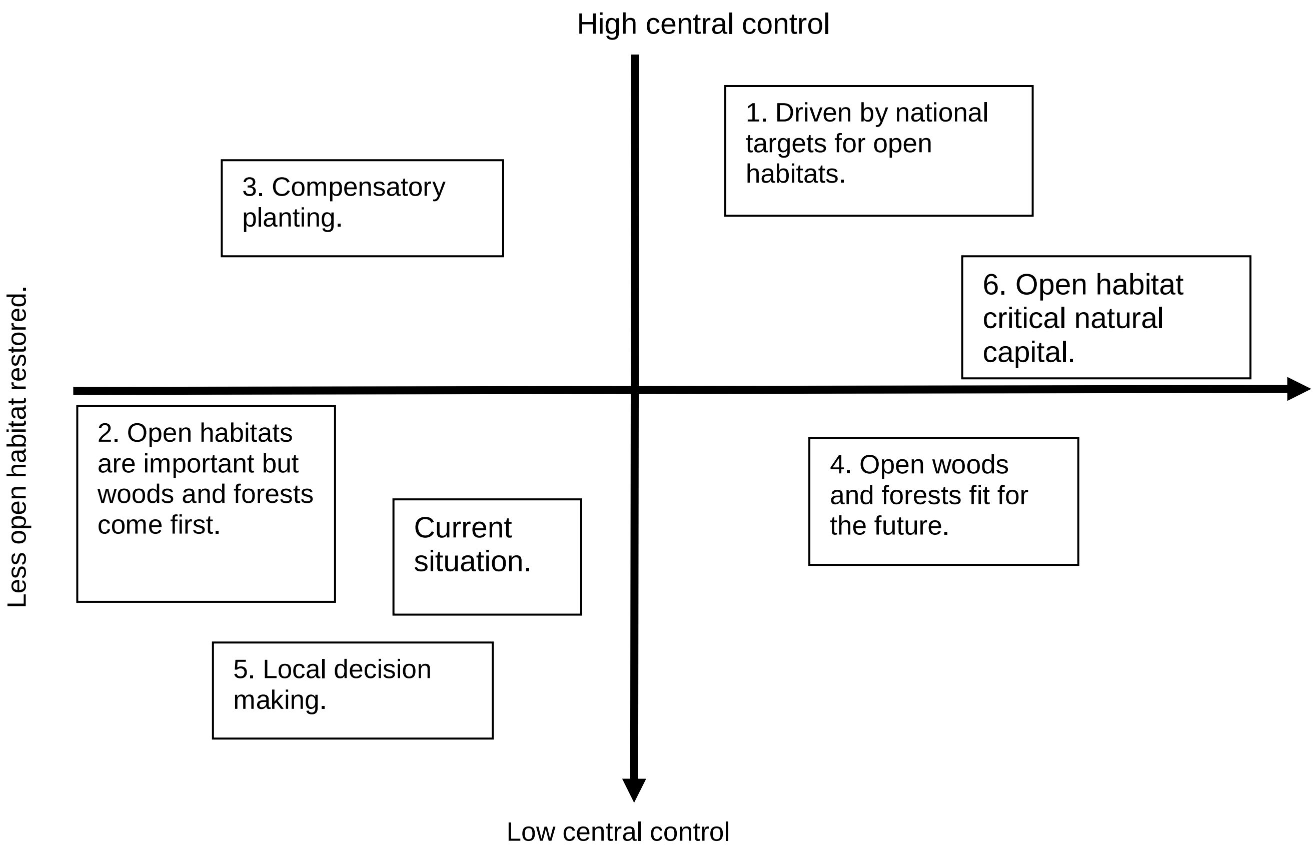

Figure 1 Options for a policy on restoration of open habitats from woods and forests.

Policy options are (in no particular order):

Option 1: Driven by national targets for open habitats

If Government adopted this policy it would make the following kind of policy statement: "We will identify a target and timescale for the number of hectares of open habitat restored from woods or forests. We will promote the conversion of selected woods and forests to open habitats through removal of recent regeneration or felling at economic maturity of plantations. We will make decisions about which restoration proposals to support via integrated local processes based on maximising open habitats without unreasonably detracting from other Government objectives for woods and forests. We will monitor progress towards the target and secure and/or redeploy resources if progress is not quick enough to deliver the targets in time."

This option emphasises delivery of HAP targets and creation of habitats that are in accordance with definitions of "good condition". The amount of habitat restored depends on the target set. However, the policy is likely to result in a large proportion of the HAP targets being delivered from restoration of woods and forests rather than from other land uses.

Option 2: Open habitats are important but woods and forests come first

If Government adopted this policy it would make the following kind of policy statement: "We view open habitats as part of a wider wooded landscape. We will not be driven by national targets but will work with land managers to identify potential sites for restoration based on agreed national criteria designed to minimise negative impact on objectives for woods and forests. We will target top priority sites as resources allow. We will test these potential sites against national targets for open habitats and monitor progress towards desired outcomes by regular measurements of indicators of these outcomes."

This option is likely to result in a reduction in the current rate of restoration of open habitats from woods and forests, although woods and forests would still make a significant contribution to HAP targets.

Option 3: Compensatory planting

If Government adopted this policy it would make the following kind of policy statement: "We will identify a target and timescale for the number of hectares of open habitat restored from woods or forests. We will promote the expansion of woods and forests to create space to allow wholesale restoration of open habitats from woods and forests without net loss of woodland and with minimal impact on other Government objectives for woods and forests. We will only support deforestation where the landowner has ensured creation of woodland that compensates for the deforestation. At a national level, the rate of restoration of open habitats will be limited by the rate of woodland creation."

This option could result in some increase to the current rate of restoration of open habitat from woods and forests but only if enough resources can be found for the associated woodland creation.

Option 4: Open woods and forests fit for the future.

If Government adopted this policy it would make the following kind of policy statement: "Woods and forests and open habitats should be managed together in landscape scale units in which change is embraced rather than seeking to create or preserve fixed areas of habitat which meet strict definitions of habitat type and condition. We will support land managers to manage land in this way. Where this includes deforestation we will make local integrated decisions based on maximising net public benefit. We will identify targets for outcome indicators (including but not simply a target for amount of open habitat restored). We will secure and/or redeploy resources to allow progress to be made. We will monitor progress towards targets by measurement of indicators of these outcomes and set up an inclusive process to agree whether progress is reasonable."

This option moves away from the application of targets based on rigid definitions of good condition and static interpretations about what is appropriate in the landscape. It is likely to result in shifting mosaics of open patches in woods and forests, open canopy woods and forests, and fully open habitats. There would probably be considerably more open habitat overall (perhaps using a more encompassing definition) but its location and condition would be dynamic and delivery of HAP targets might be hard to demonstrate.

Option 5: Local level decision making.

If Government adopted this policy it would make the following kind of policy statement: "We will support planning and decision making at a local level in regional or sub-regional frameworks. We will secure and/or redeploy resources to facilitate proposals that are in line with such local decisions. We will promote those projects that come forward locally that will add most value to biodiversity conservation and provided that other issues can be mitigated in that locality. We will monitor progress by measuring the contribution of the locally led projects to national scale outcome indicators."

This option is heavily influenced by the complexity of the decision making process and focuses on identifying local priorities and facilitating processes for local decision making rather than applying a national scale policy. The amount of open habitat restored from woods and forests depends on local reaction and there may be wide geographical variation. Some areas may have fairly high levels of restoration and others may have only limited or slow changes in land use.

Option 6: Open habitat critical natural capital.

If Government adopted this policy it would make the following kind of policy statement: "We will support the restoration from woods and forests of critical natural capital[3] that has been converted to woodland or forest from priority open habitats. Forest and woodland will play a significant role in restoring these habitats because the open habitat plant and animal communities have often survived and woods and forests tend to alter the soil and seedbank less than other land uses. We will promote the conversion of woods and forests with these characteristics to open habitats through removal of recent regeneration or felling of plantations, normally at or near economic maturity. We will map the area of open habitat critical natural capital on a national basis, agree timed targets, and monitor progress towards restoration. We will redeploy resources if progress is not quick enough to deliver the targets on time."

This policy is likely to result in a large proportion of the potential open habitat under woods and forests eventually being restored. It has some commonality with Keepers of Time.

Comparison to current practice

It is instructive to compare these options to current practice, although simply retaining current practice does not appear to be an option. A statement that summarises current practice would be along the lines of[4]:

"We view open habitats as part of a wider wooded landscape. We respond to proposals from land managers who have identified potential sites for restoration. We work with proposers and consultees to find compromises in contentious cases and approve projects when there is no longer sustained objection from statutory or local consultees. If an acceptable compromise cannot be found we refer decisions to higher governance levels. We will monitor the amount of open habitat restored and feed information into national reporting mechanisms. Support for restoration of open habitats is targeted and if the rate of woodland loss approaches the rate of woodland creation across England as a whole we would have to reconsider support for restoration of open habitats from woods and forests."

Implications for delivery mechanisms

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[3] Critical natural capital is the non-renewable part of our natural asset base. Land that has been converted from a priority open habitat to another land use but retains significant elements of the soil and seedbank of the original habitat can be regarded as critical natural capital.

[4] Note that this is a not a statement of current policy but an outline in policy language of current practice as it has evolved in the absence of a specific national policy.

Eventually, the policy will result in changes to the way Government deploys the delivery mechanisms it has at is disposal. Of these, the following are most relevant to this policy:

- Land ownership – particularly publicly owned land.
- Public funding.
- Regulation and control – particularly adapting the way existing legislation is implemented.
- Regulation and control – particularly codes of practice, standards and quality assurance schemes.
- Research and evidence.

One of the most significant delivery mechanisms is publicly owned land, particularly that managed by the FC.

The Forestry Commission estate and open habitats policy development

The impact of any emerging policy on the FC estate in England depends on both the nature of the policy approach eventually adopted and the scale of implementation applied. Given the scale of the FC estate, and both its existing and potential contribution to open habitat conservation, the implications are important to consider in detail. Significant change will certainly lead to significant impact on current management, and the scale of activity is worthy of particular consideration. Some information on the scale of the landholding will lend context to the debate.

The FC estate in England is:

- **268,000 ha**[5] in extent (the equivalent in area to a mid sized English county such as Oxfordshire).
- **68,000 ha** of this is designated as SSSI (most of which is existing open habitat).
- **219,000 ha** is forest and woodland of which c. **53,000 ha** is ancient woodland (with c. **35,000 ha** under restoration to native woodland from plantation since 2002).
- Of the remainder **49,000 ha** is open habitat (including some **17,000 ha** of heathland).
- **30,000 ha** is thought to be comprised of plantation derived from former heathland (an area roughly the size of the Isle of Wight).

The key issues for the FC estate generated by open habitats policy are (in no particular order):

- **Impact on existing public benefit:** the impact on existing public usage and enjoyment as a wooded landscape.
- **Impact of change on existing wildlife values:** the loss of known wildlife of interest and value against unknown or unproven benefits to other species.
- **Impact on running costs:** the change from low cost plantations or woodland to open habitat with high annual maintenance cost.
- **Impact on timber income:** which along with recreational income and exchequer funding provides the main support for FC activity across the country.

[5] Estimated figures – the exact dimensions fluctuate due to disposals and acquisitions

- **Impact on production forecasts:** and its underpinning role in the timber processing industry and the potential impact on the growing strategic role played by FC in the wood fuel industry and the displacement of fossil fuel usage.

The FC is currently undertaking a major study of the potential for open habitat restoration across its landholding in England. This study will consider both the potential for contributing to UK BAP targets and the impact of policy implementation on existing wildlife values, management costs, timber production forecasts and recreational usage of the forest. When complete this study will underpin the development of an open habitat strategy and plan for the FC estate.

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4 Case Study – Thursley Common NNR Rises from the Ashes

Simon Nobes

Natural England

Summary

From 14th to 17th July 2006 a wildfire raged across 160 hectares of Thursley NNR. This short presentation detailed the events of these four days, the impact on the site's wildlife and the subsequent management of the regenerating heath.

Figure 1 August 2006

Figure 2 August 2008

5 Burn mapping from space

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Summary

Although moorland burning can bring biodiversity advantages if executed correctly, if applied too frequently or within inappropriate vegetation communities and soil types it has severely negative impacts on many species (Tucker 2003). The use of fire management is now widespread and it has been estimated that approximately 114 km2 of moorland is burned annually in the English uplands (Yallop and others 2006). Despite the conservation importance and apparent extent of fire management in the uplands, no comprehensive monitoring of its use is undertaken.

Natural England, facilitated by the British National Space Centre (BNSC), have therefore sought to identify the possible role of satellite remote sensing imagery, automated classification and GIS analysis techniques in forming the core of a national monitoring programme. To achieve this, not only were very high accuracies required, the data produced would also need to be interrogated within a GIS to identify potential compliance issues with current and future statutory regulation or guidelines and identify 'bad' management practices, whether due to the sheer intensity of management or the practice on sensitive areas (e.g. proximity to water courses or soil/habitat types).

We report, for the first time, the outcomes of this just completed project. It shows that the use of VHR satellite imagery, image segmentation and classification can identify new management burns over very large areas with an accuracy easily exceeding 90%. The demonstration GIS is able to utilise this mapping to readily identify areas where non-compliance with current burning codes is occurring. Combined these approaches demonstrate that a national moorland burn monitoring programme can now be readily undertaken.

Introduction

A natural absence of tree cover is rare in England (Dimbleby 1952). The existence of large expanses of upland heath is a result of management, such as fire and grazing, following Bronze Age clearances (Brown 1997). Without this history, the extent of both Ericaceae and Poaceae moorland would be far smaller. Benefits accrue to animal species dependent on open habitats e.g. diversity of inverts (Usher & Thompson 1993) and birds like curlew, golden plover and lapwing (Tharme and others 2001; Whittingham and others 2000).

However, although heathland only exists because of such fire management, it cannot be taken that all burning is somehow 'good' for the upland environment. It is axiomatic that practices responsible for many species and communities are detrimental to others, e.g. numerous bird species (Tharme and others 2001), vegetation, invertebrates, soil structure or hydrology (Tucker 2003). Today poor burn management is second only to overgrazing as the commonest cause of unfavourable condition on upland SSSIs. It is estimated that 114 km^2 burned annually in England (at yr 2000; Yallop and others 2006).

It is obvious that fire management is inextricably linked with upland landscapes and produces effects that are both beneficial and adverse. As such there are numerous 'regulations' and guidance, yet no way to judge how these are complied with. Indeed there is little information about either the extent or frequency of this practice nationally to help judge its impacts. Basically we have no national monitoring programme for this, the most potentially damaging operation performed on these delicate sites.

This project was commissioned by Natural England and BNSC and undertaken on behalf of a partnership between the Integrated Environmental Sciences Institute (IESI) of Cranfield University and Infoterra Ltd. This called for a demonstration of the ability to map moorland burning with an accuracy >90% using automated classification procedures on earth observation (EO) imagery. The key requirements were that each burn should be a vector object to allow GIS analysis to identify extent or frequency of burning at numerous scales. Also, it should comply with current and future burning codes and guidelines, including any cross-compliance issues and local management agreements. This means identifying each burn's location in relation to soil data, slope, conservation status, drainage, etc.

It was proposed that this process should produce outputs compatible with those derived from manual aerial photograph interpretation (API) as used by Yallop and others (2006). The mapping obtained was to be integrated within a demonstration GIS with ancillary data to allow identification of areas of concern and to monitor compliance with existing and future burning guidance. The project has been undertaken in two discrete phases.

Phase 1

Phase 1 of the project was primarily concerned with the issues of development, testing and demonstration of methods suitable for delivering the required classification accuracy. Two forms of classification approaches were examined using Ikonos (Figure 1), Quickbird (Figure 2), SPOT V (Figure 3) and ADS40 airborne imagery over three discrete areas of the English Uplands.

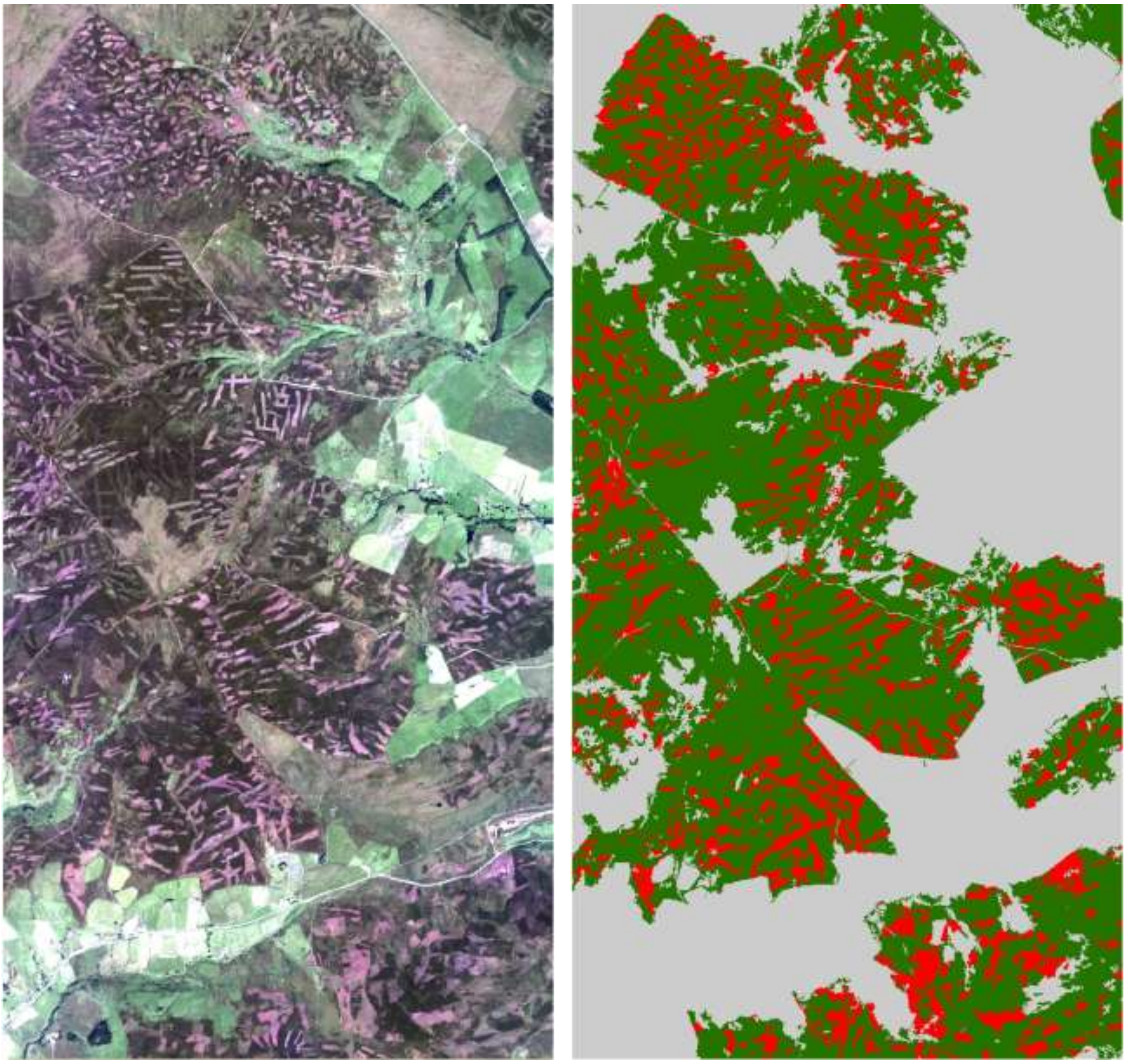


Figure 1 Example classifications. Phase 1 Development. Vector mapping of 2005 Ikonos imagery of North Yorkshire. Left: raw image; right: image classified using heather mask and extracting one burn class equivalent to Class 1 API or ‘new burn’. Note that as with all following images more burns are apparent in the RGB imagery. These are partially revegetated Class 2 burns.

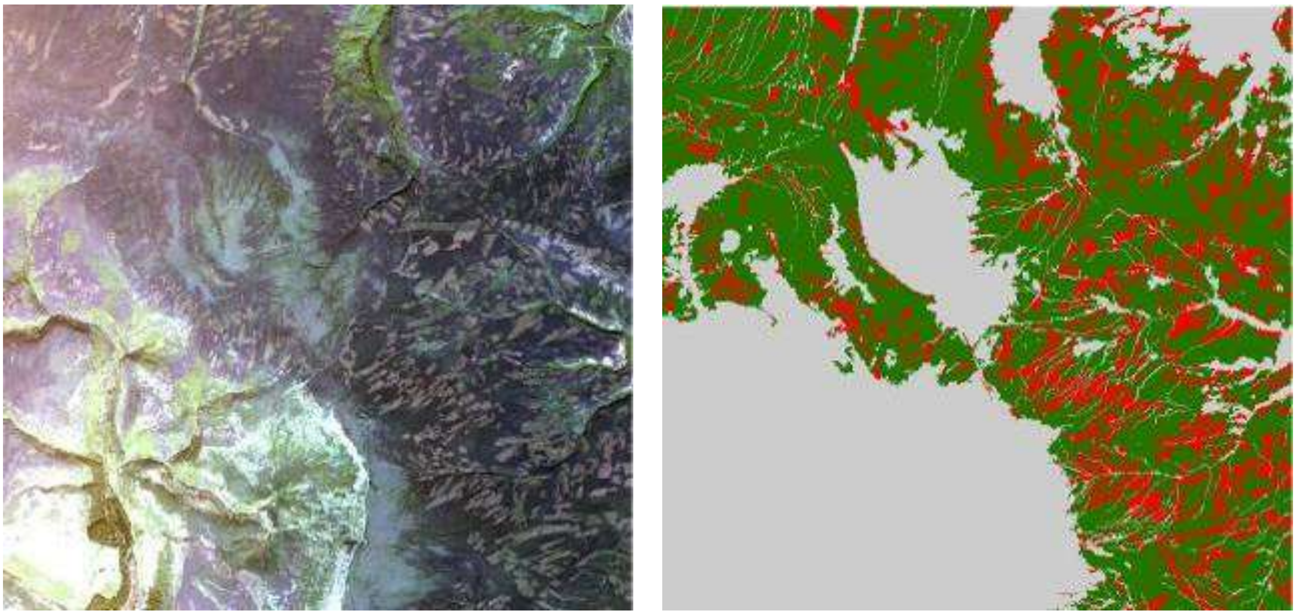


Figure 2 Vector mapping of 2005 Quickbird imagery of Peak District. Left: raw image; right: image classified using heather mask and extracting one burn class equivalent to Class 1 API or ‘new burn’.

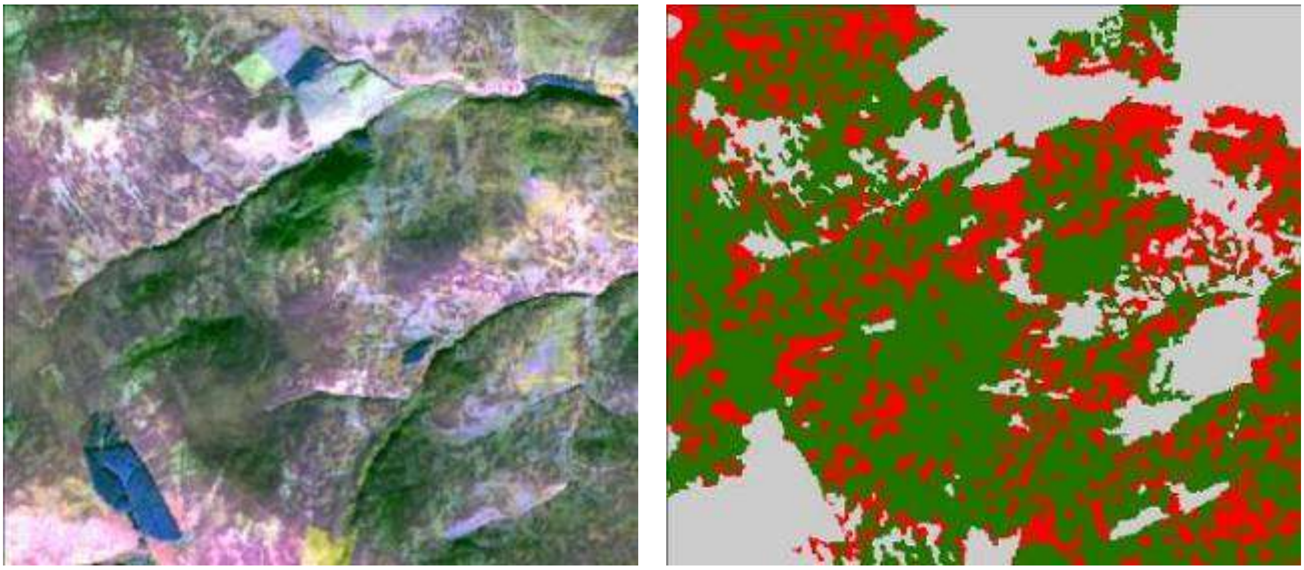


Figure 3 Vector mapping of 2006 SPOT V imagery of the Cheviot Hills. Left: raw image; right: image classified using heather mask and extracting one burn class equivalent to Class 1 API or ‘new burn’.

