Chapter 5: Mountains, Moorlands and Heaths

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Key Findings*

Mountains, Moorlands and Heaths (MMH) cover about 18% of the UK and comprise the great majority of our near-natural and semi-natural habitats and landscapes. Most occur in Scotland (3.4 million hectares (ha)) where they make up 43% of the land surface area, followed by England (693,000 ha), Wales (246,000 ha) and Northern Ireland (228,000 ha), representing 5%, 12% and 12% of the land surface respectively. While Mountains represent some of our least human-influenced ecosystems, the extent and condition of our Moorlands and Heaths have been shaped by, and continue to be dependent on, a range of human activities.	
Substantial changes to the extent, condition and use of MMH habitats have taken place since the Second World War (WWII)[1]. The greatest losses in extent have been for Bog, and upland and lowland heathland**.** Much of the once moss-dominated mountain habitats in Wales and England has been converted to grassland. Such losses have been limited during the last two decades**.** Nonetheless, there is widespread evidence of long-term reductions in habitat condition**,** notably: greater peat erosion; loss of structural diversity; decreases in species richness; and the expansion of grasses at the expense of moss and dwarf shrub-dominated communities. The economy in MMH areas has shifted from one based largely on farming to one where tourism and recreation are also important**.** Grouse and deer management continue in the uplands, although associated management practices, such as burning and predator control, have come under increasing scrutiny**.** More traditional forms of land management have largely ceased in most lowland heaths**,** except when carried out for conservation purposes.	[1] *well established*
The key drivers of change in the extent and quality of MMH habitat since WWII have been afforestation, agricultural development, changes in grazing pressures, airborne pollution and, to a lesser extent, climatic changes[2]. Almost invariably, MMH habitats have been affected by multiple pressures**;** a combination of sheep-grazing and nitrogen deposition, for example, may provide the best explanation for the replacement of dwarf shrub and moss communities by grasses. The changes in land use reflect shifts in markets towards the exploitation of provisioning services (i.e. food, timber and energy) at the expense of other services brought by MMH habitats. Economic reasons also explain the abandonment of many lowland heaths. The impacts of these factors have been moderated by cultural pressures and a number of policy mechanisms**,** such as nature conservation and pollution control schemes, that do recognise the wider values of MMH.	[2] *established but incomplete evidence*
About 70% of the UK's drinking water is sourced from MMH, and these habitats buffer water quality against the effects of atmospheric, diffuse and point source pollutants[2]. The high quality water that drains from upland environments sustains healthy aquatic ecosystems and provides drinking water to the majority of UK water customers. The soils and biota of intact MMH ecosystems can retain a significant proportion of airborne pollutants, thereby reducing pollution runoff into freshwater habitats and the drinking	[2] *established but incomplete evidence*

water supply.	
About 40% of UK soil carbon is held by MMH, mainly in upland peaty soils. This presents opportunities for short-term reductions in UK carbon dioxide emissions, both through reducing ongoing losses of soil carbon and further sequestration[2]. Any reduction in the volume of peat through its extraction for use as fuel or soil improver, or through the erosion of degrading peat, represents an exacerbation of current carbon dioxide emissions to the atmosphere. Active restoration of Moorland, notably 'degraded' blanket bog, should enhance its capacity for carbon storage and some sequestration.	[2] *established but incomplete evidence*
Mountains, Moorlands and Heaths are nationally treasured landscapes[1] which provide breathing spaces for people[2]. They are particularly cherished for their 'wildness' and as sources of inspiration. Recreation and tourism make significant contributions to their total economic value; their 'non-use' or existence value is also high. The majority of UK National Parks are located within MMH habitat; in England alone, these receive 69.4 million visitor days per year.	[1] *well established* [2] *established but incomplete evidence*
Steeped in history, MMH are important cultural landscapes[1]. Moorland and Heath habitats are shaped by society's long-term and continuing use of the land, and underpin livelihoods, as well as creating distinctive cultural identities and a sense of place. Mountain landscapes are often part of iconic imagery that is used to convey a national or regional sense of identity. The relatively low levels of physical disturbance (e .g. ploughing, building) makes them valuable sources of palaeo-environmental and archaeological evidence of past landscapes, management and culture.	[1] *well established*
Mountains, Moorlands and Heaths are of great importance for biodiversity: large parts have national and international conservation designations[1]. Whereas lowland heaths are highly fragmented, upland MMH habitats form the largest unfragmented semi-natural landscapes of the UK and are a refuge for many species that used to occur throughout the country. Due to a long history of deforestation, grazing and, more recently, grouse moor management in the uplands, UK MMH contain the majority of the world's heather-dominated landscapes. The blanket bogs and oceanic mountain habitats are also of international importance. They provide a home to some of the UK's rarest species, and communities comprise a unique mixture of temperate, alpine and arctic species.	[1] *well established*
Mountains, Moorlands and Heaths are highly multi-functional, providing different ecosystem services to different people in different places and times[1]. Some of these provide synergistic opportunities such as management for carbon storage, biodiversity and water quality. Others inevitably lead to trade-offs between ecosystem services where the provisioning of different services is mutually exclusive. Given the multi-functional nature of MMH habitats, the continued development of the evidence base must better take into account the (often contradictory and dynamic) objectives of beneficiaries if it is going to inform on sustainable management strategies in the future.	[1] *well established*

***** Each Key Finding has been assigned a level of scientific certainty, based on a 4-box model and complimented, where possible, with a likelihood scale. Superscript numbers and letters indicate the uncertainty term assigned to each finding. Full details of each term and how they were assigned is presented in Appendix 5.1.

5.1 Introduction

"Science says: 'Here is a stone. Its weighs so much. It measures so much. It is so-and-so many years old.' But a man needs to discover that the stone is strong, so that he can stand on it, and cool, so that he can lay his head against it: that it is beautiful and can be fashioned as an ornament, or hard and can be built into his home." **(Katharine Steward 1960 – A croft in the hills)**

5.1.1 Habitat Description and Historic Extent

Mountains, Moorlands and Heaths (MMH) are predominantly open, unenclosed and extensive landscapes, which many perceive as 'wild land', relatively untouched by people. In reality, the character of these often remote expanses commonly reflects hundreds, if not thousands, of years of human interference. These are, therefore, mostly cultural landscapes, kept in an 'open state' by practices such as grazing, cutting and burning (Webb 1986; Ratcliffe & Thompson 1988; Dodgshon & Olsson 2006). Mountain areas above the climatic tree-line, cliffs, screes and areas of shallow or very wet soil are naturally open as environmental conditions prevent woodland formation (Birks 1988; **Figure 5.1**).

INSERT FIG 5.1

For descriptive purposes, MMH can be divided into six broad habitats: Bracken; Dwarf Shrub Heath; Bog; Upland Fen, Marsh and Swamp; Montane; and Inland Rock (See for habitat descriptions **Box 5.1**; extent **Table 5.1**). However, they usually occur in mosaics, and are interspersed with other habitats such as semi-natural grasslands, woodlands and surface water. The latter three habitats fall outside the scope of this chapter but are referred to where they are integral to aspects of ecosystem service provision by MMH.

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Whilst the broad habitat classification has useful applications from a nature management perspective, MMH habitats are ecological constructs that may not be recognised by others. For instance, recreational visitors might describe their activities in MMH as 'going onto the moors' or 'into the hills', and may not discriminate between MMH broad habitats, or indeed between MMH and other habitats such as woodlands or semi-natural grasslands. It is, therefore, hard to separate MMH components from the wider landscape that people relate to (Swanwick *et al.* 2007). Likewise, many ecosystem services (and the 'biodiversity' underpinning them) are not necessarily specific to MMH habitats, but result from the presence of a range of habitats and the interplay between them; for example, red deer as 'goods' are products of multiple habitats.