This showed that there are no shortcuts to directly identifying burn ‘scars’ within EO imagery owing to an absence of sufficiently defined unique spectral signatures for them. However, an approach of stratifying the imagery by generation of a ‘mask’ to exclude all vegetation types not likely to be burned ie those not exhibiting a dominance of ericaceous species (primarily *Calluna*) and restricting classification to these areas, was developed.

This provided a reliable method and together with vector-based classification procedures on good quality VHR imagery, such as that currently available from Ikonos and Quickbird, can achieve identification of ‘new’ burn parcels with an accuracy that exceeds the minimum required target of 90%. These results are compatible with part of the API typology of burn aging as used by earlier surveys (Yallop and others 2006), although it should be noted only the ‘new burn’ class can be identified to the required accuracy.

The use of lower resolution imagery such as that from SPOT V does not achieve the accuracies required. Higher resolution imagery e.g. 4-band ADS40 produces accuracies similar to those obtained using VHR EO data and would provide an alternative data source. However, a full protocol for the use of this imagery was not developed.

Phase 2

Phase 2 of the project was primarily charged with a large-scale implementation of the methods identified in Phase 1 across the North Yorkshire Moors National Park (NYM). This entailed developing some final modifications to the methods used in Phase 1 to adjust for issues arising from deployment over larger areas with differing environmental conditions. In addition, some changes were adopted to help satisfy additional requirements of Natural England for a monitoring programme identified as the project progressed.

The main difference between the methods demonstrated in Phase 1 and those used in Phase 2 were the scale of image segmentation used and the creation of additional rules and/or datasets to identify zones of mixed and sparse vegetation on slopes that are not dominated by *Calluna* in which burn mapping is undertaken. This serves as guidance to areas of the imagery that are worthy of visual inspection during each monitoring round.

Using these methods, Phase 2 successfully mapped new burns across over 290 km^2 of *Calluna* dominated moorland within the NYM for which imagery was available, at accuracies >90% (Figures 4 & 5).

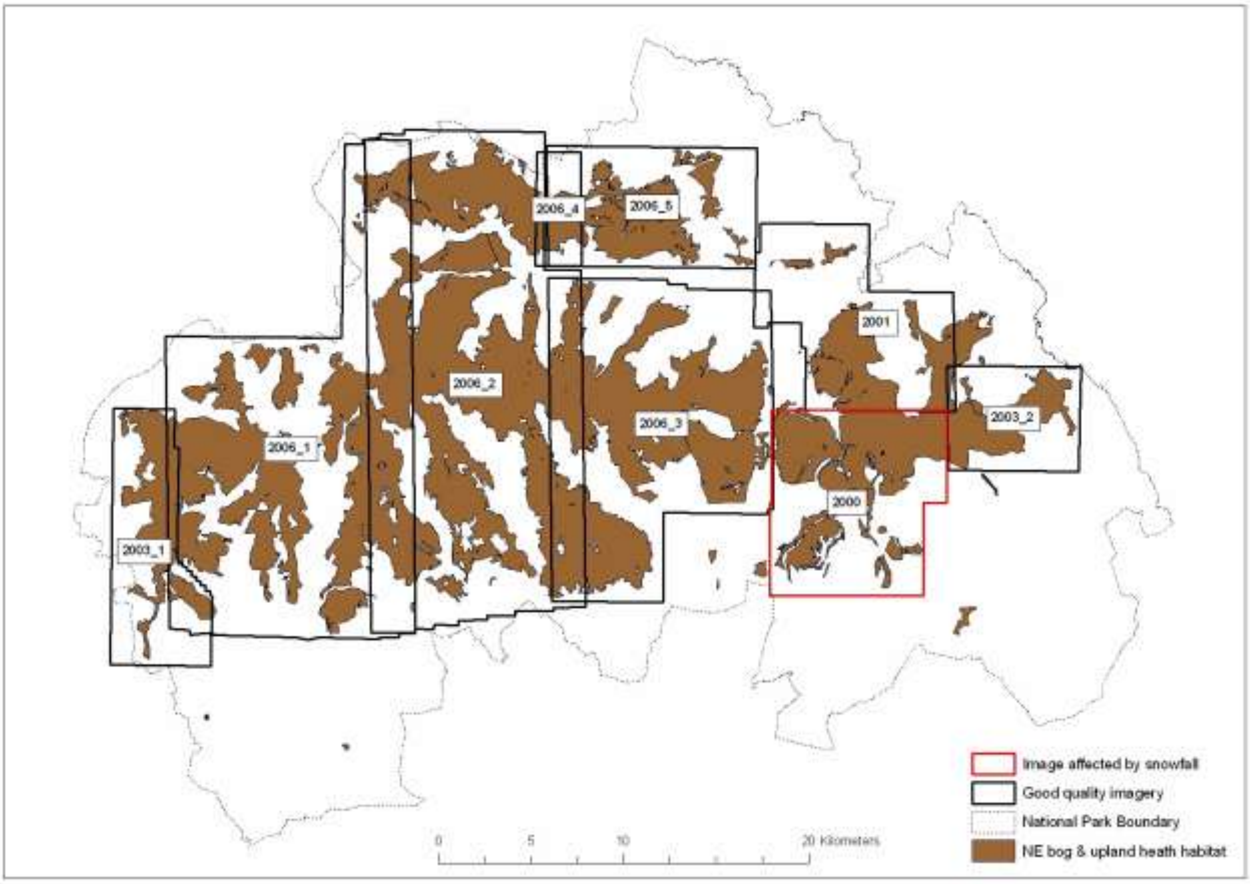


Figure 4 Availability of recent VHR imagery over *Calluna*-dominated areas in the North Yorkshire Moors National Park and used for Phase 2. (Areas of bog & heath habitat visible outside the extent of imagery did not contain *Calluna* dominated moorland).

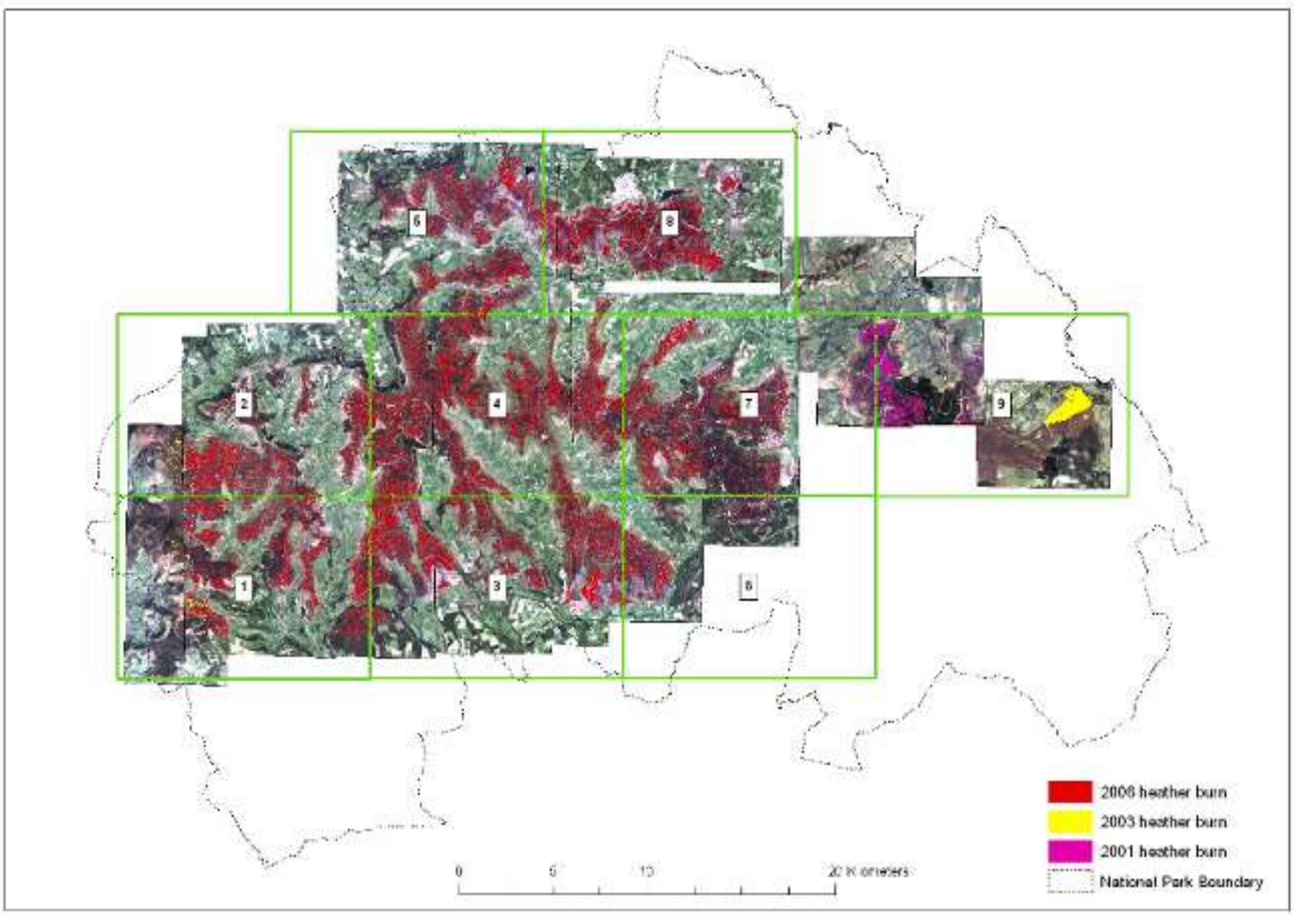
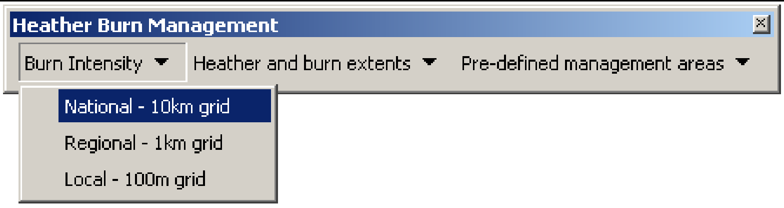
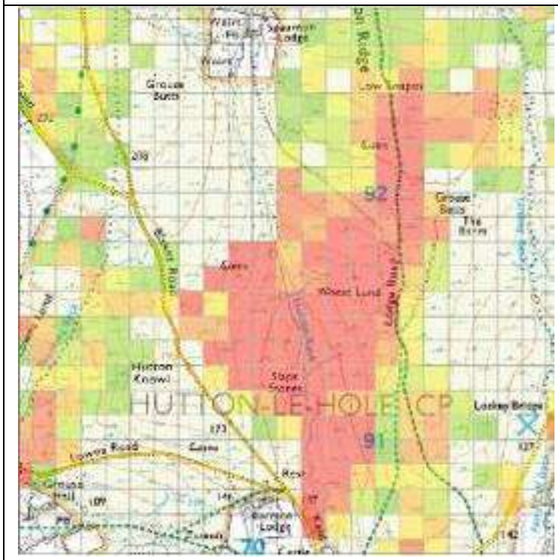
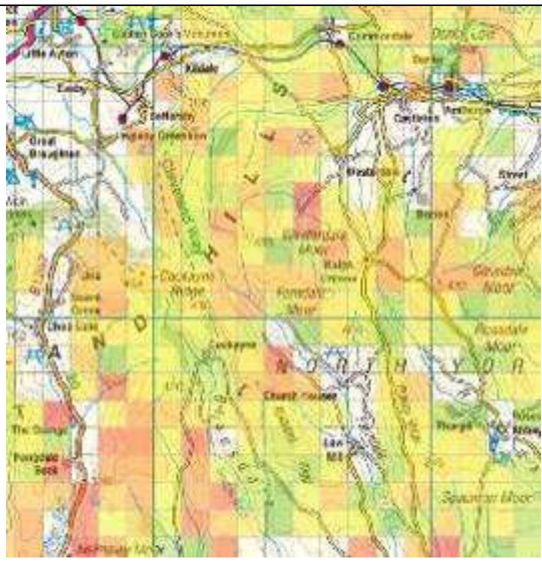


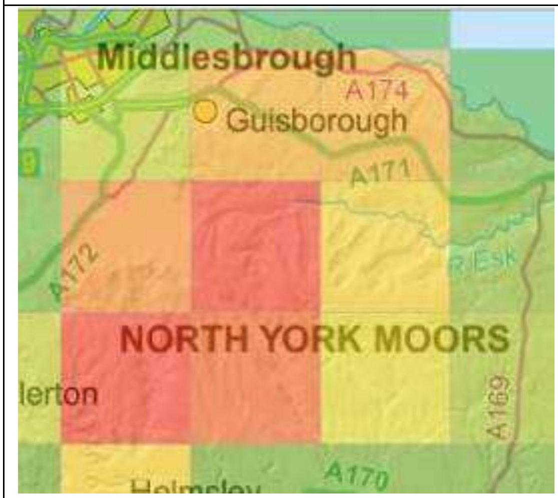
Figure 5 Overview of heather burning derived from classification of Ikonos imagery over the NYM – 2001, 2003 & 2006.

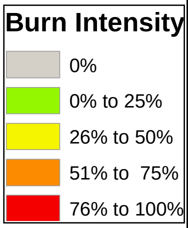
Key to the requirements for a monitoring programme identified by Natural England is the ability to use the data obtained from burn mapping within a bespoke GIS for identifying compliances issues and reporting (Figures 6 & 7). Phase 2 therefore involved the finalisation of a demonstration GIS able to undertake this role.











Top:

heather burn management tools menu showing intensity options

Centre left:

100m heather burn intensity grid (%)

Centre right

1km heather burn intensity grid (%)

Bottom left:

10km heather burn intensity grid (%)

Figure 6 Examples of heather burn intensity display options within the GIS.

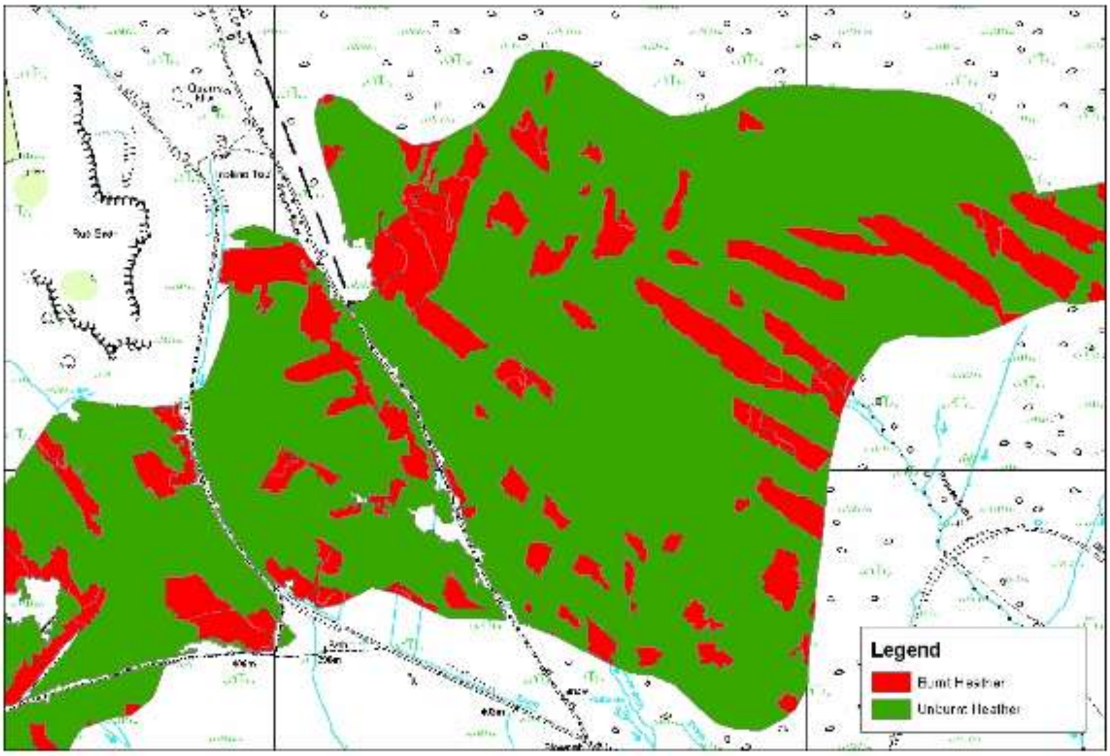


Figure 7 Example GIS output over small area for identifying burn management compliance with existing national and local guidelines and consents derive using model above. This example is for burning on Bog habitat.

A final key component of the project was an evaluation of the cost and benefits of a monitoring programme which allows a realistic appraisal of the options available to Natural England and serves as a 'roadmap' to deployment.

Summary, Implications and suggestions for national deployment

The project attempted to develop a classification protocol for mapping moorland management burning with an accuracy of >90% using a typology compatible with those used for earlier API projects. In so doing, it has explored the use of HR, VHR EO and digital aerial imagery. The final outputs from such a classification were to be in vector format for inclusion in a GIS designed to allow visualisation and interrogation of the burn data for monitoring and management programmes.

The following summary points can be made:

- The use of pixel classifiers is not suitable because of the difficulty of dealing with large numbers of isolated mis-classified pixels when transferring to a vector environment.
- Owing to lack of spectral uniqueness of burn scars compared to surrounding vegetation and the way spectral signature alter as burns regenerate there is no simple 'direct route' to burn identification, classification and mapping within an image scene.
- Permanent masks to differentiate areas likely to be burned, i.e. Ericaceous dominated communities, from those that are not is however relatively easy using VHR imagery and image segmentation procedures. This allows stratification of the image to restrict classification. This reduces spectral confusion and provides a successful route to burn mapping.
- Only classification of imagery with spatial resolutions (IFOV or pixel-size) <4.0 m can achieve the required accuracies. This means only VHR EO imagery (e.g. Ikonos, Quickbird) and RGBIR digital image data acquired from airborne sensors (eg ADS40, Vexcel) can be recommended for future burn monitoring programmes.

- If vector classifiers are used on such data burn classification accuracies of >90% can be achieved providing the images are not unduly affected by atmospheric 'haze'. This classification is however only for Class 1 (new burn).
- It should be noted that the use of ADS40 was not fully developed as part of this project and there will be a number of issues that need resolving, e.g. data handling before such data are utilised for this task.
- It is clear from the results produced here that the use of SPOT imagery is not able to achieve the accuracy of burn determination specified by Natural England. It would seem therefore that to attempt to map burning in the uplands of England as proposed using this sensor would not provide a good baseline for future monitoring and should not be pursued.

The demonstration implementation of burn mapping across the majority of the NYM national park in Phase 2 shows that the processes and methodologies developed in Phase 1 are applicable when dealing with larger areas. This suggests there is no technical impediment to the deployment of a national monitoring programme.

Acknowledgements

This project has been overseen by Alistair Crowle of Natural England and Matt O'Donnell of the BNSC. Their input, guidance and flexibility are gratefully acknowledged by the project team. The support of other researchers at both Cranfield University and Infoterra has been most helpful and for this they are thanked as are Richard Turner of BNSC and Simon Leach of Natural England.

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6 What determines fire occurrence, fire behaviour and fire effects in heathlands?

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Summary

The occurrence, behaviour and effects of fire in vegetation are the result of complex interactions between the type and structure of the vegetation, weather conditions and human behaviour. In this paper we review the factors that determine where and when fires occur in UK Heathlands and explore the factors that determine their ecological severity. Whether fire should be considered beneficial or damaging to the ecosystem depends largely on one's management objectives and whether one considers the effects over a short or long time scale. It is likely that different management objectives will result in conflicting priorities with regard to the management of both prescribed fires and wildfire.

Introduction

There are many different types of vegetation fire: natural fires and man-made fires; well-controlled management fires and wildfires; mild fires and severe fires; 'cool', slow-moving fires and hot, intense fires. Some of these fires can be considered "bad" while others are "good".

The combination of the frequency with which fires burn, how hot or intense they are and how damaging or severe they are is termed a "fire regime". Differences in fire regime are linked to climate, vegetation type and the degree of human intervention. In landscapes such as heath and moorland, which are heavily modified by the action of people, it is not particularly helpful to ask "what is the natural fire regime?" The more pertinent question is "what kind of fire regime can help us achieve our management objectives?" Fire is an integral part of most heathland landscapes whether we want it to be or not. It is therefore inappropriate to ask "how do we prevent fire?" Instead we should be asking "when is fire appropriate and when is it not?" or "how can we prevent bad fire whilst promoting fire that is beneficial?"

The first step to answering these questions has to be a clear understanding of when and why fires occur, what makes fires different and how we can control the effects of fire. Once we understand fire better we can then start to think about what we mean by "good" and "bad" and how we might manage fire to achieve our conservation and management objectives.

What determines where and when fires occur?

There are three conditions necessary for vegetation to burn: a suitable source of fuel, appropriate weather conditions and a source of ignition. It is the interplay between these three factors that determines the timing and distribution of fires – the fire regime.

Fire hazard describes the flammability of a given fuel type based on, for example, the amount and type of vegetation present, the relative amounts of dead and live material and the fuel moisture content. Fire risk describes the probability of an ignition due to the presence of an ignition source. In our case this is largely accounted for by people whether fires are lit deliberately for management or accidentally. Fire danger is the interplay between hazard and risk and describes the likelihood of a fire occurring based on the presence of ignition sources (risk) and the ability of the vegetation to carry a fire (hazard). These are important distinctions as we will see below.

Vegetation as a fuel

Most green plants are very difficult to burn. The water content of healthy, green vegetation is usually so high that there is insufficient heat generated by the combustion process to evaporate off the water content of living tissues. However, when plant tissues die the water content of the dead material rapidly approaches equilibrium with the atmosphere or ground with which it is in contact. It is largely dead fuels that determine when and where fires will occur, though the situation is a little more complex for heather fires (see below).

In the UK heathlands and moorlands there are several major vegetation types where an accumulation of dead fuel creates a significant fire hazard. These include grasslands dominated by purple moor grass *Molinia caerulea,* particularly in the west of Britain, or stands of bracken *Pteridium aquilinum*. In both these cases the fuel is the litter formed by dead leaves and this remains in contact with the ground. In winter the bulk of the litter is likely to remain damp and most fires that occur will be fairly superficial, removing only the surface layer of litter that is aerated and exposed to drying winds. These aerated fuels can, however, dry out extremely rapidly and fires can occur at almost any time when drying conditions occur, even if only a few hours after rain (Hamilton 2000). The greatest fire danger occurs in late spring when managers set prescribed fires, walkers begin to take to the outdoors and exceptional periods of fine weather can dry out the litter to a greater depth, increasing the total amount of fuel that is available to burn. As summer progresses the litter remains a fire hazard, but decomposition and breakdown increases contact with the soil and new green growth of *Molinia*, or other grasses associated with *Pteridium* may effectively increase the water content of the vegetation/litter complex. All other things being equal, this reduces the fire hazard.

Gorse *Ulex* spp have a totally different fuel structure. In this case the ground litter is again in close contact with the soil and, being more woody and beneath the shrub canopy, will be slower to dry than grass or *Pteridium*. However, there is a second layer of dead fuel suspended in the canopy just beneath the green shoots. It is this layer of aerated fuel that dries out very rapidly and, once ignited, can generate very intense fires at any time of year.

Heather or ling *Calluna vulgaris* is exceptional amongst the heathland fuels. The canopy of *Calluna* comprises a branching system of fine stems with tiny overlapping leaves dispersed throughout the upper part of the canopy. The canopy can be seen to have two layers, the lower grey and dominated by dead foliage, while the upper canopy is green and alive. However even in the upper canopy there is a fine mixture of dead and living material. Whilst the moisture content of the dead fuel in the lower canopy may be crucial for allowing initial ignition of a fire, particularly in marginal burning conditions, subsequent fire spread and intensity is strongly influenced by the moisture of live material which forms the majority of vegetation.

The moisture content of the living material may also be very low in comparison to what is expected from green plant material. The moisture content of live foliage often drops markedly in late winter and spring when the acidic soil is cold (or frozen), and possibly anaerobic, making soil water relatively inaccessible. Frost and wind-driven ice can also damage the leaf cuticles such that the plant is unable to control water loss by stomatal closure. If these conditions are combined with a drying environment (eg winter sunshine or drying winds with low atmospheric humidity) then the water content of the living canopy material may be as low as 45% of oven-dry weight and *Calluna* is then extremely flammable. Canopy moisture content below about 60% is sufficient to support a fire, though the litter and moss beneath the *Calluna* canopy is usually damp at this time of year and unlikely to be consumed.

During the summer and autumn, the new growth of *Calluna* usually has a moisture content in excess of 120% of dry weight, and this is too high to sustain a fire by itself. Dead material and the moss and litter layer on the ground are usually drier than in spring and may play a crucial role in determining the ignition probability and spread of the fire. Once ignited, the heat generated from burning litter, moss and dead material is sufficient to dry out and ignite the living canopy material above. However, restrictions on burning in the summer mean there has been very little experimental research on vegetation flammability outside of the legal burning season.

Peat and organic soils represent a completely different class of heathland fuel. Peat fires are smouldering fires, rather than flaming combustion. They are difficult to ignite but, once established, are very difficult to extinguish. Fortunately, peat fires are rare in the UK, but when they do occur they may continue to burn for many weeks and cause very significant environmental damage. Experimental evidence suggests that peat must have a moisture content below about 120% dry weight to support smouldering combustion (Rein and others 2008). This means that peat fires are most likely to occur in summer and early autumn after periods of prolonged drought. We do not yet understand the role of peat type or structure on fire, but piping and cracking of peat are likely to be associated with more rapid drying of the peat and hence an increase in the frequency of periods when peat fires are a possibility.

Weather conditions and fire occurrence

The primary role of weather is in determining the moisture content of the fuel. However, it will be clear from the discussion above that different types of fuel will respond to weather conditions in different ways. In particular, finely divided fuels might be expected to dry out (and re-wet) much more rapidly than coarser woody fuels or deep peat. Thus the moisture content of fine fuel is closely coupled with recent weather conditions, but that of coarser fuels and peat display a time-lag.

The conventional way to handle this problem in fire science is exemplified by the Canadian Forest Fire Weather Index (FWI) System (Van Wagner 1987). The FWI System uses weather data to calculate three different fuel moisture indices: the Fine Fuel Moisture Code (FFMC), the Duff Moisture Code (DMC) and the Drought Code (DC). FFMC is calibrated to correlate well with the moisture content of pine needles lying on the forest floor and integrates the drying conditions of the weather over the previous few days. DMC is calibrated to correlate with the moisture content of 'duff' (loosely compacted organic layers of ca 7 cm depth), reflecting weather conditions over the previous weeks. DC provides an indication of the moisture content of deeper organic soils (ca 18 cm) and is a useful indicator of seasonal drought effects on forest fuels.

Since it is almost always the fine fuels that are first ignited to start a fire, the FFMC is calibrated to be an indicator of the ignition potential – the probability that a fire will be started if a firebrand is dropped on the vegetation. The Drought Code, however, will give a better indication of the severity of a fire, because it will correlate well with the depth of fuel that can be consumed.

The Canadian FWI System has been widely applied in countries throughout the world and has been adapted and re-calibrated against many different types of vegetation. So how well might it apply to UK vegetation? The Met Office routinely publish the Met Office Fire Severity Index for England and Wales (Met Office 2005, Thomas 2008). This is an index based on the Canadian Fire Weather Index (basically an amalgam of FFMC, DMC, DC and wind speed) which provides a general index of fire hazard that will relate to the intensity of the fire. The Met Office Fire Severity Index was developed in direct response to the Countryside and Rights of Way (CROW) Act 2000. It provides a five-day forecast of exceptional weather conditions when Open Access Land in England and Wales may be closed to the general public because of the fire danger. This it does well – if a fire occurs when the Met Office Fire Severity Index is 5 ('Exceptional') then you can be pretty sure that it will be a bad fire. Conversely, however, the majority of both wildfires and management fires occur when the FSI is either 1 ('Very Low') or 2 ('Low'); it is not, therefore, a good indicator of when fires are likely to occur (Legg and others 2007). However, it should be clear from the discussion above that not all of the variations in fuel condition and fire behaviour can be captured in a single 5-point scale.

The Canadian model was originally calibrated for the drying rates of fuels on the floor of Jack pine *Pinus banksiana* forest in Canada. While it is likely that the Drought Code and Duff Moisture Codes will translate reasonably well for UK conditions (Kitchen and others 2006), the FFMC, calibrated in Canada for dead pine needles, does not reflect the moisture content of either *Ulex europaeus* (Anderson 2006) or the *Calluna* canopy (Figure 1).

A complete model relating weather conditions to fire occurrence needs to take into account these different interactions between vegetation type, season and weather. Our understanding of fuel moisture in heathlands is clearly dependent on a new model for *Calluna* canopy moisture content that considers the low availability of water from cold, acid soils and the susceptibility of the plant to desiccation. Understanding the drying rates of aerial dead material in *Ulex* canopies and the seasonal changes in proportions of dead material in grassland and *Pteridium*-dominated vegetation are also critical for predicting fire occurrence and behaviour in these vegetation types.

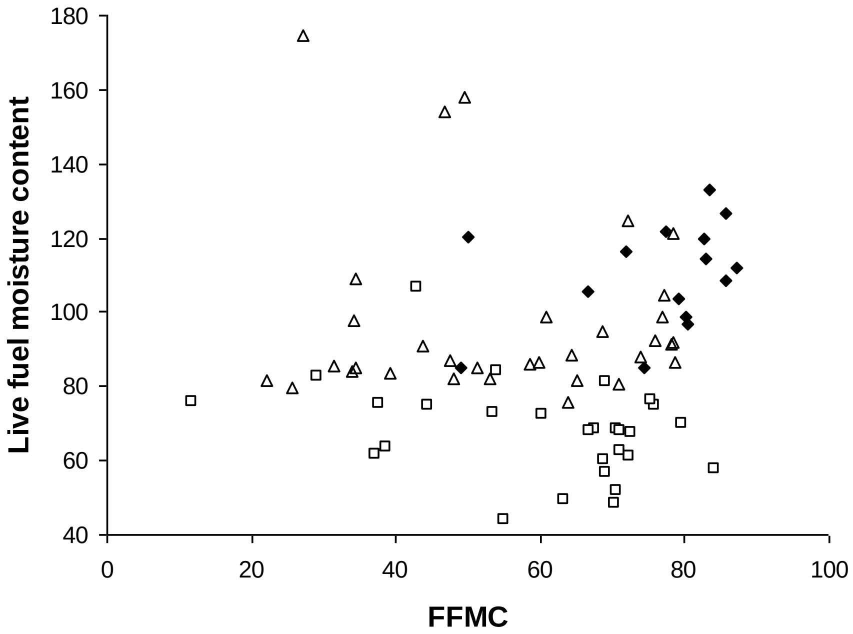

Figure 1 Fuel Moisture Content (FMC) of live *Calluna* canopy material plotted against the Canadian Fine Fuel Moisture Code (FFMC) calculated from Met Office Numerical Weather Prediction data. Data are for samples taken from Scottish heather moorland in spring (squares), summer (diamonds) and autumn (triangles) respectively. FFMC is calibrated to give high values when pine needles on a forest floor have very low moisture content, but it does not well reflect the moisture content of live *Calluna* canopy material. It is also comparably poor at predicting the moisture of dead *Calluna*.

The ignition event

Lightning as a source of ignition of vegetation fires is common in many parts of the world and has been recorded in the UK (eg Allison 1954; Weatherall 1954), but the vast majority of vegetation fires in the UK are caused by people. Of these a high proportion are controlled management fires that are used to improve habitat quality for red grouse *Lagopus lagopus scotticus*, sheep or deer. Burning is legally restricted to the periods between various dates in autumn, winter and early spring (see SEERAD 2001 (Scotland) and DEFRA 2007 (England & Wales) for the exact dates which depend on location and circumstances), but in practice the majority of management fires occur in February, March and April.

A small proportion of management fires may get out of control and become wildfires, but the vast majority of recorded wildfires are either malicious or accidental and occur throughout the year. Their spatial and temporal distribution depends on the behaviour and patterns of the people concerned. Thus, for example, urban outdoor fires reported to the Fire and Rescue Services are about 23% more frequent at weekends than on weekdays; for rural areas weekend fires are only about 15% more frequent. Urban fires are most frequently reported between 19.00 and 21.00 hrs on weekdays, but urban weekend fires and all rural fires are mostly reported between14.00 and 17.00 hrs (see Legg and others 2007 for details of data and methods).

There have also been detailed spatial analyses of fires in the Peak District (McMorrow and others 2006) and Dorset Heaths (Kirby & Tantram 1999) that show heathland fires occurring with increased frequency near to roads and car parks. Concern has been expressed that increasing recreational activity in the countryside will inevitably mean more accidental fires from discarded cigarette ends and camp fires that get out of control, but the flip side is that more people in the countryside also means more eyes to spot fires when they occur and more rapid reporting. It is often difficult from fire records to distinguish between an increase in fire occurrence and an increase in the reporting of fires.

Where and when do fires occur?

The actual spatial and temporal distributions of fires are the result of the distribution and phenological state of different vegetation types, the weather conditions over the last few days that determine the moisture content of fine fuels, and human behaviour. Whilst the quantity and structure of dead fuel determine hazard in late autumn and winter, it is not until late spring that longer days, warmer sun and better drying conditions increase the probability of ignition. Cold soils but drying sun and winds in late spring reduce the moisture content of the *Calluna* canopy at the time of maximum management burning and maximum potential for escaped management fires. Mid-late summer provides the warmer weather which coincides with maximum recreational activity and an increased number of ignition sources (people), but the ratio of dead to living material is lower resulting in a higher average water content of the fuels.

Any model designed to forecast where vegetation fires occur would need to take most of these factors into account. Given the comments above about the rather poor ability of the FFMC to predict fuel moisture in *Calluna* heathland, it is rather surprising that FFMC does seem to be good at predicting the outdoor fires reported to Fire and Rescue Services (Figure 2). Perhaps FFMC is identifying those warm and sunny days when there are most people active in the countryside who represent the ignition risk. Further research that examines fire occurrence in different fuel types separately and allows us to develop an in-depth understanding of variation in vegetation moisture content is urgently needed to clarify these relationships.

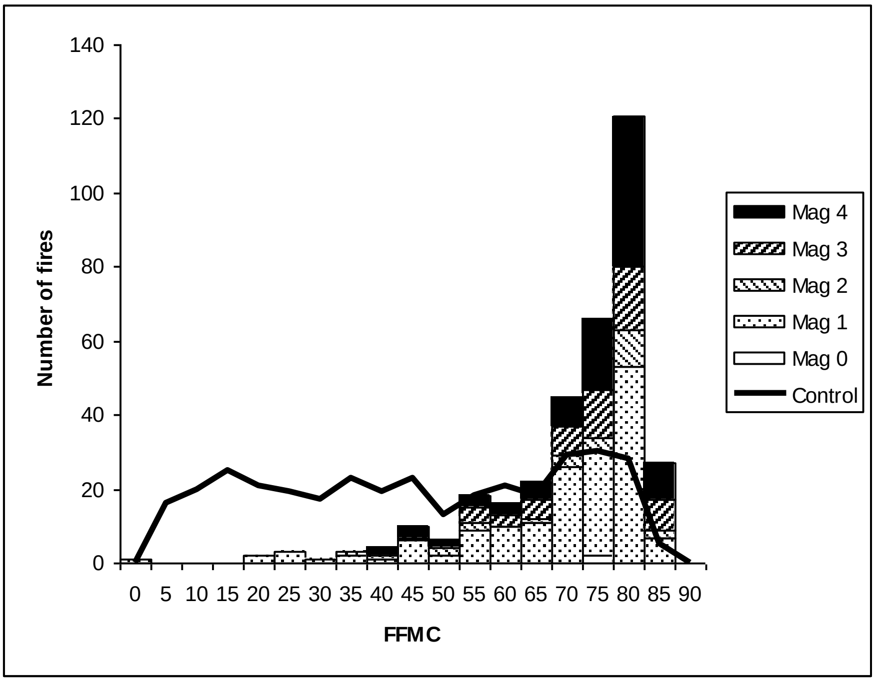

Figure 2 The frequency of wildfires in dwarf-shrub heath reported to the Fire and Rescue Services in four regions in Scotland plotted against the Fine Fuel Moisture Code (FFMC). 'Mag 0' to 'Mag 4' represent an arbitrary ordinal scale of fire magnitude. The continuous 'Control' line is the null model that represents the expected distribution if fire occurrence were independent of weather conditions. See MacKinnon (2008) for details of data sources and methods.

What determines fire behaviour?

Fire scientists normally recognise rate of spread and fireline intensity as the two main characteristics of fire behaviour. Fireline intensity is defined as the rate of heat output per unit length of the fire front and is related to how 'hot' the fire feels to a person standing near to it. Fireline intensity and rate of spread determine the difficulty with which a fire can be extinguished and are therefore the prime factors of interest to fire fighters. Rate of spread is affected partly by wind speed and partly by the structure and moisture content of the fuel (Davies 2005, Davies and others 2006, Legg and others 2007). Fires in fine, dry fuel that is easily ignited will spread much faster than fires in coarse or damp fuel which must be exposed to high temperatures for much longer before the combustion process becomes exothermic. Fast-spreading fires consume fuel at a much higher rate and therefore fireline intensity will also be higher.

The structure of fuel also affects rate of fire spread. For example, fire spread can be inhibited by the gaps present in the canopy of old or degenerate *Calluna*. This can result in an irregular or broken fire front. However, fires in this vegetation will respond strongly to increased wind speed. As the wind flattens the flames they are able to jump across gaps in the canopy much more rapidly. Wind may have less effect on the rate of spread in even-canopied building-phase *Calluna* because the density of the canopy limits oxygen availability which dampens the rate of combustion (Davies 2005, Davies and others 2006, Legg and others 2007).

For the ecologist and conservationist, however, rate of spread and intensity are poor indicators of damage caused by the fire (Hartford & Frandsen 1992, Neary and others 1999). Of more interest will be the residence time and the depth of penetration into the soil of lethal temperatures. These are much less well understood, but slow moving fires (eg back fires burning into the wind) may have longer residence times than fast-moving fires that spread rapidly over the surface of the vegetation but have rather superficial effects (Ascoli and others 2006). However, residence time depends less on wind speed and direction than on the nature of the fuel: coarse fuels will burn much more slowly than fine fuels, whatever the wind speed.

Depth of penetration of heat in UK situations is likely to depend mostly on the moisture content of the litter and soil. On damp organic soils the temperature rarely rises more than a few degrees centigrade even 2 cm below the surface of compacted litter (Davies 2005). Where the litter is dry and can ignite, however, smouldering fires can establish. Although spreading at only a few centimetres per hour with temperatures much lower than those of flaming combustion, smouldering fires will consume large quantities of organic material, destroy seed banks and kill the rootstocks of plants (Maltby and others 1990, Neary and others 1999).

What determines fire effects?

While fire intensity is a measure of the rate of heat output, fire severity refers to the amount of change that the fire causes to the ecosystem. Fire affects a very great number of different aspects of ecosystem state and function and the ‘amount of change’ is not easily measured on a simple scale. Of course, some of the changes that occur may be considered seriously undesirable to some land managers, while people with other management objectives consider them trivial or even beneficial. It is therefore inevitable that fire severity is a vague concept that defies precise definition.

One possible way to consider the severity of the disturbance would be to estimate the time that is required for the system to return to something close to its original state. However, this raises further problems: if the next fire comes before the system has recovered, or if the system does not return to exactly its former state, then repeated fires will have cumulative and long-term effects that might be quite different from the more apparent short or medium-term effects.

The rate at which the ecosystem recovers from a disturbance event will also depend on the type of ecosystem. Thus vegetation that has been burned a hundred times before is likely to recover very rapidly and completely, because all the species present before the fire are there because they managed to recover from the previous fires and will probably do so again. A fire in a community that has not experienced previous fire, however, may contain many fire-sensitive species that will take many years to return. Fire effects are thus the result of a strong interaction between the characteristics of the fire and the vegetation that has been burned.

Short-term effects

The immediate effect of fire is the destruction of above-ground biomass and the heating of the surface soil. This kills many animals (particularly invertebrates living in the canopy or surface litter) and changes the habitat conditions for others. Some plants will be killed, though others will re-sprout from the stem bases and most of the seed bank usually survives. Carbon and nutrients are lost to the atmosphere. Heating of the soil can make it non-wettable and change the hydrology by reducing permeability and increasing run-off. Removal of the vegetation makes the soil more susceptible to erosion (Neary and others 1999). Fire creates a visual scar on the landscape with sharp edges that reduce the ‘wilderness’ effect.

The severity of these changes will depend very largely on the proportion of the fuel that is consumed and the depth and duration of heat penetration below ground. However, the recovery of vegetation depends as much on the nature of the vegetation burned as on the intensity of the fire. Thus, a spring fire in *Molinia* grassland or *Pteridium* litter may only remove material that is dead anyway, with very little impact on the re-growth of the dominant species. Normal or even relatively intense fires through building-phase *Calluna* heathland will damage neither the seed bank nor the root-stocks of *Calluna* which will re-sprout rapidly (Bullock & Webb 1995, Davies 2005). In this situation fast moving head-fires give little opportunity for prolonged heating of the ground and thus seed-banks, roots and rhizomes remain intact.

A fire after a prolonged dry spell that ignites the litter and surface peat may both kill the rootstocks and damage the seed bank (Maltby and others 1990, Legg and others 1992). Vegetation recovery will then be very patchy and depend on occasional surviving seeds or plants, or on invasion from outside the fire site. The open shrub canopy that results will be very susceptible to invasion by other species.

Calluna heathland that has reached the mature or degenerate stage, however, is much more susceptible to damage by fire and recovery will be slow. Compared with building-phase plants, mature *Calluna* plants have a smaller number of stems at ground level and a high proportion of these are unable to re-sprout after even a mild fire. Regeneration therefore becomes dependent on the seed bank. Mature heathland vegetation often has a dense ground layer of feather mosses which make a very poor seedbed. Regeneration of *Calluna* from seed will therefore be very poor following mild fires that leave the moss and litter behind, but moderately intense fires that consume the moss and litter layer leave a surface of exposed peat or mineral soil and seedling establishment will be much more successful (Davies 2005). A slow-moving back fire (burning into the wind) with a long residence time may achieve this much more safely than a rapid head fire (burning with the wind) where high fuel loads create an intense fire that may be difficult to control.

A peat fire represents the extreme end of the severity spectrum in which the organic soil, which has taken thousands of years to accumulate, is consumed. The ash, mineral soil and any residual peat material left behind are sterile and the vegetation that returns is likely to be totally different from that which was present before the fire. Peat fires cause a complete change in ecosystem structure and function that is effectively irreversible (Maltby and others 1990, Legg and others 1992).

Medium-term effects

Most of the short-term impacts of fire listed above will be seen by most people as detrimental. However, many of our heathland ecosystems have experienced a long history of disturbance through cutting, grazing and burning. Some of the characteristics that we cherish are due to the history of management burning and wildfire. Indeed, the majority of lowland heathlands are successional communities that, without intense management of some sort, would long ago have reverted to woodland. The detrimental short-term impacts of fire must therefore be weighed against the potential benefits in the medium and long term.

Fire is a disturbance event that stimulates successional changes in the ecosystem. When the majority of plant species survive the fire, either as stem bases or a persistent seed bank, the species composition *per se* is little altered by the fire; there may be changes in cover and abundance but there is no species turnover. This is called autosuccession (Hanes 1971). However, the exposure of bare soil permits new species to establish which would not be able to survive in closed vegetation in the absence of fire. This is well illustrated by the numerous species of terricolous lichens (including many species of *Cladonia*) that can establish in the early phase of post-fire succession, but are overgrown by weft mosses in mature stands (Davies & Legg 2008).

One consequence of regularly repeated fire is the dominance of a single competitive species that suppresses other species so reducing the local (alpha) diversity. Thus *Calluna* will come to dominate on drier sites, and *Molinia* or hare's tail cottongrass *Eriophorum vaginatum* on wetter sites. The regrowth of *Molinia* and *Eriophorum* after mild or moderate fire can be so rapid that there is little opportunity for other species to establish. *Calluna*, in contrast, takes several years to achieve dominance and loses dominance again in the mature phase. The pioneer or late-mature and degenerate stages may therefore contain many species that are suppressed in the building phase. This means that where many small fires create a mosaic of stands of different ages there is a contrast in structure and species composition between neighbouring patches that increases the beta diversity of the landscape. Habitat mosaic has been shown to be beneficial to several species, some of high conservation importance, such as lichens (Davies & Legg 2008), red grouse that feed on young stands but nest in older stands (Palmer & Bacon 2001), and hen harriers that preferentially hunt along the edges of stands (Arroyo and others 2009). The silver studded blue butterfly *Plebejus argus* is also dependent on the dynamic mosaic of stands of different ages (Thomas 1985)

The structural mosaic of stands of different ages also influences fire behaviour at the landscape level. Sites of recent fires will have insufficient fuel to sustain a fire. Fires in young stands of *Calluna* where the fuel load is low will be much easier to control and extinguish than fires where the fuel load is high. Managed fire can therefore be used around sites where the risk of accidental (or malicious) ignition is high to create fuel breaks that greatly reduce the risk of uncontrollable wildfires occurring in severe weather conditions.

Long-term effects

The long-term effects of fire, ie the effects that accumulate over several fire cycles, are much less well understood. The majority of research in the UK has concerned either single fire events or the post-fire succession following single fire events. As mentioned above, many heathland sites exist because of the history of disturbance, so repeated fire will create and maintain a particular and distinctive type of vegetation. Equally, cessation of burning where it has been an important factor in the past will also cause vegetation to change. This may be a gradual change in species composition or, for example, where trees invade the transition to woodland may be rapid. When considered at the landscape scale and long-temporal scales, fire is not a present-or-absent factor: changes in fire regime – frequency, intensity, size, season, etc. – will all influence the type of ecosystem that develops.

It has now been recognised in most countries of the world with fire-prone vegetation that total prevention of fire is neither desirable nor possible. The results of trying to remove fire from a fire-prone environment are sadly predictable as demonstrated by the extreme examples of the devastating fires in Greece in 2007 (as effectively anticipated by Xanthopoulos and others 2006) and Australia in 2009 (as anticipated by Cheney 2008) . Despite best attempts to the contrary, accidental or malicious wildfires will happen on some occasions. The more effort that is put into preventing fire, the greater the quantity of fuel that accumulates. When wildfires do then happen there is an increased probability that they will be intense summer fires that are hard to extinguish and have a major impact on the ecosystem. This risk of occasional, but severe, wildfire has to be balanced against the costs of lesser environmental damage caused by more frequent but low-intensity fires (Davies and others 2008).

Associated with changes in fire regime that cause major long-term shifts in vegetation may come changes in land use. These can have knock-on effects on the ecosystem that exceed the direct effects of the change in fire regime itself. For example, a change in burning management that reduces the economic value of a grouse moor may result in a switch to grazing or forestry as the dominant land use. Alternatively, an increase in recreational activity could result in an increase in accidental summer wildfires that have more severe impacts on the ecosystem than the grouse-moor management that they replace.

There has been growing debate recently on the effects of fire on both the carbon budgets of *Calluna*-dominated moorlands and the effects on the hydrology and water quality of upland streams (Davies and others 2008). Given that the vegetation on sites that have a long history of burning will re-grow to its former status within a few years of a fire, 'cool' fires that do not damage the organic content of the soil can be considered carbon neutral or even carbon positive when averaged over a fire cycle (Clay & Worral 2008). Severe fires that consume the organic soil horizons, however, will probably result in a net loss of carbon to the atmosphere where the fire return time is less than the time for replenishment.

Perhaps of more concern than the carbon lost to the atmosphere by combustion in the fire itself is the change to the hydrology of the moorland system. Many *Calluna*-dominated moorlands are based on peat that was formed under a different vegetation type – perhaps formerly dominated by *Eriophorum* and *Sphagnum*. Management (by a combination of burning, grazing and drainage) has changed this to a *Calluna*-dominated system with a much reduced rate of peat formation. Further, the changes to surface hydrology caused by burning (and exacerbated by drainage) can result in a drying of the peat. As peat dries, so it shrinks leading to cracking and piping with increased rates of runoff. Once dried, peat is not easily re-wetted. Aeration of peat (perhaps exacerbated by atmospheric nitrogen deposition) increases microbial activity and wet oxidation with potential deleterious effects on water quality. Thus, even though the effects of a single fire may be considered carbon neutral, the long-term effects of regular burning management over several fire cycles may have cumulative effects that are hard to measure. For certain these problems will get worse over the next few decades with climate warming.