Prior to human activity (about 5,000-6,000 years ago) woodland covered much of what is now the tree-less landscape of MMH in the UK (Simmons 2003; Tipping 2003). Over time, the extent of moorland and heath increased through a combination of woodland clearance, managed burning, livestock-grazing and the removal of turf and vegetation, although climatic changes are also believed to have played a part (Crawford 2000). In this increasingly open landscape, herbivores, such as cattle, sheep, goats and deer, kept woodland regeneration in check (Averis *et al.* 2004). Changes in land management for both livestock and, more recently, grouse fostered a further increase in the extent of MMH, with palaeo-ecological evidence pointing to an increase in heather extent from 1500, peaking in about 1800 (Stevenson & Thompson 1993). Until this time, stocking impacts on MMH habitats were generally relatively light due to their limited seasonal and spatial nature (Dodgshon and Olsson 2006). Indeed, it was viewed that "much of the hill pastures was virtually wasteland and could be made much more profitable if systematically grazed by sheep" (Dryerre 1945).

From the 19th Century onwards, cattle-grazing decreased across the whole country. Sheep-grazing started to develop as an industry in the uplands, which caused a step-change in stocking levels, involving larger breeds and the utilisation of ground further uphill. This fostered what was, from a farming perspective, a desired change in vegetation from heather moorland to grass (Dodgshon & Olsson 2006). However, only 40 to 50 years later, with both profitability of sheep farming and opportunities for winter-feeding of livestock increasing, reports of pasture overgrazing started to appear (Dryerre 1945; Dodgshon & Olsson 2006). Meanwhile, many lowland heaths were abandoned and changed into scrub or woodland (Webb 1986).

Loss of MMH area and condition continued into the 20th Century, most notably after the Second World War, due to the increasing use of the UK's uplands for forestry, changes in subsidies for agriculture in marginal areas, changes in the game management of moorland, and increases in the deposition and accumulation of atmospheric pollutants. The main pressures in the lowlands were urban development, agricultural improvements, abandonment of traditional practices, and afforestation (Webb 1986; Dallimer *et al.* 2009). More recently, a variety of conservation-based initiatives have been developed to arrest or reverse long-term decline in MMH area. Reductions in acidic deposition have led to a reduction in soil acidity and reduced the pressure on acid-sensitive plant species. Conservation objectives are also behind the current promotion of natural and assisted regeneration of native woodland which will inevitably be at the expense of open MMH habitats in some areas.

During the last 20 years, MMH is estimated consistently to cover about 18% of the UK (**Table 5.1**; **Figure 5.2**). Most occurs in Scotland (34,310km2), where it makes up 43% of the land surface area; followed by England (6,930km2), Wales (2,460km2), and Northern Ireland (2,280km2), representing 5%, 12% and 12% of the land surface respectively. The largest share of MMH is found in the uplands, but smaller and often highly fragmented areas also occur in the lowlands.

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5.1.2 Environmental Conditions

The basic character of MMH habitats is strongly influenced by three sets of factors. First, local-scale geographic factors, such as slope, aspect and altitude, are fundamental to the vegetation character and associated wildlife in these habitats (Koerner & Ohsawa 2005). Local environmental conditions, such as air temperature, wind, cloud cover, rainfall, and snow cover, change rapidly with altitude (**Figure 5.3**) and proximity to the coast, promoting great diversity of life. The more climatically unfavourable conditions experienced in the uplands also serve to restrict human habitation. Second, larger-scale geographic factors that give rise to climatic conditions exert a strong additional influence, notably the strong east-west gradient in oceanicity (Crawford 2000) and north-south gradient in temperature. Both local and larger-scale geographic factors, therefore, determine that Britain tends to be wetter in the west and cooler in the north. Third, the geological substratum is hugely diverse across MMH habitats. It governs landform and drainage; soil pH, rates of nutrient cycling and sensitivity to atmospherically deposited pollutants; opportunities for agricultural use and wider ecosystem services including the exploitation of specific minerals or storage of societal waste products. Together, and under conditions of anthropogenic influences, these factors have allowed the development of a range of MMH habitats with their communities and species. Notably, moorland and bog developed where cooler and wetter conditions restrict organic matter decomposition rates to encourage the development of peat; heathland resulted where moderate to high rainfall on thin, nutrient-poor soils has led to podsolisation.

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5.1.3 Societal Use

The upland environment is such that human occupation has never been extensive, although, in the past, many more people inhabited these landscapes than do so currently. On the other hand, many lowland heaths and some upland habitats, such as the Peak District, are now in relatively close proximity to urban centres. The general low fertility of MMH soils has mostly limited agricultural practices to livestock-grazing. Whilst provisioning services, such as livestock-grazing, continue to be important in the uplands, agriculture increasingly fulfils additional functions of maintaining cultural landscapes and small-scale rural economies. The once important extraction of minerals, rock, coal and peat from MMH landscapes now takes place at a much reduced scale.

Mountains are known to play a key role in the Earth's water cycle, providing feedbacks to regional climate and modulation of the run-off regime (Koerner & Ohsawa 2005), and there is an increasing awareness that MMH in the uplands provide a wide range of regulating services including water purification, carbon storage and carbon sequestration, as well as potential for some flood regulation (Bonn *et al.* 2009; Bonn *et al.* 2010).

MMH continue to inspire people and form part of our cultural identity (SNH 2008; Natural England 2009b). They offer attractive scenery, exposure to the elements in often remote locations, areas to engage in outdoor pursuits, sites of historic human artefacts and a wide variety of plant and animal species. In so doing, MMH draw people into them, either physically or in their imagination, thus providing a rich set of cultural services to society. Furthermore, MMH include the UK's largest and last unfragmented habitats, which provide a refuge to many species of plants and animals. Collectively, these factors have led to the designation of a major part of MMH as National Parks, Sites of Special Scientific Interest (SSSI)/Areas of Special Scientific Interest (ASSI), Special Areas of Conservation (SAC), Special Protection Areas (SPA) and/or Ramsar sites. While biodiversity has played an important role behind such designations, emphasis on additional MMH aspects, like geodiversity (i.e. the diversity of rocks, minerals and landforms; Gray 2008), is currently developing. Some of these designations have contributed to a situation where tourism and recreation now form an important source of rural economic revenue (Deloitte 2008), while field sports, such as deer and grouse shooting, remain important market-valued activities. Fundamentally, the continued delivery of provisioning, cultural, regulating and supporting ecosystem services requires well-functioning, extensive and intact ecosystems; i.e. both losses in scale and deteriorations in quality constrain ecosystem service supply.

5.1.4 Approach

This chapter provides a first assessment of the status and trends in MMH habitats and their use by society from 1945 to 2010, including an evaluation of the prime drivers behind such trends. A number of 'direct' factors, notably land use changes (grazing, development), airborne pollution, climate change and recreational pressures, drive the contemporary changes in MMH habitats and the ecosystem services they provide. In turn, these direct factors depend on a number of underlying factors such as population growth, changes in leisure time and disposable incomes, agricultural prices, the Common Agricultural Policy (CAP), and agri-environmental schemes. Both direct and underlying factors are moderated in terms of their impacts by a number of policy mechanisms (e.g. EC Birds, Habitats, Water Framework and National Emissions Ceilings Directives) and cultural pressures. Here, we aim to cover both drivers and moderating factors directly or indirectly responsible for contemporary changes in MMH.