The UK is responsible for a massive store of carbon in peat and organic soils (estimated as the equivalent to the above-ground carbon in all the forests of the UK and France and possibly Germany combined). The protection of this carbon store must be a priority. This will become more difficult in the face of climate change over the next few decades. Climate-driven changes in fire hazard in vegetation are difficult to predict because they will be associated with the vegetation itself changing in response to the new climate, new land use and new fire regimes. It is likely that, all other things being equal, warmer and drier summers over most of Britain will increase the probability of ignition, and increase the intensity and severity of summer fires. An increase in the frequency of peat fires following hot, dry summers may be the most significant, and serious, change in terms of threats to the carbon store. Our concern should perhaps therefore not be "how does burning affect carbon sequestration?" but rather "how can we protect existing carbon reserves?". Fuel management though prescribed burning or other management interventions has a role to play in this.

Conclusion: management options for conservationists

If we return to our original question: "when is fire appropriate and when is it not?" we now see that this is not a simple question and the answer will depend very much on precise circumstances. Fire will be detrimental to some species and habitats, but essential for the survival of others. Prevention of fire is impossible – the risk of rare but extreme wildfire fire needs to be weighed against the environmental costs of frequent, but less severe fire. The effects of fire are very variable and depend as much on the characteristics of the vegetation being burned as the characteristics of the fire itself making generalisation difficult. It would be a mistake to draw conclusions from the characteristics of an individual fire. Rather, it is necessary to look at fire as a component of the whole landscape, and to consider the effects fire regime over a number of fire cycles. The short- or medium-term effects of fire may contrast starkly with the effects viewed over the long-term. Changes to existing fire regimes will result in progressive changes in vegetation and ecosystem character, and hence changes in land use priorities.

Different people will have different management objectives for heathlands. Clearly defined objectives are required to determine the best way to manage fire. These might include economic land use (eg for sheep, grouse or deer); species or habitat conservation; recreation; carbon storage or water quality. It is likely that these multiple objectives will be conflicting and prioritising will require difficult decisions.

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7 The hydrology and fluvial carbon fluxes of upland organic soils

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Summary

The hydrology of upland organic soils is fundamental to nutrient and carbon transfers and to plant growth. The presentation provided an overview of what we understand about the hydrology of these systems. It will be shown that while surface flow is important, particularly in wet heaths, movement of water through cracks and natural cavities (called soil pipes) is also very important in organic soils, and particularly in heathlands. This leads to large amounts of carbon movement not only at the surface which is where most of the research has so far focussed, but through heathland soils in the form of eroded material, dissolved organic carbon and dissolved gases. The presentation discussed impacts of management activity on hydrology and carbon fluxes in wet heaths.

Follow-up material

If you are interested in this topic then the following annotated list provides useful information on our recent research and review documents. Much of the material I covered in the presentation can be found within these references. I also provide the abstracts for research papers where appropriate which summarises our work.

General overviews

1. HOLDEN, J., SHOTBOLT, L., BONN, A., BURT, T.P., CHAPMAN, P.J., DOUGILL, A.J., FRASER, E.D.G., HUBACEK, K., IRVINE, B., KIRKBY, M.J., REED, M.S., PRELL, C., STAGL, S., STRINGER, L.C., TURNER, A., WORRALL, F. 2007. Environmental change in moorland landscapes. *Earth-Science Reviews,* 82, 75-100

Comment: This is a significant review paper in an international journal on moorland management and moorland soils and provides a comprehensive overview of what we know about these systems.

Abstract: Moorlands are unique environments found in uplands of the temperate zone including in the UK, New Zealand and Ireland, and in some high altitude tropical zones such as the Andean páramos. Many have been managed through grazing, burning or drainage practices. However, there are a number of other environmental and social factors that are likely to drive changes in management practice over the next few decades. Some moorlands have been severely degraded and in some countries conservation and restoration schemes are being attempted, particularly to revegetate bare soils. Native or non-native woodland planting may increase in some moorland environments while atmospheric deposition of many pollutants may also vary. Moorland environments are very sensitive to changes in management, climate or pollution. This paper reviews how environmental management change, such as changes in grazing or burning practices, may impact upon moorland processes based on existing scientific understanding. It also reviews impacts of changes in climate and atmospheric deposition chemistry. The paper focuses on the UK moorlands as a case study of moorland landscapes that are in different states of degradation. Future research that is required to improve our understanding of moorland processes is outlined. The paper shows that there is a need for more holistic and spatial approaches to understanding moorland processes and management.

There is also a need to develop approaches that combine understanding of interlinked social and natural processes.

2. LIMPENS, J., BERENDSE, F., BLODAU, C., CANADELL, P., FREEMAN, C., HOLDEN, J., ROULET, N. RYDIN, H. & SCHAEPMAN-STRUB, G. 2008. Peatlands and the carbon cycle: from local processes to global implications - a synthesis. *Biogeosciences* 5, 1475-1491.

Comment: This is an international review paper authored by major international experts following a conference on peatlands and the carbon cycle.

Abstract: Peatlands cover only 3% of the Earth's land surface but boreal and subarctic peatlands store about 15-30% of the world's soil carbon (C) as peat. Despite their potential for large positive feedbacks to the climate system through sequestration and emission of greenhouse gases, peatlands are not explicitly included in global climate models and therefore in predictions of future climate change. In April 2007 a symposium was held in Wageningen, the Netherlands, to advance our understanding of peatland C cycling. This paper synthesizes the main findings of the symposium, focusing on (i) small-scale processes, (ii) C fluxes at the landscape scale, and (iii) peatlands in the context of climate change. The main drivers controlling C fluxes are largely scale dependent and most are related to some aspects of hydrology. Despite high spatial and annual variability in Net Ecosystem Exchange (NEE), the differences in cumulative annual NEE are more a function of broad scale geographic location and physical setting than internal factors, suggesting the existence of strong feedbacks. In contrast, trace gas emissions seem mainly controlled by local factors. Key uncertainties remain concerning the existence of perturbation thresholds, the relative strengths of the CO2 and CH4 feedback, the links among peatland surface climate, hydrology, ecosystem structure and function, and trace gas biogeochemistry as well as the similarity of process rates across peatland types and climatic zones. Progress on these research areas can only be realized by stronger co-operation between disciplines that address different spatial and temporal scales.

3. HOLDEN, J. 2005. Peatland hydrology and carbon cycling: why small-scale process matters. *Philosophical Transactions of the Royal Society A,* 363, 2891-2913 doi:10.1098/rsta.2005.1671

Comment: This was a personal comment and review paper invited by the journal

Abstract: Peatlands cover over 400 million hectares of the Earth's surface and store between one third and one-half of the world's soil carbon pool. The long-term ability of peatlands to absorb carbon dioxide from the atmosphere means that they play a major role in moderating global climate. Peatlands can also either attenuate or accentuate flooding. Changing climate or management can alter peatland hydrological processes and pathways for water movement across and below the peat surface. It is the movement of water in peats that drives carbon storage and flux. These small-scale processes can have global impacts through exacerbated terrestrial carbon release. This paper will describe advances in understanding environmental processes operating in peatlands. Recent (and future) advances in high-resolution topographic data collection and hydrological modelling provide an insight into the spatial impacts of land management and climate change in peatlands. Nevertheless, there are still some major challenges form future research. These include the problem that impacts of disturbance in peat can be irreversible, at least on human time-scales. This has implications for the perceived success and understanding of peatland restoration strategies. In some circumstances, peatland restoration may lead to exacerbated carbon loss. This will also be important if we decide to start to create peatlands in order to counter the threat from enhanced atmospheric carbon.

4. HOLDEN, J., CHAPMAN, P.J., EVANS, M.G., HAYCOCK, N. HUBACEK, K., KAY, P. & WARBURTON, J. 2007. *Vulnerability of organic soils in England and Wales*. Defra Report SP0352, full technical report, 151pp.

Comment: This is a comprehensive review of the science and status of organic and minero-organic soils in England and Wales. There are two versions of the report; a summary 25 page version and a full 151 page detailed review of the science that was known at the time of writing in 2007. It details management impacts and remediation tools as well as soil services and degradation status. The reports are available at: www.geog.leeds.ac.uk/people/j.holden

5. HOLDEN, J., WALKER, J. EVANS, M.G., WORRALL, F. & DAVISON, S. 2008. *A compendium of UK peat restoration projects.* Final report to Defra. Defra published report SP0556.

Comment: This report produces a database and reviews the results of a detailed questionnaire examining peat restoration and management projects. The report and website with database are available at www.peatlands.org.uk [Accessed March 2009].

General hydrology

Comment: The papers below all provide new science explaining the hydrological processes operating in upland peats. The first two are overview papers while the rest are more specific scientific enquiries.

6. HOLDEN, J. 2008. Upland hydrology. In: A. BONN, K. HUBACEK, A. STEWART, T. ALLOTT, eds. *Drivers of change in upland environments.* Routledge, 113-134.

7. HOLDEN, J. 2006. Peat hydrology. In: I.P. MARTINI, A.M. CORTIZAS & W. CHESWORTH, eds. *Peatlands: basin evolution and depository of records of global environmental and climatic changes,* Amsterdam, Elsevier, 319-346,

8. HOLDEN, J., KIRKBY, M.J., LANE, S.N., MILLEDGE, D.J., BROOKES, C.J., HOLDEN, V. & MCDONALD, A.T. 2008. Factors affecting overland flow velocity in peatlands. *Water Resources Research*, 44, W06415, doi: 10.1029/2007WR006052.

9. HOLDEN, J. & BURT, T.P. 2003. Runoff production in blanket peat covered catchments. *Water Resources Research,* 39, 1191, DOI: 10.1029/2003WR002067.

10. HOLDEN, J. & BURT, T.P. 2003. Hydraulic conductivity in upland blanket peat; measurement and variability. *Hydrological Processes,* 17, 1227-1237.

11. HOLDEN, J. & BURT, T.P. 2003. Hydrological studies on blanket peat: The significance of the acrotelm-catotelm model. *Journal of Ecology*, 91, 86-102.

12. HOLDEN, J. & BURT, T.P. 2002. Infiltration, runoff and sediment production in blanket peat catchments: implications of field rainfall simulation experiments. *Hydrological Processes,* 16, 2537-2557.

13. EVANS, M.G., BURT, T.P., HOLDEN, J. & ADAMSON, J. 1999. Runoff generation and water table fluctuations in blanket peat: evidence from UK data spanning the dry summer of 1995. *Journal of Hydrology*, 221, 141-160.

14. EVANS, M.G., ALLOTT, T. HOLDEN, J., FLITCROFT, C. & BONN, A., eds. 2005. *Understanding gully blocking in deep peat.* Moors for the Future, Castleton.

Drainage/gripping and drain blocking impacts

Comment: The papers below outline the known impacts of drainage and drain blocking on hydrology and carbon production in UK peatlands. Papers 15 and 16 are overview papers. Paper 17 provides evidence of long-term changes to peat hydrology and stream flow caused by drains. The work demonstrates that short term responses are quite different to those seen 50 years after drainage has taken place. Paper 18 provides quantification of erosion rates from drains and recovery from blocking while papers 19 and 20 find DOC reductions related to blocking of drains.

15. HOLDEN, J., CHAPMAN, P.J. & LABADZ, J.C. 2004. Artificial drainage of peatlands: Hydrological and hydrochemical process and wetland restoration. *Progress in Physical Geography,* 28, 95-123.

16. HOLDEN, J., CHAPMAN, P.J., LANE, S.N & BROOKES, C.J. 2006. Impacts of artificial drainage of peatlands on runoff production and water quality. In: I.P. MARTINI, A.M. CORTIZAS &

W. CHESWORTH, eds. *Peatlands: basin evolution and depository of records of global environmental and climatic changes,* 501-528, Amsterdam, Elsevier.
17. HOLDEN, J., BURT, T.P., EVANS, M.G. & HORTON, M. 2006. Impact of land drainage on peatland hydrology. *Journal of Environmental Quality,* 35, 1764-1778, doi:10.2134/jeq2005.0477.

18. HOLDEN, J., GASCOIGN, M. & BOSANKO, N.R. 2007. Erosion and natural revegetation associated with surface land drains in upland peatlands. *Earth Surface Processes and Landforms,* 32, 1547-1557.

19. WORRALL, F., ARMSTRONG, A. & HOLDEN, J. 2007. Short-term impact of peat drain-blocking on water colour, dissolved organic carbon concentration and water table depth. *Journal of Hydrology,* 337, 315-325.

20. WALLAGE, Z.E., HOLDEN, J. & MCDONALD, A.T. 2006. Drain blocking is an effective treatment for reducing dissolved organic carbon loss and water colour in peatlands. *The Science of the Total Environment* 367, 811-821.

Flow and carbon released from cracks and cavities

Comment: Flow through cracks and natural pipes in organic soils is common and the work below shows how management action such as encouragement of *Calluna* growth and drainage of organic soils leads to increased flow through these pipes and as such more erosion occurs below ground. This releases carbon from the peat. Paper 21 is a book chapter forthcoming in 2009 and provides completely new data on carbon produced by subsurface erosion of natural soil pipes. The other papers provide details of new measurements and measurement techniques demonstrating the importance of pipes and macropores in flow and carbon export in organic soils.

21. HOLDEN, J., SMART, R., CHAPMAN, P.J., BAIRD, A.J. & BILLETT, M. (in press) The role of natural soil pipes in water and carbon transfer in and from peatlands. In: A.J. BAIRD, L. BELYEA, X. COMAS, A. REEVE & L. SLATER, eds. *Northern Peatlands and Carbon Cycling.* American Geophysical Union Monograph.

22. HOLDEN, J. 2009. Flow through macropores of different size classes in blanket peat. *Journal of Hydrology*, 364, 342-348.

23. HOLDEN, J. 2006. Sediment and particulate carbon removal by pipe erosion increase over time in blanket peatlands as a consequence of land drainage. *Journal of Geophysical Research,* 111, F02010, doi:10.1029/2005JF000386.

24. HOLDEN, J. 2005. Piping and woody plants in peatlands: cause or effect? *Water Resources Research*, 41, W06009: DOI: 10.1029/2004WR003909.

25. HOLDEN, J. 2005. Controls of soil pipe density in blanket peat uplands. *Journal of Geophysical Research,*110, F010002, DOI: 10.1029/2004JF000143.

26. HOLDEN, J. 2004. Hydrological connectivity of soil pipes determined by ground penetrating radar tracer detection. *Earth Surface Processes and Landforms,* 29, 437-442.

27. HOLDEN, J., BURT, T.P. & VILAS, M. 2002. Application of ground penetrating radar to the identification of subsurface piping in blanket peat. *Earth Surface Processes and Landforms, 27, 235-249.*

28. HOLDEN, J. & BURT, T.P. 2002. Laboratory experiments on drought and runoff in blanket peat. *European Journal of Soil Science,* 53, 675-689.

29. HOLDEN, J. & BURT, T.P. 2002. Piping and pipeflow in a deep peat catchment. *Catena,* 48, *163-199.*

30. HOLDEN, J., BURT, T.P. & COX, N.J. 2001. Macroporosity and infiltration in blanket peat: the implications of tension disc infiltrometer measurements. *Hydrological Processes,* 15, 289-303.

8 Detecting and attributing nitrogen deposition in heathland ecosystems

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Summary

Atmospheric nitrogen deposition represents a considerable threat to heathland ecosystems contributing to a reduction in heather cover, increasing grass cover, reducing species richness and encouraging species typical of more nutrient rich environments through acidification and eutrophication. The damage reported in the Netherlands over the last 25 years clearly shows the extent to which heathlands can be degraded by nitrogen deposition. These impacts are not just restricted to heather dominated habitats but are also found in the bogs and acid grasslands found in a matrix with heathland habitats. All of these habitats have acid soils with a low capacity to buffer further reductions in pH and all are dominated by species typical of nutrient poor habitats. Acid grasslands have been shown to be especially sensitive to nitrogen deposition with species richness being reduced by even low levels of nitrogen deposition.

Substantial areas of the UK are under threat from acidification and/or eutrophication but detecting impacts of this at a site level is not easy. Upland areas are especially under threat from nitrogen deposition with critical loads (the level below which there is no harm from the pollutant) exceeded in most upland areas of the UK. The current framework for Common Standards Monitoring (CSM), employed by the conservation agencies to assess site condition, does not assess impacts of air pollution making it very difficult to determine the impact that nitrogen deposition might have on individual sites of conservation importance.

This paper reports on the findings of a project funded by Joint Nature Conservation Committee (JNCC) and Natural England to identify indicators of N deposition that could be incorporated into CSM guidance. Using national data sets of with information on species composition and nitrogen deposition and evidence from long-term controlled experiments we identified potential indicators of nitrogen deposition in heathland, acid grassland and bog habitats that could be used to detect and attribute damage caused by nitrogen deposition. We evaluate these indicators in terms of their potential to detect the impact of nitrogen deposition and their suitability for incorporation into CSM guidance.

Introduction

In the global environment, biotic nitrogen fixation provides about 90-130 Tg N yr^{-1} but human activities have resulted in the fixation of an additional ~140 Tg N yr^{-1} by energy production, ~80 Tg N yr^{-1} by fertiliser production and ~40 Tg N yr^{-1} by cultivation of crops (Galloway and others 1995). The global nitrogen (N) cycle has now reached the point where more N is fixed annually by human-driven than by natural processes (Vitousek 1994). Galloway and others (1995) predict that anthropogenic N-fixation rates will increase by about 60% by the year 2020. The main nitrogenous air pollutants include nitric oxide (NO), nitrogen dioxide (NO2) and ammonia (NH3) which are dry deposited as particulates or as gas, together with nitrate (NO3-) and ammonium (NH4+) as wet deposition in rain.

The relative importance of the different N forms depends on the location and proximity to pollutant sources. The largest emissions of pollutant nitrogen globally are in the form of ammonia, emitted from animal excreta, synthetic fertilisers and biomass burning. Nitrogen oxides, mainly from burning fossil fuels, account for approximately one third of global emissions (Olivier and others1998).

The effects of N deposition on vegetation and soils are varied. The different effects on vegetation can be divided into several classes: direct toxicity, increased susceptibility to pests and disease, increased susceptibility to environmental stressors (eg frost) and soil-mediated effects of acidification and eutrophication. Amongst these, acidification and eutrophication are the most widespread.

Atmospheric deposition of N represents a considerable threat to heathland ecosystems, contributing to a reduction in heather cover, increasing grass cover, reducing species richness and encouraging species typical of more nutrient-rich environments. The damage reported in the Netherlands over the last 25 years (eg Heil & Diemont 1983, Bobbink and others 1998) clearly shows the extent to which heathlands can be degraded by nitrogen deposition. These impacts are not just restricted to heather dominated habitats but are also found in a wide range of habitats including the bogs and acid grasslands found in a matrix with heathlands. All of these habitats have acid soils with a low capacity to buffer further reductions in pH and all are dominated by species typical of nutrient-poor habitats.

Substantial areas of the UK are under threat from acidification and eutrophication but detecting impacts of this threat at a site level is not easy. Upland areas in general are especially threatened by N due to the high rates of deposition and critical loads (the level below which there is assumed to be no measurable harm from the pollutant) being exceeded in most upland areas of the England (NEGTAP 2001). The current framework for Common Standards Monitoring (CSM), employed by the conservation agencies to address SSSI condition in the UK, does not assess impacts of air pollution making it very difficult to determine the impact that nitrogen deposition might have on individual sites of conservation importance.

CSM is used in the UK to provide data contributing to the assessment of the condition of designated features in sites of conservation importance as required under the ‘Conservation of Natural Habitats and of Wild Fauna and Flora Directive (92/43/EEC)’ or the ‘Habitats Directive’. CSM provides a basic framework to ensure consistent monitoring of site condition in the UK. For each interest feature a series of mandatory attributes are identified together with targets and a method of assessment. Targets are variable and may include those such as “no measurable decline in the area of the feature”, management impacts such as “no signs of burning or other disturbance” or the presence of positive site condition indicators and the absence of negative site condition indicators (JNCC 2004b).

This paper will report the findings of a project funded by the JNCC and Natural England to identify indicators of nitrogen deposition that could be incorporated into CSM guidance. For the full report see Stevens and others (2008). In order to monitor the impact of air pollution, indicators need to be identified that are sensitive to N deposition, robust and, for rapid assessments such as this, quick to assess and easy for non-specialist surveyors to use.

Evaluation of existing indicators in CSM guidance

Indicators taken from the list of existing indicator species in CSM guidance with potential for determining site condition in relation to N deposition are identified below. References are given for literature providing supporting evidence for their use as indicators. Positive site condition indicators could be described as indicators of lower levels of nitrogen deposition. Negative site condition indicators are indicators of higher levels of nitrogen deposition.

Heathlands

For heathlands (upland and lowland, wet and dry) there are 55 positive site condition indicators and 24 negative site condition indicators described in CSM guidance (JNCC 2004b,c). For all of these there was insufficient evidence in published literature to identify any clear indicators of

N deposition, but there were a few species that showed potential for use as indicators. Potential indicators for positive site condition (not impacted by N deposition) for heathlands are: *Racomitrium lanuginosum* (Pearce & van der Wal 2002, Pearce and others 2003) and *Drosera* spp. (Redbotorstensson 1994). Potential indicators for negative site condition in relation to N deposition are *Molinia caerulea* (Aerts and others 1990, Alonso and others 2001; Hartley & Mitchell 2005) and *Nardus stricta* (Leith and others 1999).

Bogs

For bogs (upland and lowland) there are 32 positive site condition indicators and 13 negative site condition indicators described in CSM guidance (JNCC 2004b). Potential positive site condition indicators for bogs are: *Calluna vulgaris* (eg Heil & Diemont 1983, Caporn and others 2000, Brunsting & Heil 1985), *Drosera* spp. (Redbotorstensson 1994), *Racomitrium lanuginosum* (Pearce & van der Wal 2002, Pearce and others 2003), and *Sphagnum capillifolium* (Carfrae and others 2007). *Urtica dioica* (Hogg and others 1995) was identified as a potential negative site condition indicator for N deposition; however other sources of eutrophication would need to be ruled out. As with heathlands above there is no conclusive evidence for any of these species and further research is needed to determine their value as indicators

Acid grassland

For acid grassland (upland and lowland) there are 42 positive site condition indicators and 22 negative site condition indicators described in CSM guidance (JNCC 2004a,c). Potential positive site condition indicators for acid grasslands are: *Calluna vulgaris* (eg Heil & Diemont 1983, Caporn and others 2000, Brunsting & Heil 1985), *Campanula rotundifolia* (Stevens and others 2004), *Galium verum* (van den Berg and others 2005) and *Lotus corniculatus* (Stevens and others 2004). A potential negative site condition indicator in relation to N deposition for acid grasslands is *Deschampsia flexuosa* (Alonso and others 2001; Hartley & Mitchell 2005). For all of the habitats investigated there was insufficient evidence to identify indicators of nitrogen deposition from those listed in CSM guidance so further indicators that could potentially be incorporated into CSM were investigated.

New indicators

Heathlands

To identify potential species indicators of N deposition we have focused on upland and lowland dry heath. These have been studied in depth through long term N addition experiments since 1989 on an upland heather moor near Ruabon, North Wales (eg Carroll and others 1999, Pilkington and others 2007) and since 1996 at a lowland dry heath near Little Budworth in Cheshire (Wilson 2003; Caporn and others 2007). In the case of the upland dry heath, these studies were supported by field surveys of vegetation and plant-soil biogeochemistry along gradients of N pollution in north-west Britain in 2005 and 2006 (Edmondson 2007; Caporn and others 2007).

The experiments at Ruabon have not generated higher plant species indicators of eutrophication. The failure of grasses (eg *Deschampsia flexuosa*) or other herbaceous vegetation to establish in N-treated plots (up to 120 kg N ha^{-1} yr^{-1} for as long as 19 years) suggests that this is not a suitable indicator of high deposition or negative site condition with regards to N deposition.

Within a few years of starting the experiment at Ruabon, it was clear that while the abundance of vascular plants was relatively insensitive to N, the lichen and bryophyte flora in general was negatively affected by N additions (Carroll and others 1999). After 11 years lichens were most sensitive, responding adversely to additions of just 10 kg N ha^{-1} yr^{-1} (Pilkington and others 2007). This investigation also highlights the crucial influence of timing of monitoring during the development of the *Calluna* stand and the potential influence of other nutrient limitations – such as phosphorus availability.

Further observations of the effects of N additions on bryophytes were made at Budworth Common by Wilson (2003), Ashmore (2004) and Ray (2007). All researchers found that *Hypnum jutlandicum* was dominant in all plots while other bryophytes and lichens appeared rarely. An N addition of 20 kg ha^{-1} yr^{-1} above ambient (approximately 20 kg ha^{-1} yr^{-1}) was optimal for the abundance of this moss, but higher loadings reducing its cover.