In five separate sections we provide an overview of: the major changes in habitats and underlying drivers (Section 5.2); associated goods and ecosystem services provided by MMH habitats (Section 5.3); trade-offs and synergies between the delivery of such goods and services (Section 5.4); near-term options for sustainable management (Section 5.5); and major knowledge gaps that need addressing to facilitate the development of such management options (Section 5.6). The longer-term future of MMH habitats is the focus of Chapter 25, Chapter 22 looks at the past and present value of ecosystem services, and Chapter 26 looks at how these values might change under a range of future scenarios.

5.2 Trends and Changes in MMH

5.2.1 Drivers of Change

5.2.1.1 Land use

Forestry. Perhaps one of the greatest losses of MMH habitat area since the Second World War has been to commercial forestry. Supply shortages during the First World War led to the formation of the Forestry Commission in 1919, which was tasked with creating a strategic reserve of timber as a matter of national security (Condliffe 2009). Attention concentrated initially on high quality agricultural land, but focus gradually shifted towards more marginal land including moorland and heath (**Table 5.2**). The 1950s saw the development of powered cableway extraction methods that allowed access to previously unmanageable areas, and access roads across areas of MMH were opened up in many parts of the UK. Since 1990, there has been a steep decline in the afforestation of organic soils due to the disappearance of tax incentives, the recognition that wood production (in what are often wet and nutrient-poor habitats) tends to be poor, concerns about the loss of habitat for plant and animal species of open landscapes, and the development of the UK Woodland Assurance Scheme (UK WAS) (Chapter 8). However, planting on more mineral soils, natural regeneration through reducing grazing pressure, and a localised loss of other management practices, such as cutting and controlled burning, have resulted in the development of (mostly native broad-leaved) woodland at the expense of open MMH (Webb 1986; Marrs *et al.* 1986; Mitchell *et al.* 1997).

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Some plantations are being felled for conservation purposes or converted to broad-leaved woodland. A change in market conditions (certification), rising demands from new biomass plants and changes in real prices will drive further changes in MMH forestry. National and regional level targets for new forest planting can also be seen as drivers, although these are currently not being achieved. Planting on deep peat is being discouraged (Forestry Commission 2009) due to negative effects on soil properties, potential long-term reductions in carbon storage and biodiversity goals. Given current grants, land prices and lack of officially sanctioned carbon markets for UK forests, rising imports might be the most likely consequence of increased demand for timber, rather than significant new planting.

Grazing. Arguably the most significant driver of change in MMH habitat quality has been changes in grazing by sheep and deer in the Scottish Highlands, and by sheep, cattle and ponies in England, Wales and Northern Ireland. High grazing pressure throughout much of the uplands has substantially reduced the quality and extent of alpine and sub-alpine dwarf-shrub heath, moss heath, scrub and herb-rich vegetation. Conversely, reduced grazing is considered a prime cause of deterioration of lowland heath. There is also experimental evidence that intermediate grazing pressure can be of benefit to some bird species in the uplands (Evans *et al.* 2006a; Pearce-Higgins & Grant 2006).

The effects of grazing and trampling on upland MMH habitat are widely documented (Stevenson & Thompson 1993; Welch & Scott 1995; Lake *et al.* 2001; Hulme *et al.* 2002). Notably, the transition from heather to grass has been observed following an increase in pressure from sheep-grazing (**Figure 5.4**) with consequences for plant diversity. Sheep preferentially graze grasses but utilise heather and other dwarf shrubs along the edge of grass patches and paths (Palmer *et al.* 2003). Consequently, the condition of heather can be severely impacted by grazers and ultimately leads to grass-dominance across hill slopes, as is the case in much of upland Wales and Northern Ireland. For deer, heather represents a higher quality winter food, so grazing impacts on these shrubs and others, such as bilberry, can be greater. Estimates of the number of red deer in the Scottish Highlands indicate a continuing upward trend from the 1920s onwards (**Figure 5.5**), although this may have been more gradual than generally portrayed due to complications of estimating deer in woodland (Clutton-Brock *et al.* 2004).

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Livestock numbers in MMH areas reflect changes in agricultural market conditions, technology (e.g. new breeds of sheep; introduction of the turnip in the late 18th Century –Dryerre 1945) and land ownership and management. These determinants had direct impacts on agricultural land use, and indirect effects on biodiversity (Hanley *et al.* 2008). Since the end of the Second World War, the UK government has supported farming in MMH areas through a variety of price support and headage payments schemes, supported by the EC CAP from 1974 (Condliffe 2009). Key drivers include the 1946 Hill Farm Act, the 1947 Agricultural Act, the 1972 European Economic Community (EEC) livestock headage payments, the 1975 EC Directive with introduction of Less Favoured Area Scheme, the UK Hill Livestock Compensatory Allowance scheme, and subsidies for large-scale drainage schemes. The net effect of these inducements has been a substantial increase in stocking densities, which have damaged and fragmented MMH habitats, particularly in the hills and mountains (Anderson & Yalden 1981; Dallimer *et al.* 2009). In Wales, for example, sheep numbers rose by 71% between 1974 and 1994 (Fuller & Gough 1999); in the Carneddau area of Snowdonia specifically, sheep densities may have risen from 1.2 to between 5-6 sheep per hectare (ha) over the second half of the 20th Century (Britton *et al.* 2005).

In contrast to the problem of land abandonment in mountains encountered in many other countries (MacDonald *et al.* 2000), the lack of herbivore-grazing to maintain a desired vegetation structure and species composition in the uplands of the UK has rarely been an issue of concern. However, a significant reduction in the grazing of lowland heaths over the last century led to the development of scrub and woodland through natural succession (Webb 1986), and consequently to the loss of rare species (Byfield & Pearman 1995). Webb *et al.* (2010) showed that of the 133 UK Biodiversity Action Plan (UK BAP) priority species associated with lowland heath, 53% required bare ground and early successional stages. Since grazing can provide such features when combined with other management options (Lake *et al.* 2001), livestock is now being reintroduced to many lowland heaths, often supported by agri-environment schemes, but mostly by conservation organisations, rather than by farmers.

Over the last decade, pressure from sheep-grazing on upland MMH habitats has eased in some regions (RSE 2008), with as yet undetermined impacts on ecosystems. Income support for farmers has gradually moved away from a production-related basis. From 1987 to 1991, the first agri-environment scheme was launched, with Environmentally Sensitive Area (ESA) payments rewarding farmers for caring for the environmental, historical and cultural features on their land, while reducing stocking numbers. The ESA (England and Scotland) and Tir Gofal (Wales) schemes covered a large proportion of MMH habitats. In Scotland, MMH comprises one third of the 19% of total land area under ESA prescription. While these schemes have reduced sheep- and cattle-grazing pressure in some areas, other factors, including decreasing subsidies, unstable market prices, increasing input costs and additional regulatory burdens, have been implicated in a wider, recent reduction in hill sheep, particularly on the west coast of Scotland (SAC 2008).

Ten years is a very short period to gauge environmental trends, and the efficacy of agri-environment schemes in promoting ecological improvement remains contested (Whittingham 2007). The consequence of different grazing pressures on ecosystem services (e.g. carbon sequestration, water purification, tourism) are beginning to be investigated through modelling and land use experiments, but scientific understanding is currently limited.