The N manipulation experiments and the regional surveys of comparable moorland habitat generated one clear outcome - that the overall abundance and diversity of mosses, liverworts and lichens are negatively affected by N pollution. The lichen genus *Cladonia* (notably *C. portentosa*) and the moss *Hylocomium splendens* emerged from the regional survey along with supporting research as candidates for positive site condition indicators i.e. negative indicators of N pollution) for upland heathland. As well as *H. splendens*, another moss appearing to be pollution sensitive from the regional survey was *Dicranum scoparium*. However, neither of these mosses were confirmed as sensitive in the Ruabon experiment because *H. splendens* was not present at the site and *D. scoparium* showed no consistent responses to N treatments (apart from a decline only at the highest addition rate) (Edmondson 2007). Further survey work in a wider range of heathland types and management regimes is recommended to substantiate these species relationships with N pollution.

The frequency of potential indicator species in the survey sites was examined in relation to the estimates of N pollution to evaluate whether it provided a better indicator than presence or absence. Three species were found, to varying extents, across the entire range of N deposition. The other, the moss *H. splendens*, was only recorded consistently at low deposition sites in Scotland (Carroll & Caporn, unpublished).

The abundance of the mosses was recorded as frequency at each site and correlations with N pollution were calculated. Rate of N deposition was strongly negatively correlated with frequency of *H. splendens*, and less well correlated with *D. scoparium* and *H. jutlandicum*.

Bogs

The Countryside Survey of Great Britain (Smart and others 2003) was used to look for positive and negative site condition indicators of N deposition in bogs. This is a nationwide survey of 1 km squares based on a stratified random sampling system where the stratification is by landclass (a combination of soils, geology, OS data, climate). Within the 1 km squares all of the habitats are mapped and a number of different plot types are sampled. The plots used in this investigation were 2 m x 2 m in size. To select bogs, plots were initially selected by broad habitat type as identified by the land-cover mapping carried out in each square, then a subset was selected which was classified to a bog community (M1-M4, M6, M15-M21, M25 as defined by the NVC) with a Jaccard coefficient of greater than 0.5. Species positively associated with rate of N deposition in this data set were the dwarf shrubs *Vaccinium oxycoccus*, *Vaccinium myrtillus* and *Empetrum nigrum*, the grasses *Agrostis canina* and *Deschampsia flexuosa*, the bryophyte *Polytrichum commune*, the forb *Galium saxatile* and the rush *Juncus effusus*. Log cover for these species was plotted against N deposition. There were significant positive relationships between log cover of *Molinia caerulea* (r^2=0.11, p<0.001), *Vaccinium myrtillus* (r^2=0.32, p<0.001) and *Polytrichum commune* (r^2=0.4, p<0.05) and N deposition. Negative associations with N were found for the lichen *Cladonia arbuscula*, the bryophytes *Pleurozia purpurea*, *Hylocomium splendens* and *Rhytidiadelphus squarrosus*, and the forbs *Drosera intermedia*, *Pinguicula vulgaris*, *Polygala serpyllifolia*, *Succisa pratensis*, *Pedicularis sylvatica* and *Dactylorhiza maculata*.

Species richness was the strongest signal in the data and showed a negative relationship with nitrogen deposition (p<0.001). The r^2 value was low (0.08) but the data are extremely variable with a long N deposition gradient. When broken down into six functional groups (i.e. forbs, mosses, grasses, woody species, sedges or monocots), there was no significant relationships between group richness and N deposition. There was a significant relationship in the Countryside Survey data between the grass:forb ratio and N deposition rate in bogs and log cover of grass and forbs (r^2 = 0.06, p < 0.001).

Acid grassland

In order to identify potential positive and negative site condition indicators of N deposition in acid grassland we used three different data sets. The data were analysed independently using Canonical Correspondence Analysis (ter Braak & Smilauer 2002) because different collection methods meant that they were not directly comparable. The results of the different surveys were then compared in order to identify robust indicators.

The first data used were from a survey of 68 U4 grassland sites (Stevens 2004; Stevens and others 2004; Stevens and others 2006). This data set encompasses both upland and lowland U4 grasslands throughout England, Scotland and Wales. The second data set used was restricted to lowland acid grasslands in Wales covering the communities U1, U2, U3 and U4 (CCW 2004). 905 2 m x 2 m quadrats collected between 1988 and 2004 were included in the analysis. The third data set was taken from the Countryside Survey of Great Britain (Smart and others 2003). To select acid grassland, plots were initially selected by broad habitat type as identified by the land-cover mapping carried out in each square, then within this a subset was selected that were classified to an acid grassland NVC category with a Jaccard coefficient of greater than 0.5.

Two potential indicators were identified that were consistently associated with low deposition: *Campanula rotundifolia* and *Euphrasia officinalis*. *Hypnum cupressiforme* agg. and *Carex panicea* were identified as indicators for high N deposition, but all these species occur across the range of deposition so presence or absence is not sufficient to record response to N deposition.

The strongest trend between species variables and N deposition was with species richness (mean of five 2 m x 2 m quadrats placed randomly within 1 ha). Regression analysis showed a statistically significant negative correlation between N deposition and species richness (r^2=0.52; $p<0.01$) (Stevens and others 2004). Although species richness would appear to be a good indicator of N deposition, there are some drawbacks. Species richness is also governed by many different factors (including management), so care would need to be taken in interpreting the data. It is also time consuming to measure species richness and requires a trained botanist. This may make it prohibitively time consuming or costly for incorporation into CSM.

Grass:forb ratio showed a significant positive relationship ($p<0.05$) with N deposition in both the Stevens and Countryside Survey datasets (the CCW data set did not have sufficiently detailed species cover data to apply this analysis). This relationship shows that at the highest rates of N deposition, the grass:forb ratio tends to increase suddenly indicating that this may be an indicator of the sites most severely affected by N deposition. Although there is a less clear trend in the Countryside Survey data the levels of the grass:forb ratios are similar between the two data sets. In both data sets a grass:forb ratio of above 5 could be taken as indicative of higher levels of N deposition. The grass:forb ratios may vary considerably over a site and several estimates would need to be made: it will also vary with time of year and should only be estimated during the summer as this is when these baseline data were gathered. Using a graminoid:forb ratio is easier to assess and gave very similar results.

Discussion and Conclusions

By answering several key questions regarding the current and past management of the site, the presence of local N sources and critical load exceedance, signs of nutrient enrichment can be attributed to N deposition with a much greater degree of certainty than would be possible using the indicators alone. Changes in management are a particular concern and may lead to similar changes in vegetation composition to N enrichment by deposition. Although these types of questions are not currently incorporated into the CSM assessment, all the information should be easy to determine from a site visit and looking at a management plan.

We recommend that the indicators outlined in Table 1 should be tested further for their suitability for incorporation into CSM. These are all indicators that we believe have the potential to detect the impact of N deposition on individual sites.

Table 1 Suggested indicators of N deposition for incorporation into CSM guidance.

Attribute	Target	Method of assessment / Comments
Heathland	The combined frequency of *Hylocomium splendens* and *Dicranum scoparium* should be more than 0.5	Target assessed against presence or absence in five randomly placed 0.25m^2 areas to give a combined frequency score. This indicator was found for upland dry heath; other combinations of bryophyte species may be equally valuable depending on the heath type.
Bogs	Presence of positive site condition indicator species	The presence of three of the following seven species indicates positive site condition: *Drosera rotundifolia* *D. intermedia* *Pinguicula vulgaris* *Polygala serpyllifolia* *Dactylorhiza maculata* *Pedicularis sylvatica* *Hylocomium splendens*
	Less than 5% of vegetation cover should consist of either *Vaccinium myrtillus* or *Polytrichum commune*	Target assessed against visual estimate of % cover at a 4m^2 scale. Five estimates should be made spread throughout the site and an average values estimated for the site.
Acid grassland	Graminoid:forb ratio should be less than 5	Target assessed against visual estimate of % cover for graminoids (grasses, sedges and small rushes, such as *Luzula* spp.) and forb at a 4m^2 scale. Graminoid cover should then be divided by forb cover. Five estimates should be made spread throughout the site and an average values estimated for the site.

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9 Bearing soil and archaeological interests in mind when restoring heathlands – a proposed good practice guidance

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Summary

Most people are aware of the biological and landscape importance of lowland heathlands in the UK and in other western Europe countries. However, the same people may not be aware of two important facts: (1) Heathlands occur in soils that sometimes have not been disturbed for centuries. They are therefore important in their own right, scientifically and for conservation, as they provide important functions such as carbon storage and nutrient recycling. (2) Due to the long historical association of heathland with human habitation, there are numerous archaeological remains in many heathland areas, some known and protected, but many still to be discovered.

Site managers have been restoring and re-creating lowland heathland in order to meet the Biodiversity Action Plan (BAP) targets for, at least, the last ten-fifteen years. However, soil conservation matters and the protection of archaeological remains has not always been in their minds when selecting the most appropriate technique for their objectives. Natural England published a report earlier this year (Hawley and others 2008) describing the most commonly used techniques and the potential impacts. The final section is a proposal for a best practice guidance.

Introduction

Lowland heathlands are landscapes of great importance in terms of biodiversity, for recreation and as tourist attraction. However they have also a significant cultural and historical value, as they were created and maintained by human intervention over centuries (Webb 1986).

Changing economic priorities led to significant changes in land use during the last century. This in turn resulted in losses between 50-90% of the extent of heathlands across Europe (Diemont and others 1996). In response, the UK government signed up to the Convention on Biological Diversity and produced Biodiversity Action Plans (BAPs), one of which deals specifically with lowland heathlands. The targets for the conservation of this habitat were revised recently and they currently stand as follows:

- T1. Maintain the current extent of lowland heathland in the UK;
- T2. Maintain the area which is currently in favourable condition;
- T3. Improve condition on those sites currently in unfavourable condition;
- T4. Increase the extent by 7,600 ha by 2015; and
- T5. Increase the number of patches >30 ha from 10% today to 50% by 2030.

The breakdown by country for the expansion target (T5) is: 208 ha in Scotland, 260 ha in Northern Ireland, 1,000 ha in Wales and 6,110 ha in England.

In order to deliver these ambitious targets many restoration and re-creation projects have taken place since the lowland heathland BAP was signed off, some involving drastic interventions which could potentially damage other interests, such as the soil conservation value and/or archaeological remains.

A project was set up in 2007 to define the importance of heathland soil features and their archaeological interest and the risk of damage through current restoration and re-creation practices. The first step was to provide an analysis of the existing scientific literature on the benefits and potential impacts on the soil characteristics and archaeology of various methods of soil preparation being used across Europe. They included methods for both heathland restoration and/or re-creation. Restoration was defined as management to improve the condition of existing heathland; re-creation implied a change in the land use, mostly from agriculture or forestry. The methods available to contemporary practitioners were categorised based upon the general broad similarity of methodologies and their perceived impact.

A questionnaire was also used to determine which practices had been used in the UK in the last 10 years and gather further information about the projects and their success in the view of their project managers. Twenty six returns were analysed. The size of the projects was 0.1 ha (removal of top soil after plantation) to 5,000 ha (including a mix of plantation, secondary growth, rhododendron dominated plots, arable land and areas which had been drained).

Under the First Soil Action Plan for England (Defra 2004), Natural England has to have regard to the proper management of soil alongside other requirements. However, the conservation and restoration of habitats such as heathlands, also supported and promoted by Natural England, involves widely-used techniques which could potentially pose a risk for the soil and the historic environment interest of soils.

Thus the main objective of this project, once all the information available was compiled, was to draft a 'best practice guidance' for practitioners to meet the BAP targets having considered all possible management options and their potential impacts.

Importance of heathland soils and potential for damage

Soils perform a number of essential functions, such as support for crops, forestry and ecosystems, as well as being a habitat is their own right, source of minerals or protection for the cultural heritage. They occupy a very important position interacting with the rocks, the atmosphere, the water cycle and the living organisms (Stace & Larwood 2006). Besides the above functions, they can offer researchers the opportunity to learn about past climates and life.

Heathland soils, in particular, are important because in many cases have not been significantly disturbed for centuries. They developed from brown woodland soils as a result of human intervention consisting in burning, cutting and grazing the existing aboveground vegetation (Webb 1986) but leaving the soils relatively untouched. The main changes these interventions brought were to decrease the nutrients in the soil. The resulting vegetation was one more open and adapted to this acidic and nutrient-poor situation. Heathlands are associated with podzol soils, in free draining areas, and stagnopodzols in waterlogged ones. They often exhibit distinctive horizonation (layers), which in some cases have persisted for millennia.

The presence of bare ground, or ground with little vegetation, is also an essential feature of the habitat of many rare heathland species. In fact a recent unpublished study indicates that of the 110 BAP species associated with heathland, about 56% require bare ground and early successional stages (J Webb pers. comm.).

Heathland soils can be destroyed when sealed through development (houses, roads) or when cultivated. Cultivation changes the soil physical characteristics, sometimes irreversibly, as ploughing will mix the different layers. Chemical changes are caused when (semi)natural soils receive fertilisers (increasing nutrient levels) and the acidity is reduced (eg by liming). But even when the soil profile is maintained, inappropriate management techniques associated with farming practices can damage it. For example, overgrazing and loss of the vegetation cover can lead to trampling resulting in erosion and soil loss (Britton and others 2005; Pakeman and others 2003).

Excessive trampling can also be caused by humans (Gallet & Rozé 2002). Other activities may cause indirect damage to heathland soils, such as pollution which results in acidification and nutrient enrichment (Power and others 1998).

Heathland soils in many cases contain remains of early human habitation such as flint tools (axes, arrows); burial monuments; defensive and domestic structures or implements; metalwork such as jewellery or coins (Wilkes & Hewitt 2002); or vestiges of earlier field systems or other land uses such as the cutting of sods (Karg 2008). If management, restoration or re-creation of heathland is carried out without due care, all these artefacts or remains can be damaged or destroyed.

Common heathland restoration and re-creation techniques

The destruction and abandonment of heathland has occurred all over Europe (Diemont and others 1996); but in many countries the last few decades have also seen a revived interest on this habitat and attempts to restore or re-create it. See for example, The Netherlands (Aerts and others 1995); Spain (Bartolomé and others 2005); France (Gallet & Rozé 2001); Germany (Keienburg & Prüter 2004); Norway (Kvamme and others 2004); Portugal (Leite 2004); Czech Republic (Sedlakova & Chytrì 1999); Denmark (Strange and others 2007); and the UK (Walker and others 2007).

A literature search was performed to find out the techniques most commonly used to prepare the soil to favour characteristic heathland vegetation in Europe during the last 10 years. They were classified into four categories:

- Surface vegetation management and removal techniques, usually for herbaceous vegetation or small shrubs (grazing, cutting, herbicide application and burning);
- Soil acidity and nutrient status amelioration techniques (cropping and acidification with sulphur, bracken/pine litter or peat);
- Surface and below-ground vegetation removal techniques, usually involving trees and shrubs, (pulling roots); and
- Soil disturbance and soil removal techniques (litter removal, surface disturbance, ploughing, inversion and rotovation).

Some of the methods have an impact only on the vegetation above ground (eg cutting or grazing). They are therefore more appropriate when archaeological remains are suspected, or there are no signs of earlier soil damage. At the other end of the scale, there are techniques based on significantly disturbing the soil, either by burying the richer top layers or removing them altogether; or by chemical intervention to change the pH and the nutrient levels. Removing the roots of trees and shrubs can also disturb the soils. In most cases these techniques are carried out in combination to improve or speed up the results.

Surface vegetation


Isabel Alonso, Natural England

Cutting the above ground vegetation is used to knock back the succession and as a mean to reduce nutrients (Britton and others 2000; Härdtle and others 2006), sometimes replacing grazing when it is not possible to use animals. However, used on its own cutting results in large patches of homogeneous vegetation structure. Cutting alone is unlikely to damage the soil or the historic environment remains.

Isabel Alonso, Natural England

Grazing creates a diverse vegetation structure and gaps in the vegetation cover (Bullock & Pakeman 1997; Lake and others 2001). Grazing can be an effective way of controlling the growth of trees or undesired species but in many cases some tree and scrub clearance is required before grazing can be introduced. Overgrazing and subsequent trampling and/or erosion could be detrimental for the soil or any archaeological remains. However, grazing with the right type and number of animals and for the appropriate period of time, can have a positive effect by reducing the damage of deep rooting vegetation to those remains.

Isabel Alonso, Natural England

Herbicide is generally applied to control bracken (Marrs and others 1998a), excessive grass (Ross and others 2000), tree cover (Marrs 1985) or undesirable species such as rhododendron (Edwards and others 2000). It is unlikely to cause damage to the soil, but this technique is rarely used in isolation.

Isabel Alonso, Natural England

Burning the aerial vegetation creates bare ground, rejuvenates the vegetation and removes nutrients from the soil (Mohamed and others 2007). It is commonly used as a precursor to grazing, since it results in a flush of young growth very attractive to grazing animals. In the UK there are regulations to burn appropriately (eg The Heather and Grass Burning Code and Regulations in England or the Muirburn Code in Scotland). However, if burning occurs in the wrong season (summer), usually by arson, it results in very destructive hot fires (Bullock & Webb 1995) for the vegetation and the wildlife that depends on it. There could be a risk of erosion and damage to the historic environment if the vegetation is completely removed by burning over large areas.

Soil amelioration

A method to reduce nutrient levels is **cropping** eg linseed, barley or other cereal over various seasons (Marrs and others 1998b). However, as this usually involves ploughing, there could be negative impacts on the soil conservation and archaeological interest. This technique is of limited value in sandy soils, where leaching will naturally deplete some nutrients (Walker and others 2004) whereas others such as phosphorous will require more drastic intervention (Walker and others 2007). The negative impact of ploughing could be minimised by direct drilling at reduced depth if the level of nutrients need to be reduced to allow successful heathland re-creation.

Much research has been done on **acidifying** ex-arable soils to make them more similar to those of remaining heathlands (eg Owen & Marrs 2001; Walker and others 2007). Bracken and pine chippings (Mitchell & Hare 1999; Owen & Marrs 2001), sulphur (see eg Tibbett & Diaz 2005; Walker and others 2007); peat (Dunsford and others 1998) and litter and/or acidic soil addition (Pywell and others 1995) have all been used. Although these techniques do reduce the pH, in some cases the results are not permanent or may have unintended consequences, such as the release of toxic elements such as aluminium (de Graaf and others 1997) or damaging archaeological remains such as bones or shells. See below for specific problems with soil translocation when peat or other soil is used. Some researchers have also pointed out the fact that although the technique may produce a heather-dominated vegetation, other elements of the system, such as mycorrhiza may be negatively affected (Diaz and others 2006).

Sub-surface vegetation

Isabel Alonso, Natural England

Tree and scrub removal is a common method to revert succession to restore heathland (Box and others 1999; Pywell and others 2002). In many cases this implies mechanically or manually cutting the trees or shrubs, which should have little impact on underlying archaeology. In some instances it may be positive as the shallow roots of the heathers cause less damage than those of trees. However, some restoration projects involved pulling out the roots of trees or rhododendron, creating disturbance at a much larger scale and potentially more damaging.

Soil disturbance or removal

S. Lewis , Natural England

Soil disturbance is a widely used heathland restoration/re-creation practice (figure 1), alone or in combination with other soil preparation techniques. The techniques involved range from those of relatively low impact, such as removing only loose vegetation and litter (Allison & Ausden 2006), to those of higher impact including top soil removal (Allison & Ausden 2004) or even ploughing, rotovation or soil inversion (Pywell and others 1995; Snow & Marrs 1997). "Plaggen" or regular top soil removal is still commonly practised in The Netherlands and Germany to reduce nutrients (Niemeyer and others 2007; Vergeer and others 2004) although some negative effects in the soil chemistry have been detected (Dorland and others 2003). Both the removal and/or the translocation of peat or soil are potentially the most destructive methods for the soil conservation and the potential historic environment remains. Unless both the donor and the recipient sites are subjected to a proper historic environment evaluation before the process takes place, there is a risk of destroying historical artefacts which may have been protected by anaerobic conditions and muddling future understanding of the landscape history in the project area. In fact, importation of soil should only be considered when the donor site is going to be destroyed by development.

Top soil stripping or removing is also the most expensive method and creates other problems such as dealing with the surplus soil (the top 25 cm of soil from 1 ha is likely to weigh between three and four thousand tonnes). It is also illegal to dispose of such material on scheduled sites as it may obscure some features.

In the questionnaire to project managers done for this study soil removal was the most popular technique (11 projects included it). The depth of soil removed varied from 8 cm to 40 cm. This technique was also commonly use in combination with other chemical or physical interventions. Figure 1 shows the extent of use of the above techniques in the UK as shown by the responses of project managers (n=26) to the questionnaire.

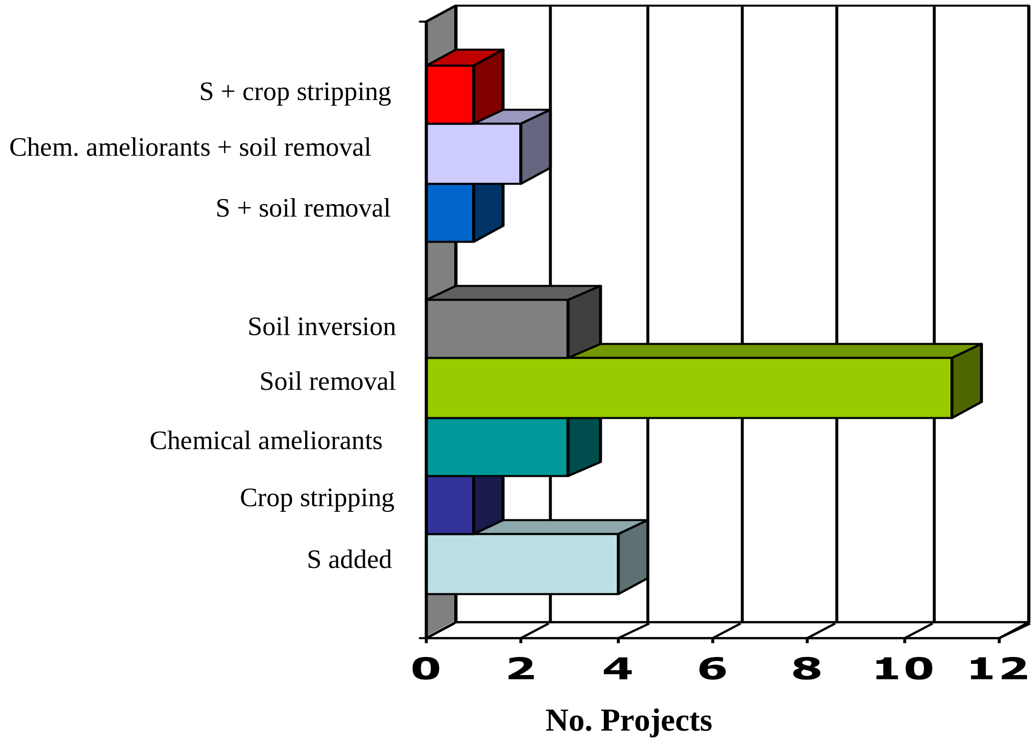

Figure 1 Ground preparation techniques: on top techniques used in combination. (S = sulphur)

Discussion

The literature review and the questionnaire responses showed that there is a diversity of methods available to heathland managers when considering improving the condition of their sites or increasing their extent. The options will depend on the original situation and the resources available. However, it is advisable to consider carefully the implications of the choices and consult with the appropriate experts for further support. Otherwise, valuable soil features, functions or the historical environment remains that it may contain could be damaged.

In soils confirmed as having particular scientific or conservation value, or any historical environment interest, non-disturbance methods are the only option to avoid causing irreversible damage to these features. Methods such as cutting the above ground vegetation, burning, or targeted herbicide application can be successful in restoring former heathland (Härdtle and others 2006; Mohamed and others 2007). When there is archaeological interest in conifer plantations or secondary woodland, the use of methods that do not cause major disturbance, such as manual cutting, shallow rotovation or burning followed by grazing, has been proven to produce good results.

The re-creation of heathland on former arable land can be problematic and expensive owing to the presence of soils with a high nutrient concentration and elevated pH (Walker and others 2004). The removal of soil or deep ploughing that might be necessary could compromise any archaeology that might have survived the previous agricultural processes and adversely impact on soil functions. In addition, any acidification of the soil using elemental sulphur in particular, could affect soil processes and archaeological preservation. The effectiveness of these methods in successfully re-creating heathland can be limited where soil nutrients need to be reduced quickly to meet short term targets. It may be then unpractical or undesirable to consider heathland re-creation on arable land, especially if archaeological interest is suspected.

The questionnaire results suggested that nearly two thirds of heathland restoration practitioners who responded were aware of the need to protect any archaeological interest. However, project management practice did not always incorporate a full archaeological assessment, which could inform the restoration approach or gave the same regard to the intrinsic scientific, and nature conservation and sustainability value of soils.