Grouse Moor Management. Burning is a principal tool in the creation and maintenance of habitat suitable for grouse. Long-term data on red grouse hunting bags from across 495 estates (Aebischer & Baines 2008; **Figure 5.6**) indicates that high numbers of grouse were shot prior to the Second World War, but that there was a collapse in numbers during the war, partial recovery until the early 1970s, and further, gradual decline during the last 40 years. This long-term reduction may partly be due to a relaxation of Victorian/ Edwardian practices of predator eradication and rotational heather-burning to produce a patchwork of small areas with heather growth of different ages (Aebischer & Baines 2008), but increased sheep-grazing and afforestation are also thought to have contributed (Holloway 1996). With the recent decline in income for stocking sheep, some estates are viewing shooting as the most profitable use of the land; as a result, grouse shooting activity in the English uplands increased between 2001 and 2009 (Natural England 2009a).

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Grouse management carries cultural importance and contributes to the maintenance of large areas of heather moorland which are of international importance (Thompson *et al.* 1995). However, there are mounting concerns over: i) the visual impact of burning; ii) potential damage to peat structure and subsequent carbon losses through atmospheric exposure in more heavily burnt areas (Yallop & Clutterbuck 2009); and iii) the impacts of associated long-term predator control on some elements of biodiversity. The killing of mammals and birds regarded as 'vermin' to protect agricultural and hunting interests has taken place for at least 450 years, leading to unprecedented species removal, most notably from upland habitats (Lovegrove 2007; **Box 5.2).** Whilst this may benefit ground breeding moorland birds such as lapwing (*Vanellus vanellus*) and curlew (*Numenius arquata*) (Fletcher *et al*. 2010), persecution has resulted in the extermination of several birds of prey, including osprey and white-tailed eagle, well before agricultural pesticides started taking their toll in the 1960s. Several species of raptors, such as red kite and white-tailed eagle, are now being reintroduced; yet illegal persecution is still ongoing, for example, of hen harriers (Etheridge et al 1997), golden eagle (Whitfield et al. 2004) and red kite (Smart et al 2010). This situation indicates the importance of working towards a consensus, whereby the diversity of birds and mammals is enhanced, while also accommodating cultural practices such as grouse management, which are perceived to play a vital role in rural economies (Thirgood & Redpath 2008; White *et al.* 2009).

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Urban development*.* The main loss of MMH to urban development has been in southern England. Webb (1986) indicates that, of the 40,000 ha of lowland heathland present in Dorset in the 1750s, 17,500 ha was lost to agricultural improvements and forestry by 1896, and later losses, mainly to development, left around 6,000 ha by the 1980s. Many towns and cities in southern counties, including London and Bournemouth, have expanded ten-fold in 100 years, often on previous heath (Webb 1986); it is estimated that 12% of the heathland in the Poole-Christchurch-Bournemouth area has been converted to urban sprawl in recent decades (Haskins 2000).

Urban encroachment also impacts on the quality of our remaining heathland through disturbance of wildlife (Liley and Clarke 2003), arson, dumping of rubbish and trampling (Gallet and Roze 2001), and the increased vulnerability of populations of rare species through habitat fragmentation (Haskins 2000).

5.2.1.2 Air pollution

MMH soils and vegetation are sensitive to the atmospheric deposition of sulphur and nitrogen derived primarily from oil and coal burning by the electricity generating sector (both sulphur and nitrogen), motor vehicle exhausts (oxidised nitrogen) and intensive agriculture (reduced nitrogen). Levels of sulphur and nitrogen contamination over most of the past two centuries of industrialisation have generally been highest in the south of the UK and lowest in the far north and west – a consequence of the location of population centres and heavy industry. However, atmospheric pollutant deposition is amplified in the uplands by the presence of hill (orographic) cloud that captures fine pollutant aerosols in cloud droplets (Fowler *et al.* 1988). Upland areas at mid-latitudes have therefore been some of the most impacted areas of the UK. There are two key effects of particular concern for MMH habitat: acidification and eutrophication; and trends in both are detailed in the current Review of Transboundary Air Pollution (RoTAP2011).

Acid deposition results from the transformation of sulphur and nitrogen oxides in the atmosphere to sulphuric and nitric acids which are subsequently deposited to the land surface in particles, gases or precipitation. Sulphur has been the primary source of 'acid rain' since the early stages of the industrial revolution, but levels have declined steeply since the 1970s (Chapter 14). Acid deposition acidifies soils by stripping them of their base cations (such as calcium and magnesium) and raising concentrations of hydrogen and inorganic aluminium ions that are damaging to the roots of sensitive plant species and microbial communities involved in nutrient cycling. In the south Pennines, the UK's most heavily impacted area, sulphur deposition has been argued to be the main factor driving long-term decline in sensitive bog vegetation (Lee 1998). Nitrogen deposition can also have an acidifying effect when deposited in a reduced form (as ammonium); acidity is generated if ammonium ions are oxidised to nitrate by bacteria in the soil (nitrification). The prime effect of nitrogen deposition, however, is eutrophication.

Having evolved under conditions of low nitrogen availability, MMH plant species are often vulnerable to even small elevations in nitrogen inputs at low ambient concentrations through the effects of eutrophication (Bobbink *et al.* 1992). Low nutrient levels encourage the presence of specialist species, which are frequently used as indicators of high biodiversity value, but these may fail to compete with more nutrient-demanding species once nitrogen becomes more abundant. Nitrogen enrichment can also result in phosphorus limitation and other nutrient imbalances (Phoenix *et al.* 2003), and has been linked to other environmental stresses including pests, diseases and late winter injury (Power *et al.* 1998; Carroll *et al.* 1999; Nordin *et al.* 2009). If these effects open up the dwarf shrub canopy, grasses that are more able to utilise higher levels of nitrogen (and particularly reduced nitrogen), such as *Molinia caerulea* and *Deschampsia flexuosa*, may then begin to dominate (Krupa 2003).

Gaseous ammonia appears to be considerably more damaging per unit of nitrogen deposited than either oxidised nitrogen or ammonium (RoTAP 2011), and has been shown to exert clear toxic effects on some bog species including *Calluna vulgaris*, *Sphagnum capillifolium* and *Cladonia portentosa* (Leith *et al.* 2004; Sheppard *et al.* 2008). In contrast to nitrogen oxide and ammonium, ammonia tends to be deposited relatively locally, i.e. mostly within a few hundred metres of sources such as animal enclosures, fertilised crops and motor vehicles (Krupa 2003). Therefore, ammonia pollution tends to pose a greater threat to lowland heathland than more remote upland MMH habitats, although critical levels of ammonia set for generally more sensitive lower plants remain exceeded across 69% of the UK's land surface area (RoTAP 2011).

The impact of airborne pollutants within MMH has likely been greatest for moss- and lichen-rich communities, in part due to the large surface area to mass ratios, and also due to physiological adaptations to obtaining nutrients and water directly from the atmosphere rather than via root systems. There are few long-term vegetation monitoring records for upland terrestrial environments in the UK, but it is apparent that some montane communities, such as the prostrate *Calluna vulgaris-Cladonia arbuscula* heath and *Carex bigelowii-Racomitrium lanuginosum* moss heath that are common in the Scottish Highlands, are now only found in a degraded condition (reduced cover of mosses, lichens and dwarf shrubs) in more polluted upland areas to the south (Armitage *et al.* 2011).

While eutrophication from nitrogen deposition is frequently implicated in upland ecological change, it is often difficult to separate the effects from those of upland grazing, which have often been more intensive at lower latitudes (Britton *et al.* 2005). The conversion of lowland heaths into grasslands as a result of high nitrogen deposition is well-documented across Europe (Aerts & Bobbink 1999), but, since the loss of nitrophobe species may have occurred decades ago, it may now be increasingly difficult to demonstrate the impact of particular nitrogen emission sources (e.g. pig or poultry units, power stations) close to sensitive habitats.

The chief controls on national emissions of sulphur and nitrogen to the atmosphere have been a series of protocols under the UN Economic Commission for Europe Convention on Long Range Transboundary Air Pollution and the European Union National Emissions Ceilings Directive that came into force in 1991. Most policy targets are underpinned by Critical Loads modelling. Over the past two decades, acid deposition in the UK has declined by over 50%, largely due to reductions in sulphur deposition. Nitrogen deposition has not fallen as expected, possibly due to changes in atmospheric chemistry associated with the reduction in sulphate. Thus it remains a powerful driver of habitat quality, notably in mountain areas (RoTAP 2011; **Box 5.3**).

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5.2.1.3 Climatic changes

Climate and topography have shaped MMH distribution and characteristics and continue to exert a dominant influence. For example, Yeo and Blackstock (2002) concluded that geography, rather than land use, remains the primary predictor of vegetation type for the upland moorlands of Wales. However, whereas topography can be considered static over long timescales, the UK climate has changed significantly (Jenkins *et al.* 2008), and is predicted to continue to change in response to the accumulation of greenhouse gasses in the atmosphere. Across the UK, a wide range of climatic conditions affect and mould MMH in many different ways, and these habitats are likely to respond differentially to forecast changes in factors such as temperature and rainfall.

In the montane habitat, low temperatures favour hardy, but slow-growing, arctic and alpine plant species, particularly where there is transient snow-lie. Seasonal snow patches support their own unique ecosystems and species, including cold-sensitive mosses and liverworts that depend on snow for winter insulation, and snow buntings that feed upon snow-patch dwelling insects (Hill *et al.* 1999). Bioclimatic envelope models have been used to describe species distribution in 'climate space' and predict how the suitable geographical ranges of species might alter with a changing climate (Berry *et al.* 2002). Such approaches, however, are contested on grounds of associated algorithmic and ecological uncertainties; for a discussion on their reliability for birds, for example, see the disagreement between Beale *et al.* (2008) and Araujo *et al.* (2009). Uphill movement in plant distributions have been observed in various mountain ranges outside the UK and interpreted as a response to a warming climate (Kelly & Goulden 2008; Lenoir *et al.* 2008). Similar distributional changes are predicted for the UK (Trivedi *et al.* 2008), but no strong empirical evidence has yet been provided. While some species may be able to move uphill, there are concerns that arctic-alpine mountaintop species, such as the Snowdon lily and the Northern Dart moth, are at risk of losing their UK refugia (Hossell *et al.* 2000). However, a great range of climatic parameters other than temperature and snow cover (such as wind speed, rainfall and cloudiness, and hence, light availability) are likely to influence species abundance and survival. This makes the study of actual climate change impacts on species in mountain ranges demanding, and predictions uncertain.

At lower altitudes, blanket bog and heath development depend on interactions between a cool, wet, Atlantic climate and the extent of drainage (Lindsay *et al.* 1988; O'Connell 1990). Response to climate change in these environments will depend on how shifts in precipitation, air temperature, humidity and wind speed affect soil moisture balances both seasonally and inter-annually.

Providing that soil moisture does not become limiting, higher temperatures predicted under UK climate change scenarios are expected to result in increased biomass production of heathlands (Peñuelas *et al.* 2004), and may pose management challenges if the open habitat, required by several characteristic species, is to be maintained. Summer drought may curb plant growth and induce changes in plant species composition, such as the suppression of bracken by heather as shown by Gordon *et al.* (1999). Their controlled-environment experiments also revealed the complexities involved in predicting climate-driven vegetation change: a very cold winter spell proved most damaging to heather that had been subject to drought the previous summer; while winter damage occurred in bracken plants that had been subject to raised temperatures in summer.

Spatial relationships are evident between the location of UK peatlands and climate variables responsible for maintaining positive water balance that is temperature, growing season length and moisture. This has allowed the development of a range of bioclimatic envelope models for peat occurrence (Clark in 2010b). The majority of models predict that the area with climate suitable for active peat formation in the UK will decline over the next century under a range of UK Climate Impacts Programme 2002 (UKCIP02) scenarios (Clark 2010a), and by as much as 84% according to the most extreme prediction that would see climate favourable for peat formation only in parts of western Scotland (Gallego-Sala *et al.* 2010).

Determination of the influence of recent changes in climatic conditions on MMH habitats is hampered by a limited evidence base, absence of effective 'controls', and strong inter-annual variability in both biological indices and climatic parameters, of which there are many. Moreover, the effects of climatic factors, such as air temperature, rainfall, wind speed or cloud cover, do not present themselves in isolation, but are likely to interact with each other and with effects of anthropogenic drivers such as atmospheric pollutant deposition, stocking levels and burning intensities. Indeed, some potentially significant land use changes might themselves be influenced by changes in climate; for example, wetter winters may influence opportunities for, and hence timing of, burning). But perhaps most importantly, long-term and sufficiently dispersed environmental monitoring programmes, which capture information on both potential environmental drivers and target species at appropriate spatial and temporal scales, are rare. The UK's best established monitoring programmes covering MMH habitats are relatively young and, hence, are only now starting to provide hints of possible 'climate change' impacts (Morecroft *et al.* 2009). With continued data collection and the development of statistical techniques for assessing time-series, their records should increasingly inform us about the vulnerability of MMH habitats to 'global warming'. However, carefully designed experiments, coupled with process-based modelling, and ideally conducted in conjunction with long-term monitoring, will be required to elucidate the precise mechanisms involved.

5.2.1.4 Interactions between drivers of change

Almost invariably, MMH habitats are vulnerable to multiple pressures. For example, sheep-grazing and nitrogen deposition in tandem (Box 5.4) may provide the best explanation for the increased dominance of grasses over dwarf shrub (Alonso *et al.* 2001) and moss communities (Van der Wal *et al.* 2003; Britton *et al.* 2005) on mountains and heaths. *Calluna vulgaris* can continue to dominate in experimental conditions under elevated nitrogen deposition providing there is no physical damage from grazing or other factors, such as heather beetle outbreaks or severe frosts (Aerts & Bobbink 1999). A loss of plant cover in bogs through grazing can expose peat soils to the actions of frost and desiccation, resulting in material that can be degraded by wind and rain (Bragg & Tallis 2001) as well as biological decomposition. These changes are likely to have much wider implications for biodiversity and to have knock-on impacts on nutrient and water cycling, as well as carbon, nitrogen and pollutant retention. Better understanding of how multiple pressures lead to changes in habitat extent and condition, and how these influence ecosystem service provision, should be a key focus for future research.

5.2.2 MMH Trends

5.2.2.1 Loss of MMH area

Substantial reductions in the total cover of MMH habitats have occurred over the last 60 years, primarily due to afforestation and conversion to rough grassland by drainage, liming, burning and grazing. Loss of lowland heath has been mainly due to the development of towns and roads, afforestation, agricultural improvement and abandonment; the extent today is around 20% of what it was in 1900 (UK Steering Group 1995).