Acidic podzol soils and heathland seed banks are able to survive in the long-term under conifer plantations (Mitchell and others 1998; Walker and others 2004). Therefore, natural regeneration, keeping undesirable species in check, could be the most practical and cost-effective target for restoring or re-creating lowland *Calluna* heathland. The timber crop, when present, could be sold in some cases to offset costs of restoration, and there should be no need to dispose of large volumes of soil. In addition there would be little need to improve the soils. This option is likely to be the less damaging for both soil and the historic environment. However, it is rarely the preferred option, as projects are usually driven by policy agreements or short term funding.

Natural England is developing a 'best practice guidance' for the protection of soils and archaeological interest when restoring or re-creating heathlands. This guidance was outlined in Hawley and others (2008). In summary (figure 2) it will advise the following:

- Carry out a desktop study to establish the former land use: this can be done consulting archives, maps, photographs and talking to owners, managers or neighbours;
- Thoroughly survey the site, taking samples where appropriate to determine the initial condition (soil characteristics and potential historical environment remains) involving relevant experts;
- Evaluate the potential impact of the intervention versus the current value of the soils (bio/geodiversity), the potential presence of archaeological remains and the value of the habitat to be restored;
- Apply the most appropriate techniques to reduce soil disturbance and increase the likelihood of success;
- Monitor the project progress regularly, record difficulties or problems and share with other interested parties.

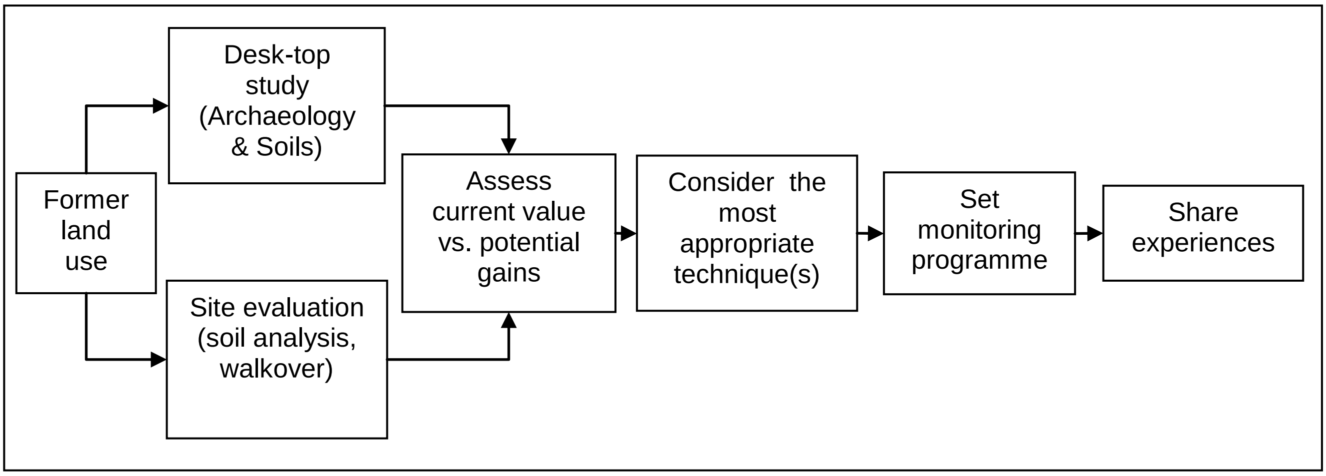

Figure 2 Outline of the best practice guidance for the restoration and re-creation of heathland projects.

The guidance (Alonso 2009) has links to relevant sources of help and information for each step and we hope it will be widely used by managers before embarking in future restoration and re-creation projects.

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10 Understanding the links between housing development, access levels and disturbance to birds

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Summary

Housing projections for many heathland areas (and their surroundings) in southern England are such that dramatic increases in the amount of development are likely over the next 20 years. New housing results in a redistribution of where people live and an increase in the local population.

For some key bird species, such as stone curlews and nightjars, there is evidence for an avoidance of sites or areas with high levels of surrounding housing. Such work has clear implications for future planning relating to European Protected Sites.

Understanding the impacts of housing, and in particular the complex links between housing and where people go in the countryside, is important to guide strategic planning and potential mitigation. Using visitor survey data it is possible to predict where people go, how visitor rates may change in the future and to draw comparisons between different heathland areas. In the New Forest such modelling highlights a projected increase in visitor numbers of over a million people per annum over the next twenty years. In Dorset it is the sites within the urban conurbations of Poole and Bournemouth that will see the most change. Visitor data can also be used to explain the spatial distribution of key bird species, highlighting the impacts of the current levels of access and the potential impacts of further increases in recreational use.

Introduction

The UK population is projected to rise from the current levels of 61 million to around 71 million by 2031[6] and there is continued and increasing pressure for new development, especially in southern England. Many heathland areas are already close to large urban conurbations and for many heaths the volume of housing surrounding them is likely to increase. For example, in Dorset c.41,000 houses are proposed to be built within the south-east Dorset sub-region (which contains the Dorset Heaths) by 2026[7]; in the Thames Basin Heaths area 48,000 new homes are planned in the same period.

There is a suite of particular urban impacts associated with heaths in an urban environment (see Haskins 2000; Liley and others 2006b; Underhill-Day 2005 for reviews). These impacts include disturbance, increases in the numbers of predators such as cats and foxes, dog-fouling, trampling, increased fire incidence, erosion and path damage from horse riding, mountain bikes, trail bikes etc.

The international importance of many lowland heaths sites is recognised through their inclusion in the Natura 2000 network of European Protected Sites, designations that carry a high level of protection, transposed into UK law through the Habitats Regulations. New development close to or likely to affect a European Protected Site should be subject to Appropriate Assessment. This is a strict test and for a development to be able to proceed it must be demonstrated that it will have no adverse effect on the integrity of the Protected Sites, or in exceptional circumstances, that the development is

[6] Office for National Statistics principal/central projection in 2006
[7] http://www.southwest-ra.gov.uk/

of over-riding public interest and no alternatives are available. Conserving the quality of the heaths, while allowing the growth in housing and local population has become a key challenge and objective at all levels of local and regional government.

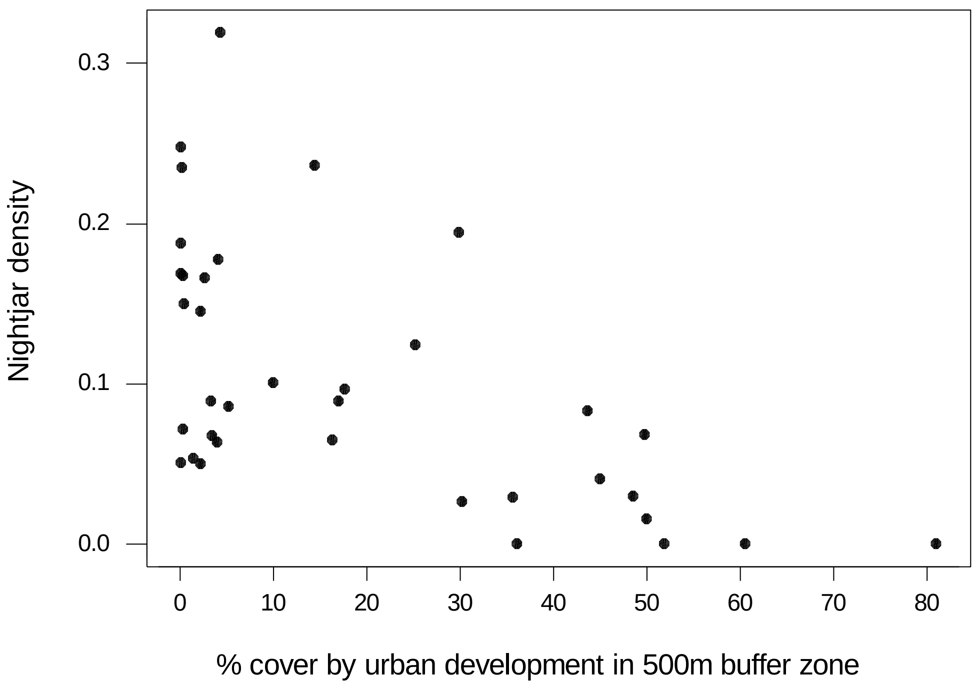
In order to achieve this sustainable growth a clear understanding is needed of how new development can impact on adjacent heaths. For many of the urban impacts there is a reasonable understanding of the baseline ecology. For example there is now a body of research on the effects of human disturbance to nightjar, woodlark and Dartford warbler, showing behavioural responses to disturbance, impacts on breeding success and even population consequences of disturbance (Langston and others 2007a; Langston and others 2007b; Mallord and others 2006; Mallord and others 2007; Murison and others 2007). None of these studies do actually address how changes in housing may actually impact the birds. In order to ensure sustainable housing growth it is necessary to understand the distances at which new housing may have impacts, how housing levels relate to visitor access patterns and what mitigation measures might be successful.

In this paper we address these issues, with the focus on Annex I birds. We draw on a range of recent studies involving work relating to the Brecks, the New Forest, The Thames Basin Heaths and the Dorset Heaths. We describe studies that directly link housing to Annex I bird species, and we also present work that explores the interaction between housing and visitor numbers and the consequences for birds.

Direct relationships between bird distributions and housing

There are a few different studies that directly relate the bird density to housing. Initial work on nightjars in Dorset (Liley & Clarke 2003) used data from the 1992 national nightjar survey and explored the impact of development (using either the area of housing mapped using aerial photographs or the actual number of residential properties extracted from postcode databases). The amount of developed land at different distances from the heath and the actual number of residential properties were all found to be highly correlated with each other and to show a strong negative relationship with the density of nightjars present on a heath (e.g. Figure 1) , regardless of the size of the heath. The amount of woodland (the preferred foraging habitat) surrounding each patch (within 500 m of the patch boundary) was also a significant predictor of nightjar numbers. When used together, the extent of woodland and developed land both gave significant improvements to predictions of nightjar density. These results indicate that the number of nightjars present on a heathland site is influenced by the surrounding land use and that the effect of urban development is more than simply the loss of off-site foraging habitat.

Figure 1 Density of nightjars (birds/ha) on Dorset Heaths (from 1992 national survey) and % cover of developed land (housing) within 500 m of the site boundary. From Liley & Clarke (2003)



A similar pattern was subsequently found on both the Thames Basin Heaths and the Dorset Heaths (Liley and others 2006a), using data from the most recent national nightjar survey, in 2004. Testing the relationship between housing and nightjar numbers in a variety of ways, negative correlations were found between nightjar numbers and housing at distances up to at least 5km away from the patch boundary. As the amount of housing in different bands was highly correlated it was impossible to attribute the effect to a specific distance band.

Stone curlews are another Annex I bird species associated with lowland heathland and, in Breckland, also occurring on farmland. In the work on nightjars we used the site boundaries of different heaths and used buffers going away from the site boundary in order to look at the effects of development. For stone curlews, occurring at low densities across a large area of farmland in the Brecks, a different approach was necessary. Within a GIS we mapped all settlements and housing across the Breckland area and then drew buffers around these built up areas (Sharp and others 2008a). Using RSPB data from stone curlew nest surveys (1988 – 2006) we calculated the number of nests at different distance bands from housing. Mean nest density (on suitable soils) showed a positive relationship with distance from settlements, with nest density increasing in successive distance bands up to 2500 m from settlement boundaries. Within every single year from 1988 to 2006, the stone curlew nest density (per ha of suitable arable land) was significantly lower on land within 0-500 m of the nearest settlement than in successive distance bands. Annual nest densities on arable land 500-1000 m from settlements were also lower than densities at subsequent distance bands in 14 of the 18 years over the period 1988-2006. This consistency across the whole study period provides strong long-term evidence of some negative impacts or association of housing on stone curlews densities on arable land and the implication is that new development may need to be at least 1500 m from farmland that supports stone curlews.

The strong avoidance of built-up areas by nesting stone curlews is interesting because there is little or no public access to farmland (unlike the heaths, where foot access is largely unrestricted on most sites). This suggests that it is not necessarily human presence (and therefore disturbance) in the landscape surrounding the houses that is underlying the avoidance of housing by stone curlew.

Housing and access levels

More people visiting a site is likely to mean more potential for disturbance to birds present on that site. The extent to which the spatial distribution and volume of housing determines visitor rates to a heath is therefore a critical link in our understanding. There have now been a wide variety of visitor surveys commissioned on heaths in southern England (see Underhill-Day & Liley 2007 for review), these include surveys sampling access points across whole SPAs (Clarke and others 2006; Liley and others 2006c) and some very comprehensive work in the New Forest National Park (Tourism South East Research Services and Geoff Broom Associates 2005).

The majority of visitors to urban and suburban heaths visit sites regularly and dog walking is one of the main reasons people visit. Visits are typically short, with the typical dog walk involving a route of around 2.1 km (eg Figure 2). Most visitors are local to the heaths. The data from the Dorset Heaths and Thames Basin Heaths surveys (see Table 1 and Figure 3) indicates that virtually all foot visitors come from within around 2 km and that between 62% (Thames Basin Heaths) and 72% (Dorset Heaths) of the car drivers had come from within 5 km. Such information provides an indication of the ‘draw’ of heathland sites, and the distance at which new housing may result in a change in visitor numbers to a heath.

Table 1 Percentage of people (adults only) travelling different distances to reach the heaths, from the respective visitor surveys (see Clarke and others 2006; Liley and others 2006c)

	Distance (m)						
	400	1000	2000	3000	4000	5000	10,000
TBH car visitors	1	7	28	39	51	62	80
TBH foot visitors	42	80	97	98	99	100	100
Dorset car visitors	2	8	26	39	52	72	98
Dorset foot visitors	1	85	88	92	93	94	98

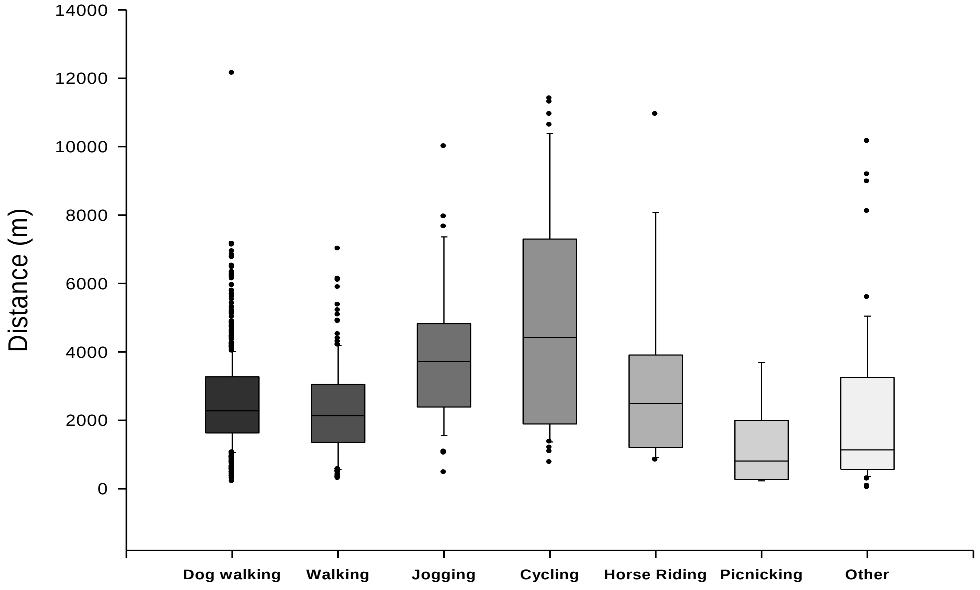


Figure 2 Length of route taken by different types of visitors to Thames Basin Heaths. Figure from Liley and others (2006c). Box plot shows median (horizontal line); 25th and 75th percentile (grey box); upper and lower limits of the data (whiskers) and outliers (asterisks). Data from 1099 interviews where at 26 different access points. Sample sizes for the different groups range from 772 (dog walkers) to 9 (picnicking)

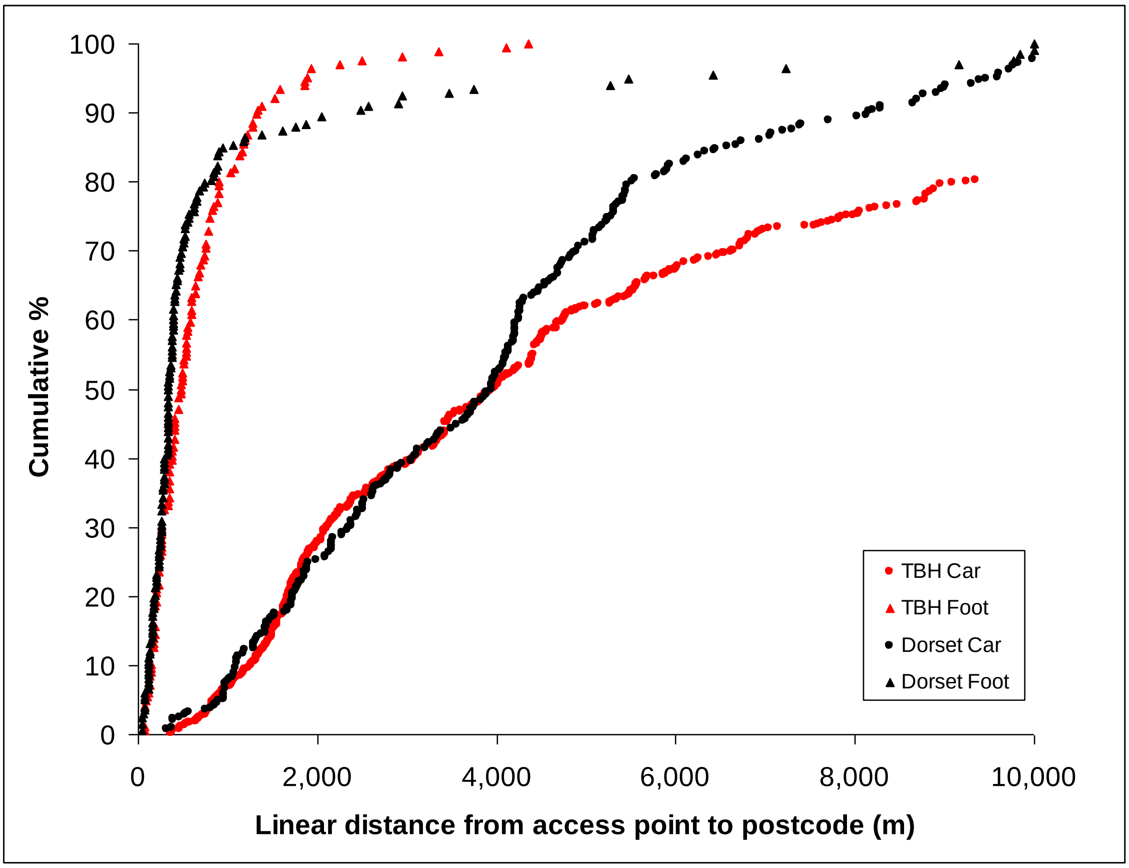


Figure 3 Distribution of the distances (in meters) travelled to heath access points by car/van (circles) and on foot (triangles). Data accounts for group size (number of adults) in each party interviewed. Data are from the two visitor surveys on the respective SPAs (see Clarke and others 2006; Liley and others 2006c).

For well-known sites the 'draw' of the sites may well be over a considerably larger area and there may be a complex mix of different types of visitors. In the New Forest, 40% of visitors are staying tourists, a further 25 % are day-trippers, coming from beyond 5 miles, and locals (living within 5 miles) account for 35% of visitors (Tourism South East Research Services and Geoff Broom Associates 2005). As a consequence of this range of visitor types, the New Forest receives a high total volume of visitors (current estimates are over 13 million visitor days per year). Most of these people tend to visit infrequently, in larger groups and, compared with Dorset and the Thames Basin Heaths, they are less likely to be visiting to walk their dog. Visitor numbers peak in the summer and the tourists tend to be attracted to particular honey-pot sites, whereas local visitors tend to chose locations away from the tourist hot spots.

With an understanding of how many visits per household are made from housing at different distances from heath sites it is possible to make predictions about how changes in the amount of housing may result in changes in the number of heath visitors. Such an approach was used by Footprint Ecology / CEH for the Dorset Heaths, to explore the effect of the new housing proposed in Dorset for the period until 2026 (Liley and others 2006b). This work suggested that visitor levels to the heaths may increase by a total of 13%. There was considerable variation between sites however, and increases of 30% were predicted for some sites.

We have also used visitor data from the New Forest to predict how visitor numbers might change as the amount of housing increases (Sharp and others 2008b). Current housing densities in the areas surrounding the New Forest are high to the east of the National Park (Southampton) and to the west (Bournemouth and Poole), with a notable peak around 8 km. Densities are lower to the north (Salisbury). Taking current estimates of future housing, the greatest percentage change will be to the north of the National Park, but the largest actual numbers of new housing will be to both the east and the west.

The existing visitor survey data (c.3800 interviews giving home postcodes of people visiting the National Park) shows that the likelihood that someone living outside the National Park will visit the park declines with distance – i.e. people living further away are less likely to visit. Assuming that the distribution of new housing will be in proportion to the existing housing distribution, using a standard occupancy rate for all new housing and assuming that the proportion of residents (at a given distance from the National Park boundary) that visit the National Park will remain the same, we estimate that housing development in the period 2006-2026 within 50 km of the New Forest will result in an additional 1.05 million person visits per annum. Much of these additional visits will be as a result of development relatively close to the National Park boundary, with an estimated 764,000 of this total coming from within 10 km of the boundary.

Relating Visitor Levels to the Annex I Birds

There is work showing the effect of disturbance on species such as nightjar, woodlark and Dartford warbler. For example, nightjar breeding success is lower for birds nesting on urban heaths and for nests close to footpaths (Murison 2002), woodlarks nest at lower densities in otherwise suitable habitat subject to high levels of access (Mallord and others 2006) and Dartford warblers in certain habitats nest later and raise fewer chicks where lots of people walk through the territory (Murison 2007). Such studies give an indication of visitor rates whereby an impact is apparent. For woodlarks, Mallord and others (2006) suggest a rate of eight people per hour (in otherwise suitable habitat), is necessary for the probability of birds to settle to be reduced to 50%. For the Dartford warblers studied by Murison (2007), thirteen people per hour walking through heather dominated territories was the suggested level at which breeding was sufficiently delayed that fewer broods were raised per pair.

It is of course difficult to relate such levels of access to different sites. The distribution of people within a site will depend on the terrain, the size of the site, the distribution of paths and the distribution of access points, as well as how far people actually walk. In the visitor studies of the Dorset Heaths (Clarke and others 2006) and the Thames Basin Heaths (Liley and others 2006c) the extent to which visitors 'penetrated' the site was determined by calculating the mid-point of people's routes, and determining how far (the straight-line distance) this point was from the access point. This distance essentially represents how far people stray from a car-park or similar access point before returning back to their start point and was around 700m for a typical dog walk (median = 712m for Thames Basin Heaths, 698m for the Dorset Heaths).

We used these penetration distances, combined with predictions of visitor rates for different access points, to create predictive maps showing the distribution of people within heathland sites across the Dorset and Thames Basin Heaths. We used these maps, in combination with maps of broad habitat categories, to explore the spatial distribution of nightjars within sites. We found that nightjar territories, especially within the Thames Basin Heaths, were consistently found in those areas of sites with the lowest levels of disturbance.

Minimising the Impacts of New Housing

The work outlined above provides some evidence for the kind of approaches that may work as mitigation to avoid or minimise the impacts of new housing. For example the travel distances give an indication of the distances at which new housing may have an impact on a heathland site and therefore the distances at which development control may be required.

There are of course a wide range of different factors besides simply the volume and spatial distribution of housing that will determine visitor numbers to sites, and then a range of measures that will influence how much impact those visitors have on the site (Figure 4). The suitability and applicability of different measures at different sites will vary.