The loss of significant areas of heather moorland to afforestation was acknowledged in the 1980s (Nature Conservancy Council 1984, 1986). Scottish Natural Heritage estimates that the extent of nationally and internationally important heather moorland (falling into both Bog and Dwarf Shrub Heath classifications) in Scotland declined by 15% (from an aerial coverage of 19% in the 1940s to 15% in the 1980s). Simultaneously, the extent of blanket bog was estimated to have declined by 44% (from 0.3% to <0.2% absolute aerial cover).

Countryside Survey data on MMH habitats showed few clear changes over the last decade, with only small areas changing from one broad habitat to another in Great Britain between 1998 and 2007 (Carey *et al.* 2008). Unsurprisingly, given their isolation, there was little indication of significant shifts in the extent of Montane and Inland Rock, while the concept of 'Bracken' as a separate habitat is relatively new, thus limiting the detection of change. More confidence can be placed in estimates for change in Dwarf Shrub Heath and Bog, but even here designations and methods have changed over time. **Table 5.1** demonstrates that the relative contribution of the six broad habitats to overall MMH cover within the Countryside Survey appears to have varied with time, but few changes are deemed statistically significant.

The most striking change observed by the Countryside Survey was a strong increase (15%) in Dwarf Shrub Heath in England between 1998 and 2007 (Carey *et al.* 2008), although this figure has yet to be independently verified. This increase has been attributed to efforts to restore and recreate lowland and upland heathland (to meet UK BAP targets) by programmes such as Tomorrow's Heathland Heritage, Countryside Stewardship and, more recently, the Higher Level Stewardship Scheme. In the uplands, the main instrument to increase heather cover has been a control on grazing pressure, possibly aided by the removal of livestock following the 2001 outbreak of Foot and Mouth Disease. In the lowlands, the main instruments have been the reduction in the extent of scrub and secondary woodland, the creation of new heathland sites (for example, more than 4,000 ha has been recreated or restored in the China Clay country, Cornwall), the chemical and mechanical control of bracken, and the reintroduction of grazing.

Conversely, Countryside Survey data provides an indication of a small reduction in Dwarf Shrub Heath in Scotland during the last 20 years, which is attributed to increases in Acid Grassland and Bracken in the uplands (Carey *et al.* 2008). Over a longer timescale, bracken has clearly expanded in recent decades; Barr *et al*. (1993) estimated a 400,000 ha increase in cover between 1984 and 1990 alone. This is a widely perceived as an unwelcome change because the habitat is considered to bring limited benefit (Pakeman & Marrs 1992), but instead to reflect 'poor management of the land' (for example previous overgrazing). Bracken is toxic and carcinogenic to livestock and potentially also humans. For example, there are concerns regarding an increased risk of oesophageal cancer among people in catchments with extensive bracken cover (Alonso-Amelot & Avendano 2002).Bracken stands are also considered a source of ticks, which, through tick-borne diseases, can negatively impact on both livestock and humans. There is no evidence to suggest a trend towards greater bracken coverage at a millennial scale, however, and palaeo-ecological records indicate that current bracken levels may be no greater than historical maximum levels throughout the Holocene (Pakeman *et al.* 2000).

5.2.2.2 Changes in MMH habitat quality

Although most of the UK land area attributed to MMH broad habitat has not changed in designation in the last 60 years, there is widespread evidence of long-term reductions in ecological status. One of the most notable examples of deterioration is found in the southern Pennines and North York Moors. Here, overgrazing, ecologically damaging levels of burning for livestock and game, and high levels of atmospheric nitrogen deposition in some areas have resulted in a major degradation of upland moorlands and heaths which has been damaging for biodiversity, has increased soil carbon losses and has reduced the aesthetic quality of the landscape.

Slow changes in species composition in less physically disturbed habitats are more subtle and are often difficult to detect with current terrestrial monitoring capabilities. The most widely reported transition has been a progressive increase in grasses, particularly *Molinia caerulea, Deschampsia flexuosa* and *Nardus stricta*, at the expense of *Calluna vulgaris* in moorland and heathland – trends which are continuing in some areas. However, the area of *C. vulgaris* has also increased, at the expense of blanket bog in some areas, mainly as a result of excessive or inappropriate burning (Yallop *et al.* 2006). The Countryside Survey indicates that between 1998 and 2007 the ratio of grasses to forbs increased in both Dwarf Shrub Heath and Bog in Scotland and also in Dwarf Shrub Heath in England Concomitantly, there has also been a small decline in mean plant species richness in Scottish Bogs and Dwarf Shrub Heaths, and increases in the proportion of competitive species relative to ruderal species in Scottish Bog. Changes in the latter were accompanied by a reduction in the number of species used as food by butterfly caterpillars and farmland birds (Carey *et al.* 2007). It has been argued that the spread of grasses in these habitats has negative impacts on conservation values (Chambers *et al.* 1999; Marrs *et al.* 2004; Milligan *et al.* 2004; **Box 5.4**).

INSERT BOX 5.4

Acidification. The pattern of soil acidification and recovery broadly follows the trend in anthropogenic sulphur deposition. Before the Second World War, soils in many upland areas from central Scotland southward (including parts of the Trossachs, Galloway, the English Lake District, North York Moors, Pennines, Snowdonia, the Cambrian Mountains of central Wales and Dartmoor) had already lost significant acid-buffering capacity. In more geologically sensitive regions, this resulted in a lowering of soil pH and mobilisation of biologically toxic inorganic aluminium, eventually resulting in the acidification of upland streams and lakes in this area and, therefore, the loss of acid-sensitive freshwater biota (NEGTAP 2001). Terrestrial impacts have received less attention, but are also likely to have involved the loss of some sensitive species, particularly as a result of disruption to root function (Stevens *et al.* 2009), to the advantage of acid-tolerant species such as the grass *Molinia caerulea*. Soil acidification continued until at least the period of peak sulphur deposition in the 1970s. Sulphur deposition has since declined, so some recovery in soil base cations and pH is expected. Replenishment of base cations where weathering rates are low (for example in granitic areas and deep organic soils), or the soil surface is poorly connected to underlying mineral horizons, is expected to be an exceptionally slow process and may take many hundreds of years.

There have been widespread increases in soil pH in response to reduced sulphur loads over the last two decades (RoTAP 2011). The Countryside Survey reported upward trends in soil pH (0-15 cm depth) in Bracken, Dwarf Shrub Heath and Bog broad habitats between 1978 and 1998 for Great Britain as a whole. Soil solution chemistry data from Environmental Change Network (ECN) upland moorland sites shows clearer pH increases in deeper mineral soil horizons than in the more organic surface soil of upland moorland sites (Morecroft *et al.* 2009). The damped response at the soil surface indicates that soil organic matter in these habitats may have provided an important ecosystem service by buffering the pH of soil and water runoff against the influence of acid pollutants.

Critical Loads for acidity (and eutrophication – see below) are mapped nationally to identify the sensitivity of terrestrial UK BAP Broad Habitats. For peaty soils, the critical load for acidity is based on the amount of acid deposition (from sulphur and nitrogen compounds) that would prevent the soil solution pH from falling below pH 4.4 (Calver *et al*. 2004) over long-term 'steady-state' conditions. It is estimated that, over the period 1986 to 2006, the proportion of MMH broad habitat area exceeding the set acidity threshold fell from 92.7% to 46.5% for Dwarf Shrub Heath, 95.9% to 67.1% for Bog, and 99.9% to 96.8% for Montane (RoTAP 2011). This suggests that Montane soils have not yet benefitted significantly from the large reductions in sulphur deposition and thus remain at risk from acidification.