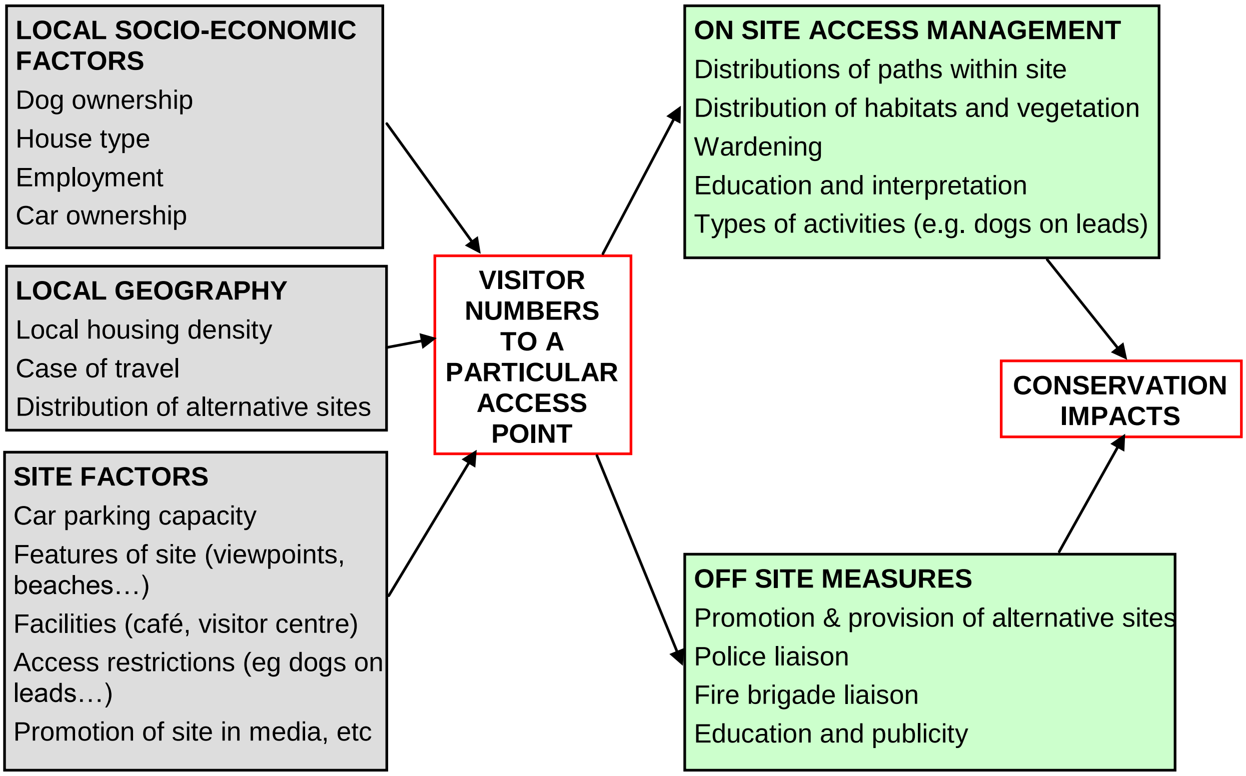


Figure 4 Summary of different factors influencing visitor numbers and their impacts to heathland sites

A household survey, sent to 5000 addresses at random in south-east Dorset, was used as a means of understanding how people choose particular sites, what influenced their choice and therefore what mitigation measures may be effective (for more information see Clarke and others 2008; Liley and others 2008). The survey asked about visits to different kinds of sites and therefore placed visits to heaths in context with other types of site such as parks or the coast.

Heaths appeared to attract people from greater distances than other types of habitat apart from coastal sites and heaths seemed to particularly attract dog walkers. In general, attractive scenery, the ability to do a range of walks and parking (low cost and availability) were key features attracting people to particular sites while parking (cost and difficulty), lack of attractiveness, too many other people, not feeling safe and long travel time from home were the most frequently cited negative reasons that detracted people from choosing particular sites. Regular heath visitors (i.e. visiting weekly or more frequently) were more likely to cite the ability to do a range of walks and in particular the ability to let their dog off a lead as important attractive features when compared to those who only visited heaths irregularly or not at all.

The presence, or amount, of some types of other habitats (such as coastal sites) close to a household was, on average, associated with fewer visits to heaths, suggesting that some types of sites may 'deflect' people that would otherwise visit a heath. Most non-heath and non-coastal sites were categorised as 'other greenspace' – a category which included parks, commons, woods, riversides etc. When large areas of such sites were present close to a household there was no evidence that households visited heaths any less. This would imply that visitors to heaths do positively choose heaths for a particular experience and alternative sites may need to be carefully designed and targeted if they are to deflect visitors that would otherwise choose the heaths.

Final thoughts

We have drawn on a series of studies to highlight some of the links between housing, access levels and Annex I bird species. We bring together ecological studies and socio-economic work on visitor access patterns to highlight the very real issues and thorny problems relating to new housing and visitor impacts to European Protected heathlands. The work we have presented has been largely commissioned by local authorities and Natural England and in most areas comprehensive monitoring schemes are being implemented to track change and determine the effectiveness of mitigation measures that have been put in place.

There is still a need for further work to look at the attractiveness of sites and how attractiveness influences people's choice of where to go. Heaths vary widely in the type of experience they offer for visitors and there may therefore be a need for different mitigation measures in different areas. The effectiveness of alternative sites as a form of mitigation needs testing and there is a need for predictive models to test different scenarios of new housing and green infrastructure provision.

Acknowledgements

We have drawn on a range of different studies and pieces of work. The Stone Curlew work was funded by Breckland District Council. The visitor surveys in the Dorset Heaths and Thames Basin Heaths were funded by the then English Nature. The New Forest work was funded by the Forestry Commission, New Forest District Council, Natural England and the New Forest National Park Authority; the visitor data relating to the New Forest was provided by the Forestry Commission and was collected as part of the Progress Project. The Dorset Household survey was funded through a consortium of local authorities within south-east Dorset. We are grateful to the following people for commissioning Footprint Ecology and for their comment, advice and permission to replicate the various pieces of work: Ian Barker (New Forest National Park Authority); Nigel Jacobs (Poole Borough Council); Andrea Long (Breckland District Council); Andrew Nicholson (Natural England); Phil Sterling (Dorset County Council).

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11 The Thames Basin Heaths SPA - finding space for people and birds

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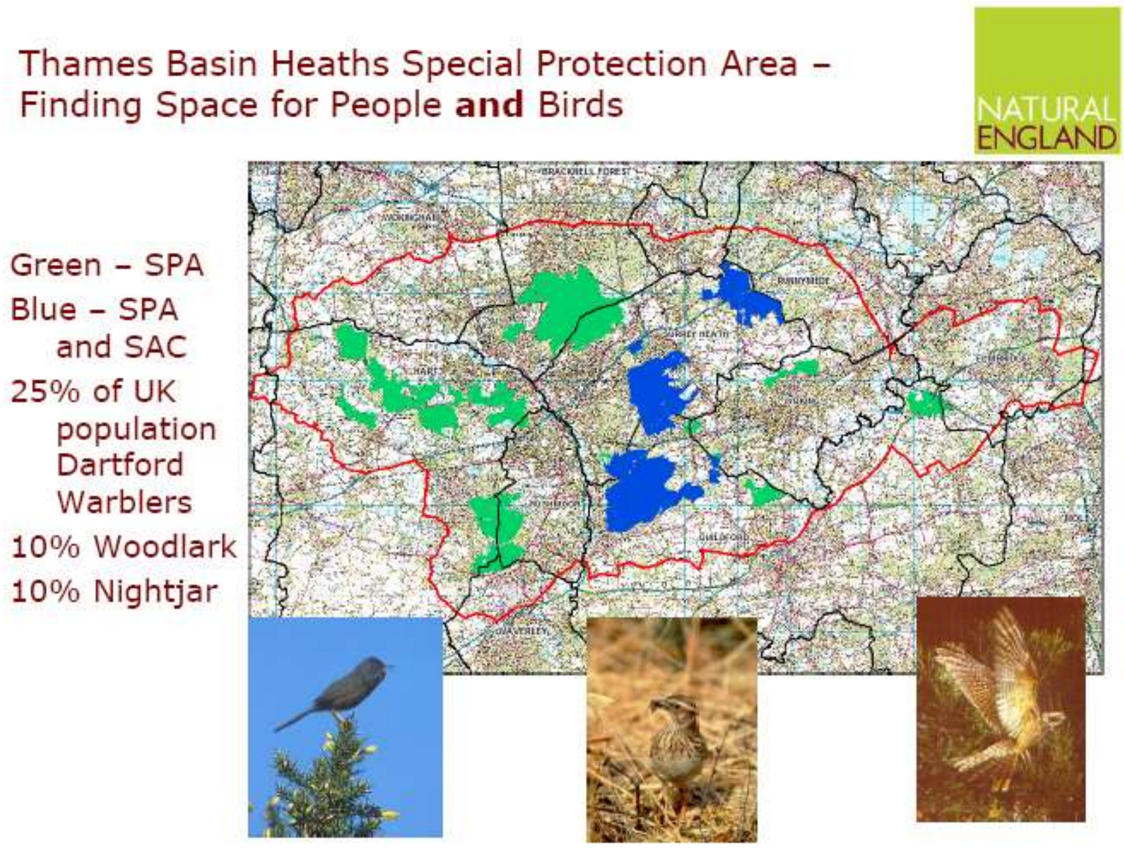
Summary

Following the classification of the Thames Basin Heaths as a Special Protection Area (SPA) in 2005, English Nature instigated a project to address the increasing problems of disturbance from the local human population on the protected ground nesting birds namely; nightjar, woodlark and Dartford warbler. This resulted in objections to all residential planning permissions around the SPA unless improved facilities of open space for local people were provided as an alternative. The project for Natural England has since moved on to consider the needs of the human population. As a result, SPA avoidance strategies have been created by 10 of the 11 local authorities in the area so far and more than 3000 permissions were given in 2007 each with an additional financial contribution to the chosen open spaces. In a densely populated area around the SPA including the towns of Guildford, Bracknell, Woking and Aldershot, the need for places to walk in, often with their dogs, is essential. Finding these alternative open spaces has been a challenge because of the high cost of land and difficulties finding the right natural features. How the needs of the public have been translated into improving access to these different areas will have to be carefully monitored to measure success over the next five years.



12 Heathland management on the Defence Estates

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Summary

The paper gives an overview of the biodiversity of the Defence Estate and a description of the variety of heathlands owned and managed by the MOD. It will describe how biodiversity is integrated into the operational use of the estate and discuss the particular challenges and advantages of use of the land for military purposes.

Selected case studies give examples of how heathland management is carried out including partnerships with conservation organisations, involvement of tenants and the wider community. The range of sites managed includes upland heathland within the Northumberland National Park, coastal dune heathland in Scotland, lowland heaths in Dorset and the Home Counties.

There is a focus on current priorities including: SSSI condition improvement project; Integrated Rural Management Plans; Natura 2000 sites and Appropriate Assessment; and Management at the Landscape Scale.

The Ministry of Defence (MOD) Estate

The MOD estate currently owns or uses approximately 450,000 hectares, which equates to MOD involvement in about 1% of land in the UK. The MOD has greater area of Sites of Special Scientific

Interest (SSSI) and Areas of Special Scientific Interest (ASSI) under its management than any other land owner. The estate comprises a wide range of protected habitat types from the lowland unimproved calcareous grassland of Salisbury Plain and Porton Down, the Brecks of East Anglia and coastal habitats to upland oak woods, limestone pavements and extensive areas of heath.

Lowland heathland SSSIs total 11,632 ha, with significant areas in Surrey, including large parts of the Thames Basin Heaths and Wealden Heaths Special Protection Areas (SPAs), and in Dorset. MOD lowland heath also occurs in the north of England with Strensall Training Area in the Vale of York one of the destinations of the Conference field visits. There are also coastal heaths including ranges on dune heathland in Scotland.

Upland heath SSSIs cover 10,964 ha. Otterburn Training Area covers approximately 24,000ha of moorland in the Northumberland National Park and designated areas include part of Harbottle Moors and Simonside Hills SSSIs and Special Areas of Conservation (SAC). There are also areas in the North Pennines (Warcop) and South Pennines (Leek).

Land exists under MOD ownership for military use. This is needed for support to operational activities and includes land used for training troops, airfields, dockyards, defence housing and technical accommodation. Since the end of the nineteenth century the armed forces have needed increasingly larger areas of land to enable the effective use of longer-range weapons and to train using more mobile tactics. Many heathland areas were acquired by the War Department and Commoners rights bought up such that by the end of World War Two, there was a huge Defence land holding. The majority of land held then became relatively unaffected by changes in agriculture and urban development such that when SSSIs started to be designated from 1949 the MOD estate was increasingly found to support some of the best examples of rare habitats.

This can be illustrated by the example of the Thames Basin across the borders of Hampshire, Surrey and Berkshire. Islands of lowland heath SSSI that remain in this heavily urbanised area coincide with several military training areas such as Sandhurst, Minley, Aldershot, Ash and Pirbright, and ex-MOD sites such as Chobham Common.

Military Training Use

In practice, much of military land use is low impact. Areas used as small arms firing ranges have large Danger Areas. While most bullets are contained, for example through the use of range stop butts, there has to be an extensive buffer zone as a precaution to protect other land users including the public. These areas are therefore out of bounds to both military personnel and members of the public during firing periods so for relatively long periods Danger Areas are relatively undisturbed. Ground nesting birds are therefore not subject to the same degree of disturbance from walkers and dogs than on other sites.

Other Range Danger Areas experience disturbance periodically, for example during armoured vehicle firing exercises. Potential impacts of firing include localised disturbance around fixed targets and the construction of tracks to allow vehicle movement. Whilst there is some habitat loss to track construction and modification of drainage this prevents more widespread damage that would result if military vehicles had free movement.

Other hazards associated with live firing include accidental fires and the presence of unexploded ordnance. The latter can restrict the management that can be carried out, for example the substrate cannot be disturbed without prior clearance of ordnance.

The MOD estate is also used for driver training. The majority of specialised training for armoured vehicles is undertaken at Bovington, much of which is Dorset Heaths SAC, Dorset Heathland SPA and Turner's Puddle Heath SSSI. Tanks used to drive across the heathland around the time of the last War but to prevent further damage they are mainly confined to an all weather driving circuit. The historic tank routes are now re-vegetating and provide ideal conditions for reptiles and invertebrates.

Dry training exercises involve infantry training without live weapons. The diverse natural environment of heathland provides an ideal location patrolling, navigation and concealment, simulated battle conditions and tactical exercises.

Aircraft use heathland areas as part of the wider landscape. Fixed-wing aircraft and helicopters use the UK low flying system. On military training areas, as with use of ground vehicles, their impact is restricted, there are specific landing areas and most activities involve over-flying.

Managing Military Activity

There are several ways in which Defence Estates manages the impact of military activity on heaths:

MOD policy aims to ensure that natural environment issues are fully integrated with operational and training requirements. This is achieved with the production of integrated land management plans.

All military and estate management activities comply with current EU and UK conservation legislation and environmental appraisals or Environmental Impact Assessments are carried out for new or revised policies, equipment acquisition and development projects.

The MOD contributes to the UK Biodiversity Action Plan and is working towards the Public Service Agreement (PSA) target of 95% of SSSIs in recovering or favourable condition by 2010.

Integrated Land Management Plans

These plans aim to reconcile the many, sometimes conflicting, interests that apply to military training areas. Many training areas have a significant nature conservation interest and multiple designations. The MOD has legal commitments to these designations but this has implications for other land uses. Separate component plans are prepared for the different land uses or activities relevant to each site. The priority plan is the military component which establishes the requirements and reasons for the military use. Separate plans are produced for the natural environment, historic environment, agriculture and estate management, public access and recreation. Following consultation with stakeholders, an integration process is carried out which seeks to achieve the optimum balance between all of the relevant interests.

Appropriate Assessment

As many of the MOD SSSIs also carry Natura 2000 designations new military training activities as well as new developments are subject to assessment under Regulation 48 of the Conservation (Natural Habitats &c) Regulations, 1994, as amended. The Natural Environment Team of Defence Estates Environmental Support Team fulfils the competent authority role.

Example Case Study: Lulworth Ranges

An operational requirement for Challenger II tank training at Lulworth Ranges in Dorset required the installation of new targets. This required the removal of small areas of dry heath to accommodate the new targets. The work was mitigated with the creation of twice as much habitat on other parts of the range. This involved making an area out of bounds for training and reseeding with heather cuttings taken from areas being managed for fire break creation.

The MOD SSSI Improvement Project

As well as managing the responsible military use of training areas, the MOD has a commitment to improve the condition of its SSSIs. The SSSI Improvement Project was initiated in 2003. The first objective was to ensure accurate information was available, initially information held on the location of designated sites under MOD ownership did not always coincide between MOD and the statutory bodies (English Nature -now Natural England-, Scottish Natural Heritage, Countryside Council for Wales etc.). There was also a need to identify why sites were in unfavourable condition. Sometimes this was due to military use restricting ideal conservation management but usually due to other factors such as forestry plantations, scrub development, tenants' grazing regimes or the activities of third parties.

A large and increasing part of the Defence Estate is tenanted; therefore SSSI management is reliant on the cooperation of tenants. Some sites were assessed as being in unfavourable condition due to overgrazing whilst in other areas lack of grazing was identified as an issue. The latter often results in localities where no suitable tenants or graziers are available.

The SSSI Improvement Project has identified management priorities for all designated sites to 2010 and beyond. Capital and maintenance works have been funded but availability of funding cannot always be guaranteed. Over £3.5 million was spent on SSSI improvement between 2004 and 2007, with around £800,000 spent on maintenance annually. The MOD budget is fully stretched and operational requirements take priority with increasing costs arising from the use of expensive technologies and full deployment. There is a need to secure sustainable long-term funding solutions for the management of the designated sites and this may include availability of Environmental Stewardship to tenants or establishment of partnerships with other organisations such as Wildlife Trusts.

Condition of MOD Heathland SSSIs

Using data available in summer 2008 from Natural England condition assessment the situation in England was as follows:

Habitat	Area	Meeting Objectives
Upland Heaths and mires	10,964 ha	80%
Lowland Heaths and mires	11,632 ha	79%
TOTAL	22,596 ha	

The area which has been assessed as favourable or unfavourable recovering is slowly increasing. Overall, MOD SSSIs covering all habitats in England in target condition have increased from 53% in 2003 to 85% in 2008 and although there is still some way to go to meet the 95% PSA target the figures are a reflection of huge efforts made in recent years.

Lowland Heath SSSI Improvement

Management works undertaken to improve the lowland heaths on the MOD estate has included the extensive removal of conifer plantations, encroaching scrub and bracken. In some areas this has taken place as part of wider partnerships such as with the Herpetological Conservation Trust or the Heritage Lottery funded “Tomorrow’s Heathland Heritage” project. Sites have been included in the Surrey Heathland, the Hampshire Heathland and the Vale of York heaths projects.

Other management activities have included control of invasive species such as Rhododendron and ditch blocking on some sites to reverse earlier attempts at drainage. Creation of fire breaks is essential to combat out of control fires in dry summers and to manage the potential fire risk posed by some military activities. Busy live firing schedules can cause problems for ongoing land management when access to ranges is restricted for much of the time. Careful forward planning of activities is needed to optimise use of the restricted windows of opportunity when land managers and contractors can access certain areas.

The long-term maintenance of heathland at some sites has been secured with the establishment of conservation grazing schemes. Before livestock could be introduced to some areas, site clearance such as scrub or conifer removal and installation of stock-proof fencing and water supplies have been required. Hardy native cattle breeds have been introduced to a number of sites in Surrey, Hampshire and Dorset whilst Hebridean and Shetland sheep graze Strensall Training Area. Grazing of the sites has been enabled through partnerships between MOD and local graziers and Wildlife Trusts with tenants applying for Higher Level Stewardship (HLS) funding.

Case Study: Ash Ranges, Surrey

Approximately 1000 hectares of lowland heath designated as SSSI, SAC and SPA occurs at Ash Ranges. Since coming into MOD ownership, the heath saw little management apart from accidental and often extensive fires until in the early 1990’s scrub clearance took place by the Herpetological Conservation Trust and as part of the Surrey Heathland Project. Since the launch of the SSSI improvement project in 2003 hundreds of hectares of pine and birch have been removed, the perimeter fence has been upgraded to provide a stock-proof barrier, a cattle handling facility has been installed, a belted Galloway cattle herd established, ongoing bracken control and fire break management has taken place and a grazing licence agreed with Surrey Wildlife Trust who have successfully applied for HLS.

Upland Heath SSSI Improvement

In contrast to many lowland heaths where lack of grazing has been a problem, in common with many sites in the English uplands, stock numbers have often been too high on the MOD estate. Upland heath management and restoration has focussed on reducing stock numbers, but on some sites establishment of appropriate grazing levels has also involved rabbit control. Some sites are managed as grouse moors while others have not been managed in this way. Controlled burning takes place, but some sites have not been managed by burning due to health and safety concerns over the possibility of unexploded ordnance. Therefore MOD moors are often less heavily burned than adjacent grouse moors. Military use can sometimes lead to accidental fires or managed fires can sometimes get out of control, therefore as with lowland heath, creation of firebreaks are sometimes needed. Other management taking place to improve site condition includes bracken control and grip blocking on mires.

Case Study: Stainton Moor

An area of heather moorland, part of Lovely Seat-Stainton Moor SSSI in the Yorkshire Dales and part of Catterick Training Area used as a Danger Area for small arms ranges. Formerly the site was assessed as being in unfavourable condition due to overgrazing and lack of burning management. Recent initiatives have included a reduction in sheep numbers through formerly English Nature Wildlife Enhancement Scheme and Countryside Stewardship agreements with tenants; now applications for HLS are in progress. Intensive rabbit control and bracken spraying has taken place and a heather burning plan drawn up and implemented. Establishment of new native woodland, including juniper scrub, has enhanced habitats along watercourses.

Conclusion

Acquisition of land for defence purposes has protected large areas of lowland and upland heath from agricultural intensification and development. The challenge of managing designated sites within the military use takes place through integrated land management planning and assessment and mitigation of potential impacts. The MOD is also committed to improvement of the condition of designated sites through the SSSI Improvement Project.

13 York's Lost Moors: The wildlife and history of the Heathlands of the Vale of York

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The pre-enclosure extent of heathland in the Vale of York was at least 35,500 ha, stretching across deposits of windblown sand along the eastern part of the Vale. This has been mapped using old maps, place names, soil types and old biological records. The windblown sand formed dunes over lacustrine clay, forming gley or podsols soils from which are derived heathlands that show transitions from fen meadow, through wet heath to dry heath. Today, a little over 900ha are extant, the major sites being Strensall, Skipwith, Allerthorpe and South Cliffe Commons. Heather still survives in other small pockets in such sites as Wheldrake Woods and Sand Hutton Woods.

Maps indicate how blocks of historic heathland or moorland were broken-up and converted to other land uses through enclosure. The 1771 Jeffery's map of Yorkshire shows the modern day Allerthorpe Common SSSI to be part of a larger block of heathland named Barmby Moor, which covered at least 1340 ha. The 1850s first edition OS map shows the same block to have been reduced in size to around 245 ha. In 2003, the remaining heathland was concentrated mainly in Allerthorpe Common SSSI and consisted of just 14 ha of extant heath.

The aim of this presentation is to convey something of the character of the remaining Vale of York heaths and to identify any features that make them unique. To the general visitor, the landscape is characterised by its flatness, the high proportion of wet or boggy ground and the mosaic of open heathland and secondary birch woodland. This has not always been so. A photograph of Skipwith Common believed to have been taken in 1918 shows the landscape to be almost completely open heath, with just scattered Scots pines (Figure 1a). AJ Brown, in his 1932 book Tramping in Yorkshire (North and East) described the landscape as:

'It [Skipwith Common] extends for about a thousand acres and looks at first glance very like a flat moor-top, with clumps of heather and gorse and marshland, and here and there a few Scotch pines. Closer investigation reveals interesting differences. In the first place, the Common teems with bird-life; it is a sort of natural bird-sanctuary, especially for wild-fowl and wading-birds.'

Figure 1 a) Skipwith Common c.1918, showing tall pines on a round barrow (photographer unknown); b) The same part of Skipwith Common in 2004 (John Mayo, Escrick Park Estate).

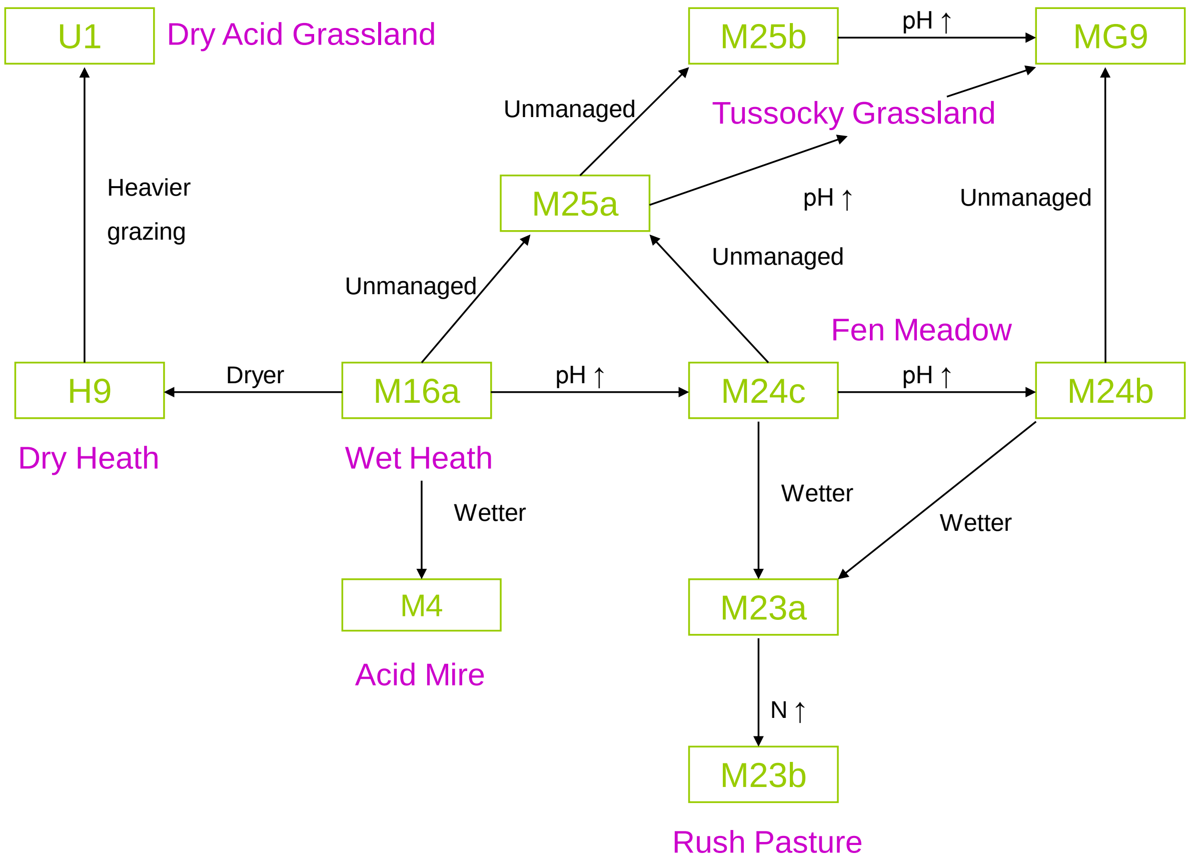
A photograph of Skipwith Common taken in 2004 from a similar spot (Figure 1 b) shows that much of the open heathland has been colonised by birch woodland. It is estimated that in the 1980s about 3 ha a year of the remaining heathland across this 280 ha common was being colonised by scrub annually.

There are perhaps four factors that differentiate the Vale of York heathlands from others in the United Kingdom. The first is the geographical location with the heaths being a northern outpost of southern lowland heathland types and showing characteristics of transitions between these and the vegetation found for example on the North York Moors. In terms of characteristic heathland plants and invertebrate species, some of the indicators of southern warm heaths are found alongside southern outliers of more northerly species. An example of the latter, and one of the unique features of the Vale of York Heaths, is the dark bordered beauty moth *Epione vespertaria* (Figure 2). This attractive geometrid moth is found in England only on Strensall Common, just north of York, where the foodplant is creeping willow. Detailed autecological investigation over the last few years has shown that large bushy foodplants are home to a disproportionately large percentage of the population. The presence of these large bushy plants are correlated with anthropogenic disturbance such as small ditches or trenches dug by the military.

Figure 2 Dark Bordered Beauty moth (Robert Goodison, Natural England).

The third unique feature of the lowland heathland of the Skipwith Common area is the rich archaeological story that is being unravelled. The Common has a rich landscape of upstanding prehistoric earthworks, with examples of Iron Age square barrows as well as a variety of prehistoric linear monuments that may have been boundary features.

Lastly the mix of vegetation types and the transitions between them is rich, resulting from the underlying sand-dune topography giving rise to variations in soil wetness and acidity. The following table shows the relationships between the differing NVC habitats present where the mosaic is best developed, on Strensall Common.



The Restoring the Heaths of the Vale of York, Heritage Lottery Fund funded project, which finishes in 2008, will enable the whole area to be managed sustainably in the future. This was achieved through large scale scrub clearance and manipulation of grazing, complimented by an exhaustive interpretative and education programme.

Workshops

Workshop A1 & B1 - What will heathlands look like in 50 years time?

Facilitator: Matthew Oates, National Trust

Headlines

- Radical change to out heaths in inevitable, although the detail is unclear. Change has always reflected social drivers, and will continue to do so.
- Heaths will remain important, but constituent features may change
- Upland/Lowland differences will continue to be significant, but in new ways and with more local differences
- Coastal heaths – sand dune systems may be subject to major change but heaths on hard rocks will be OK
- Changes to patterns of use -use of local wood, biofuel, local food products and changes to visitor patterns, i.e. more people near heaths = more visits.
- Creation of large open forests that are large and diverse and generate income based upon extensive activities
- New additional heaths have been created and they may be populated with new animals
- Heathland may become to be seen as a luxury
- Changes could take place across a broad spectrum, including species and habitats, e.g. new invasive non-natives.
- Protected areas will remain important, the core of a wider landscape, but may become more process driven systems
- Increased importance of SANGS

Drivers

- There could be major political change within 50 years
- Appreciation of ecosystem services, eg water, carbon/nitrogen storage, recreation, windfarms)
- The impact of a fuel crisis
- Changes in understanding of heaths versus heathy patches in large open forests, introduction of the landscape approach to our thinking.
- The New Forest may become a model replicated elsewhere
- Bad agriculture could lead to soil impoverishment and the creation of new heaths, acid grass and gorse developing on sites in Suffolk already.
- Collapse of livestock farming in some regions could lead to the introduction of new herbivores and carnivores on heaths
- Changing climate
- Non-native species
- Changes in public attitudes reflecting political and economic situations.

Workshop A2 - Practical Management of Nutrients on Heathlands

Facilitator: Penny Anderson, Penny Anderson Associates

General Issues and Processes

Nitrogen is key issue – processes include aerial deposition, accumulation through succession, run-off outwards and nutrients imported by dogs/horses (nutrient input from dogs is relatively low and localised, e.g. car parks)

Phosphorus is a key issue in restoration

- Grazing animals have an impact on nutrient cycling, research has been done and published
- If grazing animals are always on site, N and P are reduced and K can be eliminated
- Grazing animals move nutrients around – graziers eat rich grass and defecate elsewhere
- Leaf litter is a nutrient store
- Pine and Oak break through the iron-pan and might allow the leaching of nutrients from the system
- Birch recycles nutrients in the soil, transforms mor soils to mull soils, and organic material increases. Takes about 20 years
- Pine does not acidify the soil
- Gorse and broom increase soil N, cattle don't eat gorse but they do eat broom, mowing of gorse can reduce nutrients, roadside management can lead to increased gorse through disturbance
- Heathland management has to cope with nutrients accumulating through succession.

Mechanisms to Remove Nutrients

- Need to adjust old techniques, e.g. graze grassy heaths for longer or at a higher stocking density
- Cut birch on a shorter cycle, though this costs more
- Turf-cutting – either cut and remove or put back in areas where seed source is required
- Heather may be cut and removed, and used as a seed source
- Grazing reduces nutrient levels, but can this 'keep up' on sites with large inputs from aerial deposition?
- Cutting and burning reduces short-term accumulations
- Turf stripping reduces long-term accumulations of nutrients
- Burning and grazing together releases/removes N, and perhaps P if young livestock are used, need to have high stocking densities for big impact, the old guidance of 0.2lu/ha/year may need to be increased to have impact

- Manipulate grazing by using supplements to encourage more grazing of poor vegetation, such as heather, should this be an objective
- Need to respect the differences between sites and set appropriate objectives. Grazing leads to more habitat mosaics
- Reversion techniques – such as addition of sulphur (S). Results in nutrients being unavailable. Needs careful application
- Natural leaching will occur over time, perhaps particularly in the wetter west. May lead to unacceptable intermediate stages
- Turn soil over, to bury nutrients, but need to test whether sub-soil is suitable first
- Long-term results have not indicated particular success. Responses to the technique have been variable, including undesirable species such as birch becoming dominant
- Deep ploughing is a specialist tool that buries litter a long way down, which may be technically better than shallow burial. May have other impacts, e.g. on archaeology or hydrology
- Grazing may have different impacts on soil N at different times of year. Remember other grazing impacts such as not using persistent wormers like ivermectins
- Grazing may not work well in really urban areas
- Provide sacrificial areas for people management, i.e. dog-fouling, and raise awareness of the problem with visitors
- Soil stripping may be the best ecological method but socially and economically may not be acceptable unless there is a clear use for the materials
- Impacts on soil carbon (C) – burning releases only recently bound C
- Using materials from soil stripping uses carbon due to the transport involved. Local burners could be used to generate power

Workshop A3 - Heaths and woodlands: developing Government policy

Facilitator: Dominic Driver, Forestry Commission

Participants were divided into groups and asked to respond to a series of questions and score their importance. These were the responses:

	For	Against
Biodiversity		
Resilient ecological communities Score of 3 = misleading Open habitat = treeless landscape woods + forests need to be defined	• Increased populations • Better connectivity (Between sites/populations) • Move in response to change • Reduce edge effects eg pine encroachment	• None, but make clear that forests/woods = plantation (often non-native) + early successional and therefore generally lower biodiversity, not ancient or establish BAP woodland
Govt commitments on native + ancient woodland Score of 7	• Ancient woodland = wrong soil • Restoration targeted at plantation + early successional	
Govt Commitments on woodland biodiversity Score of 7	• Potential generally has less biodiversity value than the UKBAP habitat it has replaced (ie last 60 years or so) Proviso: local characteristics should be taken into consideration based on best practice criteria. This might mean that some plantation/ early successional woodland should not be restored.	
Carbon Satisfaction: 3 Definitions not clear – 'forest', 'woods and plantations' The science surrounding the net carbon input of restoring heath from forest is <u>not</u> clear. The evidence must show both sides including evidence that forestry operations emit carbon. In policy document: does the likely impact of the outcome of Carbon Balance taken into account soil C as well as C in vegetation?	• Coppice woodland – stable carbon sink & could store more • Farmland – Woodland, greater carbon storage • No peatland habitat is a net sequester??? • Could a Calluna landscape be a wooded landscape?	• Heaths (wet) & Bog – recognised as greater C sinks - restoration of these more important • 'Forests' is as much an 'open' landscape as a wooded or closed one • Can trees in the UK make a significant difference to C emissions/balance • Area of dry heath (BAP + designated site) not significant

Financial viability	The landscapes created through restoration of open habitats from woods and forests on poor quality timber producing land will have less impact on costs.	Removal of high quality/high productivity woodland will have a negative impact.
Learning about Landscape History Analysis = little impact: AGREE	'All' (?) woodland/heath areas in England have had history of more & less wood and open heath therefore can easily interpret change	Some people against removal/reduction in any trees…..but interpret
Preservation of Historic Features Analysis = positive if guidelines followed: AGREE Score of 8	Very case/site specific guidance for different historic features – maybe varying specialist judgements as to mechanisms & relative scale/priorities (which have to be related to other drivers)	
Quality of Life and landscape	Getting away from it all Visually soaks up numbers	
Visitor perception is they feel more 'alone' in forested area – safety issues, vulnerability, lack of visibility **Scored 7** on ten-point scale. Key that access is managed and built into the planning process and implemented as soon as possible.	Positive engagement by local and other users eg Dorset Urban Heaths Engagement key to proves to reduce negative impact	Local visitor objections and rage (!) at loss of trees
Timber With caveats mark of 10 Removal of large areas of high quality/high productivity woodland will have …….(rest of original statement) Score of 9-10	1) Scale is critical to the answer 2) Quality of lost timber is critical to the answer (Poor quality timber – disagree) Good quality/high productivity – agree Without above caveats mark of 1	
Water quality	Providing 'good' habitat restoration will have +ve effect on water quality Increased water yields provided good management and no subsequent flooding. – for this there is Scottish evidence in the Flow Country	Short term increase in P and particulate matter (ref Joe Holden's talk) Difficult to generalise – issue of scale
Air & Noise Score 3/4 for both – not clear what the evidence is & how it's been interpreted	Retaining belts/screens	Trees are better than heaths at reducing air pollution – issue of scale and location Evidence – there is probably lots at the local scale? EA Depends on scale – national/ local raises different issues

General discussion comments

‘Heath’ is not a treeless landscape

No absolutes – there is a scale from trees-treeless

Every site is different

Scales of tree’d to open landscape are needed

If heath has 15% trees – where are those trees located, are they scattered or clumps eg North York Moors where 20% is woodland

<20% tree cover = deforestation

Community Forests have increased tree cover, so we have the capacity to allow for some loss of tree cover.

Need to be clear about terminology (are we talking about heath (15% trees) or open space in woodland (20% open space) or a treeless landscape?

How much? Link to UK HAP and deliver in relation to local BAP for Heathland + species targets.

Build into policy recognition of existing biodiversity value of woodland/plantations in relation to decisions on location + quantity of ‘open habitat/heathland’

BUT is there anything wrong with having areas with very few trees? Variety in all things. Uplands especially

YES ‘open habitat’ value for heathland species includes areas of transitional/clear felled habitat as well as fully developed heathland. Mosaic + balance is key.

Workshop A4 - How best to deliver the national heathland Habitat Action Plan

Facilitator: Isabel Alonso, Natural England

The group discussed the weaknesses of the process and identified the following as issues to improve. Further comments were added by other delegates.

Policy

- We need to develop policy to re-create heathland from plantation. This is now in progress and will hopefully be delivered by the end of this financial year.

- We could achieve more by concentrating in targeting the big landowners MOD & FC. This could enable greater hectarage to be achieved.

Standards and Processes

- Common standards should be shared across conservation groups. Local groups are not familiar with the Common Standards for Monitoring (CSM) method. We also need to update the objectives as in many projects the current objectives are for too much heather, although 40% of heathland BAP spp need bare ground and pioneer stages. Also, progress on improving condition needs to be recorded in a standard way, with an agreement on when is a re-created heath a heath?

- Re-consider the merge of HAP groups, perhaps by issue such as “grazing” or “upland/lowland”?

- Better statistics and data are required at all levels. HLS data from heathland sites should be quite accurate in the future. Reporting is improving at local/country level.

- Make BAP targets BARS friendly and put more resources in place for big heathland (re)creation projects than into detailed reporting.

Ecological issues

- Need to aim for a mosaic of habitats including farmland, secondary woodland and open habitats. CSM seems to aim for a very prescriptive result that is not compatible with wildlife / reporting, etc. Integration will bring larger, more robust landscapes containing areas of heath.

- Remember bare ground is some species’ home – it is part of the heathland habitat even if it is a track, path or bridleway and must not be surfaced in any way.

- Get the science right – do we know how much heathland is needed to maintain specialist species on a National Level? (bare ground, forbs, etc) and where to target this action. Politicians always ask this question whether on a single site or eg Thames Basin Heaths.

Funding

- We need to improve sustainability prospects of heathland management, perhaps by linking funds to targets.

Public engagement

- Public engagement and communications need to improve by changing the “tree felling fear” and promoting the values of heath and positive image of heathland to the public. We should also review the use of too much conservation jargon, eg use “wildlife” instead of “biodiversity”. The link between heathland–open space–traditional use–safe recreation should be made. The local communities have to be involved so they can understand the work on heathlands and therefore support or be involved in the work. Also, in relation to the effect of dogs on ground nesting birds, etc. Areas for tree felling should be identified, communicated and discussed in good time. The local communities should be engaged with by someone from a local conservation agency so that they have a thorough understanding of the site and its local problems as well as how it fits in with HAP. New opportunities may arise by using heathland (especially new heath) as the backdrop for what the public enjoy/appreciate, eg Olympics! Is there an opportunity to potentially linking new heathland creation to the new Olympic facilities?

- Better communications among groups working at different levels (national, regional, LBAPs, local action) and with the public. Definitions need to be clarified and standardised, eg what constitutes restored/improve condition.

Workshop A5 - Inspiring Visitor: Ways to touch heathy healthy hearts

Facilitator – Caroline Comins, Yorkshire Wildlife Trust

How?

Enthusiasm from event leader/information giver

1. Provoke Thoughts: humour, ‘devil’s advocate, conserving dangerous animals like adders
- Stories – e.g. put yourself in the place of a Bronze Age person, a specific animal etc.
- Old photos and memories from older residents
- Species – especially invertebrates with their amazing life histories
- Hook – to get someone’s initial interest – use as many hooks as possible to attract different audiences
- Inspiration – heaths have big views and big skies
2. Presence on site by staff is useful for informal engagement
3. Multi-use site – have different activity zones on a site
4. Information provision – use local outlets like post offices and parish magazines

Why?

1. Support gained for conservation cause (increased membership for voluntary organisations)
- People fight to protect what they value, which is often space for recreation over heathland
- To inspire population
2. To help users to understand what we are doing on site
3. To encourage responsible use

Workshop B2 & B3: Tomorrow's Heathland Heritage (THH): lessons learned & Marketing heathland products

Facilitator's: Steve Clark & Joe Oliver, Natural England

Changes to THH

- THH begun as a BAP restoration initiative and then came to include access and people
- Dorset THH changed shape from its early days
- Now we look at multi-functional sites: ecosystem services

Lessons Learned

- Creation and now the continuation of partnerships is very important
- Maintaining communications is important, i.e. HeathNet, GAP, Nibblers etc...
- Where can local/national THH reports be accessed?
- Research has influenced the way that visitors to sites are managed
- If we want grazing, we may have to accept that some sort of agri-environment support is essential as a back-up to the enterprise

Marketing Heathland Products

- Re-created heathland is a product, but appears to generate no income by itself
- Visitor gifting ideas to generate income to support the management of the local area
- Sell visitor guides
- Need to establish cost/benefit of an enterprise
- Other products could be developed, e.g. beer, wine, honey & compost, charcoal, perhaps giving rise to direct local employment

General Conclusions

- Everything is a product!
- Marketing and selling heathland products reduces the costs of your operations
- Accept that the market changes
- Take the middle-ground with opposition groups & maintain communication with the middle-ground users of your site
- Phase in what you do, and keep on doing something- people get used to change
- Trust your heathland to be resilient
- Be more confident about using cheaper methods

Workshop B4 - The Pros and Cons of Pony Grazing on Heathlands

Facilitator – Julian Small, Natural England

The group discussed the advantages and disadvantages of grazing heathlands, upland and lowland, with ponies, and illustrated the discussion with examples from around the country. The group felt strongly that usually pony grazing was best as part of a **mixed grazing** regime.

Pros

- Ponies are relatively cheap to buy
- Running costs can be very low compared to cattle and sheep
- Ponies are very hardy
- They are good at opening up rank vegetation
- The are good at creating mosaics of long and short vegetation
- Have a particularly beneficial impact on vegetation structure as part of a mixed grazing regime
- Less paper work required than for other livestock. Although passports are needed, there are no movement licences or tagging.
- Can need less frequent checking than cattle or sheep
- Could perhaps be considered more expendable than cattle in situations such as grazing cliff tops, as they are less valuable
- Handled ponies can be used on inaccessible sites
- Ponies are often safer than cattle in boggy areas, as they are less prone to getting stuck
- Can create good species-rich lawns on mires, e.g. in the New Forest.

Cons

- Negative interactions between ponies and visitors and their dogs can develop, especially where ponies are fed by the public. It can be difficult to get a balance between wildness (limited interaction with the public) and friendliness (ability to catch etc)
- There can be a perception from 'horsey people' that ponies are not being looked after with the same standard of welfare as domestic riding horses, e.g. ragwort may be present, hoofs may not be regularly trimmed
- There is no real commercial product, i.e. no meat product
- Ponies can be ineffective at controlling most scrub species, even with year-round grazing. They browse less effectively than cattle, goats or some sheep breeds
- Can cause unwanted 'weed' problems in latrine areas, (land getting horse-sick)
- Can exacerbate rabbit problems

Workshop B5 - Timber, Turves and Heather: Bio-fuel for Thought

Facilitator: Brian Walker, Forestry Commission

There is a larger roll for human intervention in the maintenance of heathland where grazing is not an option.

Tree products would be mainly from birch and pine.

A range of uses was suggested:

- Horse-racing jumps – small diameter, coppice material for jumps, has to be cut outside bird nesting season.
- Play surfaces (chippings) – Can be used but if not impact tested must be used at an increased depth.
- Horse/livery – Chipped trees can be used in livery and exercise yards as can heather.
- Thatch – Heather can be used in traditional thatching.
- Bio-fuel – some material can be used for bio-fuels such logs, wood chips, baled heather & bracken, turf and peat.
- Bedding is a traditional use of Bracken, which can also be composted.

Where heathland restoration was being undertaken and tree removal was needed whole tree harvesting is an option affected by the nature of the plant/factory. Whole tree harvesting created a lot of problems including excessive erosion and soil inversion. It was usually better to let stumps and roots rot naturally.

Community management could be used to control excessive tree growth but in some locations people felt this might not be controllable leading to over exploitation.

Small scale – think globally.

FC is involved and has a role in developing biofuel technologies and markets.

Conference Programme

Tuesday 9th September	
10:30	**Registration and refreshments available**
11:15	**Welcome and Introduction** **Session 1: Chair Humphrey Crick, Natural England**
11:25	**Heathlands and Climate Change** Climate change adaptation of heathland biodiversity John Hopkins, Natural England Predicting ecosystem responses to multiple drivers Simon Smart, CEH Lancaster Questions to the panel
12:20	**Restoration of Open Habitats from woods and forests in England: developing Government policy** Dominic Driver and Jonathan Spencer, Forestry Commission
12:45	**Lunch at Quarks Restaurant, NSLC**
13:45	**Session 2: Chair - Matthew Oates, National Trust**
13:50	**Heathlands and Fire** Case Study – Thursley Common NNR Rises from the Ashes Simon Nobes, Natural England Burn Mapping from Space Adrian Yallop, Cranfield University What determines fire occurrence, fire behaviour and fire effects Colin Legg, Centre for the Study of Environmental Change and Sustainability Questions to the panel
15:05	**Refreshment break**
15:35	**Session 3: Chair - Rona Charles, North York Moors National Park**
15:40	**Heathland Soils and Nutrients** The hydrology and fluvial carbon fluxes of upland organic soils Joe Holden, University of Leeds Detecting and attributing nitrogen deposition in heathland ecosystems Carly Stevens, Open University Bearing soil and archaeological interests in mind when restoring heathlands - a proposed good practice guidance Isabel Alonso, Natural England Questions to the panel
16:55	**Summing-up**
17:00	**Close of plenary session**

Evening programme	
18:30	Happy hour in the Atrium: Yorkshire beer sampling with the Brown Cow Brewery!
19:30	Dinner at Quarks Restaurant, NSLC Followed by after dinner quiz and the Charms Bar will stay open till midnight

Wednesday 10th September	
07:30	**Breakfast at Quarks Restaurant**
09:30	**Welcome and Introduction** **Session 1: Chair - Peter Welsh, Natural England**
09:40	**Heathlands, housing and people** Understanding the links between housing development, access and disturbance to birds Durwyn Lilley, Footprint Ecology The Thames Basin Heaths SPA - finding space for people and birds Kristoffer Hewitt, Natural England Defence Estate as heathland managers Moira Owen, Defence Estate Questions to the panel
10:55	**Introduction to Workshops**
11:00	**Refreshment break**
11:30	**Workshop Session A** What will heathlands look like in 50 years time? Practical management of nutrients on heathlands Heaths and Woodlands: Developing Government Policy How best to deliver the national heathland Habitat Action Plan Inspiring Visitors: Ways to Touch Healthy Heathy hearts
12:30	**Lunch at Quarks Restaurant**
13:45	**Workshop Session B** What will heathlands look like in 50 years time? Tomorrow's Heathland Heritage: lessons learned Marketing heathland products Pros and cons of pony grazing on heaths Timber, turves and heather: bio-fuel for thought?
14:45	**Refreshment break**
15:15	**Session 2: Chair - Steve Clarke, Natural England**
15:20	**Further workshop feedback in plenary**

15:40	**York's Lost Moors: The wildlife and history of the Heathlands of the Vale of York** Julian Small, Natural England
16:10	**Summing-up and Close** Tom Tew, Natural England Chief Scientist
16:25	**Close of Plenary Sessions**
Evening programme	
17.45	**Coach leaves for York City Centre** Meet at the Alturin Accommodation Block Car Park
18.30	**Guided Tour of York Minster** Donations requested at the discretion of the delegates
19:30	**Sparkling drinks reception at St. Williams College (next door to York Minster)**
20.00	**Conference Dinner at St. Williams College**

Thursday 11th September	
07:30	**Breakfast at Quarks Restaurant**
By 09:30	**Check out of room**
09:30	Meet at the Alturin Accommodation Block Car Park (packed lunches provided) for **Coaches leaving to:** Skipwith Common [1.3MB pdf] – grazing, archaeology, hydrology, nutrients (leader Julian Small, Natural England) Strensall Common [1.4MB pdf] – grazing, military use, access (leader Dr Moira Owen, Defence Estates and Simon Christian, Natural England)
10:15	**Arrive at both sites**
13:15	**Leave sites for return journey**
14:00	**Coaches will deliver delegates directly to York Railway Station and then the University.**

Attendance List

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