Eutrophication. Control of nitrogen emissions over the last two decades was expected to result in a major decline in nitrogen deposition. However, analysis provided by RoTAP (2011) shows that, despite reductions in oxidised and reduced nitrogen of 50% and 19% respectively, the total deposition of nitrogen in the UK has declined by only 5%, and expectations for short-term recovery are low.

A combination of field experiments and surveys indicate that the effects of nitrogen deposition on MMH habitats have been wide-reaching and detrimental. Field surveys, including the *Calluna* Moorland Survey (Edmondson *et al.* 2006), the Countryside Survey Heath and Bog Survey and the Scottish Moorland Surveys (Britton *et al.* in press) all show significant reductions in total species richness with increased nitrogen deposition, while the Scottish Moorland survey also points to reductions in lichen cover, lichen richness, ericoid richness and graminoid richness (RoTAP 2011).

The extent to which nitrogen deposition has driven observed vegetation change through fertilisation remains unclear. In their testing of nitrogen deposition hypotheses using Countryside Survey data, Maskell *et al*. (2010) found a strongly significant nitrogen deposition effect on species richness of heathland in the 1998 dataset that could not be explained by other potentially important environmental factors. The most vulnerable species were small forbs (e.g. *Campanula rotundifolia*, *Hypericum pulchrum*, *Viola* species) and bryophytes such as *Hylocomium splendens*. However, no link was apparent between vegetation change and changes in fertility indicators, leaving the authors to propose that the dominant influence of nitrogen deposition had been through acidification rather than eutrophication.

Monitoring programmes, such as the ECN, provide surprisingly little evidence of changes in species richness over the last 15 to 30 years, with the exception of surveys in northern Scotland (**Box 5.5**). Given the widespread evidence from the spatial surveys of nitrogen effects, the most plausible explanation is that most of the damage to vegetation occurred much earlier (nitrogen deposition has been elevated in some areas since the onset of industrialisation), and that the lower deposition areas in northern Scotland are the only ones where nitrogen remains limiting. Given the small reduction in nitrogen deposition in most regions, it is not surprising that the proportion of Dwarf Shrub Heath, Bog and Montane habitats currently deemed to be exceeded by nitrogen with respect to eutrophication has changed little since the mid-1980s (**Table 5.3**). Note that the most widely exceeded habitat is considered to be Montane – the critical load for this habitat of 7 kg nitrogen/ha/yr is currently exceeded almost everywhere, and even by 2020, 90% of this area is expected to be receiving ecologically damaging levels of nitrogen deposition (RoTAP 2011).

INSERT BOX 5.5

INSERT TABLE 5.3

Climate change. Instrumental temperature records from around the UK show that air temperatures have been rising for over a century (UKCIP09). Particularly rapid increases have been seen since the 1960s, with several records for extreme high summer and winter temperatures over the last decade.

Mean daily air temperatures have risen by similar amounts across all UK regions and seasons between 1961 and 2006, with an annual rise of between 1.05 and 1.67°C. Trends are strongest for winter (December to February) and generally slightly stronger for this season in the south and east of England where MMH habitats are less common.

Nevertheless, there is evidence from a limited number of high altitude weather stations that upland environments are warming more rapidly than the national average, with particularly clear indications of trends of reductions in frost days and snow-lie. Among ECN sites, warming over the period 1993 to 2007 was more rapid in upland/montane sites (1.2ºC) than lowland sites (0.7ºC) (Morecroft *et al.* 2009); this is consistent with the observations of Pepin and Lundquist (2008) for upland environments globally. In an altitudinal comparison of air temperature increases, Holden and Rose (2010) concluded that winter warming had dominated at the upland ECN site Moor House in the north Pennines, while summer warming had dominated at the nearby lowland site in Durham. Between 1961and 2006, the duration of continuous snow cover in Scotland is reported to have shortened (starting later in autumn and ending earlier in spring), the average number of days with frost have declined by 25%, and the growing season (i.e. five consecutive days with a mean air temperature above 5°C) now starts around three weeks earlier and ends two weeks later than was typical during the 1960s (Barnett *et al.* 2006).

Some parts of Scotland and northern England have seen disproportionally large increases in winter precipitation compared to the UK as a whole (70% in northern Scotland and more than 100% in some areas of the West Highlands and Hebrides). There has not been a significant change in summer rainfall in most regions, although parts of north-west Scotland have become up to 45% drier (Barnett *et al.* 2006). Importantly, with respect to potential erosional impacts on degraded MMH soils, Scotland has also experienced a significant trend in the number of days with 'intense' rain (i.e. over 10 mm).

Some key studies are pointing to changes in the distribution patterns of some invertebrate groups, changes in timing of breeding in some birds, and possible changes in diet (Roy *et al.* 2001; Morecroft *et al.* 2009; Pearce-Higgins *et al.* 2010; Thackeray *et al*. 2010) associated with recent changes in climate, and projections by UKCIP projections identify mountain habitats as particularly sensitive to 'climate change', leading to shifts in species distribution. While there is evidence that changes in snow-lie have fostered changes in vegetation, mechanisms are less well understood. However, there are implications for montane birds dependent on insects associated with snow patches, such as snow bunting, dotterel and golden plover. Between the 1920s and 1960s, the estimated number of breeding snow bunting fell, but this decrease was followed by a recovery in the 1970s and 1980s. Unfortunately, since the early 1990s, numbers have once again declined: the Scottish breeding population of snow bunting was estimated as just 50 pairs in 2005 (Forester *et al* 2007). Another arctic specialist, the ptarmigan, has seen a decline in numbers since the 19th Century; more recently, birds have disappeared from areas where montane heath has been replaced by grassland. Changes in snow-lie are likely to strongly influence the seasonal pattern of runoff and hence are implicated in water quality (notably particulate carbon) and flood management issues. The impacts of reduced snow-lie, including the consequential increase in the number of freeze-thaw cycles, continue, with implications for surface erosion rates and carbon retention. On the other hand, milder winters have been viewed as instrumental for the expansion of other species, such as the Dartford warbler in the lowland heathlands of southern Britain (Wotton *et al.* 2009).

5.3 Ecosystem Goods and Services Provided by MMH for Human Well-being

5.3.1 Provisioning Services

5.3.1.1 Food provision: livestock and crops

Mountains, Moorlands and Heaths naturally have low agricultural productivity due to soil properties, waterlogging and topography, and are, therefore, generally classed as poor quality agricultural land. MMH habitats are mainly used for grazing sheep and, to a lesser degree, beef cattle at lower altitudes. Land improvements via drainage and lime and fertiliser treatment have been used to increase productivity; such measures have allowed a small part of MMH to be converted into arable production, but, more commonly, have led to the development of 'rough grazing' or improved grassland.

5.3.1.2 Food provision: venison and gamebirds

Sporting estate management generates supplies of venison and, to a lesser extent, gamebirds (e.g. grouse) for sale in commercial outlets such as game dealers. However, it is important to realise that the main motivations for sporting estates are not commercial sales (Sotherton *et al.* 2009), but rather provision of the hunting experience that such land offers (Section 5.3.2).

5.3.1.3 Fibre: sheep wool

Sheep wool is closely associated with sheep meat production, but is currently considered a by-product with little market value; it may, however, become more important as an insulation material in the future. There are small conservation projects that are marketing the products, such as wool, from lowland heathland grazing.

5.3.1.4 Traditional lifestyle products

Past agricultural activities in moorland and heathland required the extensive and creative use of natural material at hand. Bracken and tall rushes were used as convenient bedding material for animal stalls, and heather was used for thatching (Howkins 1997). Living from the land included snaring rabbits, collecting bilberries for jam-making, preparing peat-smoked salmon, cutting willow for basket-making and keeping bees for honey. Today, some MMH plants are still used for human benefit; for example, heather cuttings are used as mulch for the restoration of bare peat or for bio-filtration, and bog myrtle is used as midge-repellent ingredient (Sanderson & Prendergast 2002). There are currently 20,000-30,000 beekeepers in the UK, producing approximately 2,000 tonnes of honey each year (British Beekeepers' Association), of which heather honey from upland and lowland heath has twice the value of other types of British honey (Sanderson & Prendergast 2002; Chapter 15). There is an increasing demand for traditional lifestyle products, which can be purchased along with other locally produced goods (including baskets, meat from specialised breeds, game, ale and wine and works of art inspired by natural scenes) in outlets such as farm shops, tearooms and garden centres.

5.3.1.5 Peat extraction

Peat has been used as fuel for many centuries; with a calorific value of around 20 megajoules/kg, it is similar to wood and lignite in its energy capacity. The use of peat for fuel peaked in the 18^{th} and 19^{th} Centuries, but then declined with the advent of electric power. Today, peat extraction for fuel and horticultural use is still a significant, although localised, aspect of MMH (ADAS & Enviros 2008; Tomlinson 2010). Three million cubic metres of peat is extracted for horticultural use every year in the UK (Defra 2010). Although bringing commercial benefits, peat extraction negatively impacts on biodiversity through habitat destruction, and approximately 0.5 million tonnes of carbon dioxide are emitted each year as a result of peat extraction from UK sites (Defra 2010). The UK government is committed to reducing peat use under the UK BAP and has set targets for non-peat soil improvers and growing media to be supplied: 40% by 2005 (met) and 90% by 2010 (not achieved yet) (Defra 2010).

5.3.1.6 Mineral and coal extraction

Considerable amounts of minerals and coal are still being extracted from within the UK through quarries and opencast mining, some of which takes place in MMH where it leads to the destruction of the habitat in most cases. Moreover, permission for the opening of new quarries and coal mines continues to be requested and sometimes granted. Coal remains an important fuel for UK power generators and is used by many households, most notably in rural areas.

5.3.1.7 Freshwater provision

Mountains, Moorlands and Heaths are a significant source of water supply: 68% of the UK's drinking water comes from surface water sources (DWI 2008; DWQR 2008), mostly from the uplands. The Peak District National Park, for instance, holds 55 reservoirs and serves as a major water source to surrounding conurbations; abstraction licences total more than 450 billion litres of raw water per year from this area (Bonn *et al.* 2010). Reservoirs also exist in and around lowland heathlands (e.g. Chasewater Heaths SSSI).

There are three key components to this service provision: (i) *Upland landscape position*: The uplands are areas of high rainfall because of orographic enhancement (Malby *et al.* 2007). Due to their altitude, water is easily distributed. (ii) *Steep slopes, thin soils or peat cover*: Both thin soils and peat soils promote rapid, near-surface runoff of water. Blanket bog runoff is primarily by saturation-excess overland flow or near-surface through-flow, which produces a 'flashy' hydrological regime (i.e. one characterised by flash flood episodes; Evans *et al.* 1999; Holden & Burt 2003a, 2003b). Upland blanket bogs and dwarf shrub heaths are not good regulators of water supply during dry periods as the hydraulic conductivity of the peat mass is very low, thus limiting the maintenance of base flows (Holden & Burt 2003b). In these habitats, stream flow is closely linked to rainfall because water runs off rapidly and soil storage is limited. Therefore, artificial storage, in the form of reservoirs, is important for the continuous supply of drinking water. In higher mountains, where snow lies, runoff may be closely linked to thaw events (Baggaley *et al.* 2009). (iii) *Provision of clean (dilute) waters*: An important part of the freshwater provision service is the relatively dilute nature of upland waters due to limited human impacts, relatively low weathering rates, extensive peat cover and widespread overland flow. These clean waters dilute downstream pollutants, reducing water treatment costs, and increasing water quality. However, the increase in Dissolved Organic Carbon (DOC) concentrations in water from upland catchments (see below) provides a treatment challenge for water companies.

The excavation of grips (field drains) in UK upland habitats – largely grant-aided to improve land for hill farming following the 1946 Hill Farming Act (Condliffe 2009) – has dramatically increased drainage density and, in some cases, demonstrably increased the 'flashiness' of upland runoff. However, hydrological processes are complex, and there are also examples of reduced peak flows (Holden *et al.* 2004; 2006); the effects of drainage within a catchment are strongly contingent on the spatial arrangement of the wider drainage network (Holden *et al.* 2004).

5.3.2 Regulating Services

5.3.2.1 Climate regulation

Within the terrestrial biosphere, northern peatlands are the most important carbon store, and have the capacity to act as a further carbon sink. Within the UK, an estimated 44% of all terrestrial carbon (4,562 million tonnes within 0-100 cm depth) is held by unforested semi-natural habitat (Bradley *et al*. 2005); while this also comprises semi-natural grasslands and lowland wetlands, a good proportion of the carbon (2,015 million tonnes) is held within MMH (**Figure 5.7**; Chapter 14). Given the preponderance of MMH in Scotland, much of the UK's total stock of carbon is found here. Other areas with large carbon stocks are the north of England and Northern Ireland. Above-ground and below-ground forest biomass carbon stocks are estimated at 136 million tonnes (Forestry Commission 2009), and are, therefore, small compared to those held in organic soils, i.e. deep peats and organo-mineral soils.

INSERT FIGURE 5.7

In an active, peat-forming state, MMH soils represent net sinks of carbon dioxide (Gorham 1991) and, in the case of waterlogged soils, sources of methane (Huttunen *et al.* 2003). Changes in climate, notably in rainfall and temperature, are likely to influence the net flux of both gases and hence affect the capacity of ecosystems to store carbon. Therefore, MMH represent both a threat to the global carbon cycle and an opportunity in terms of climate change mitigation policies that encourage adaptive land management to safeguard carbon stores and, to a lesser degree, further carbon sequestration.

Renewable energy schemes within MMH (windfarms, hydroelectric schemes) represent an opportunity to mitigate carbon dioxide emissions. In Scotland alone, 260 developments are currently installed, of which an estimated 30% are in core MMH habitat, mostly at its fringes; many more are approved, proposed or at scoping stage (**Figure 5.8**). While these developments can make a positive contribution to the UK's net emissions, their development is highly contentious and needs careful planning. Their location may negatively influence biodiversity and landscape character (Bergmann *et al.* 2006), and their net effects on carbon flows needs to be evaluated as windfarm construction and associated drainage of deep organic soils can lead to considerable carbon losses (Nayak *et al.* 2010).

INSERT FIGURE 5.8

Disturbance of the plant-soil system tends to reduce carbon sequestration (Van der Wal *et al.* 2007; Sjogersten *et al.* 2008), with factors such as soil type, landscape position and exact management interventions all being of influence. Recent studies on peatland at Moor House National Nature Reserve have shown that changes in vegetation composition affect carbon cycling through differential rates of assimilation and transfer of recent photosynthetic carbon to soil, differences in rates of respiration (Ward *et al.* 2007; 2009), and by influencing litter decomposition. However, there is still great uncertainty over the scale of impacts from management practices such as burning and drainage (Wallage *et al.* 2006; Worrall *et al.* 2007; Clay *et al.* 2009; Yallop & Clutterbuck 2009). A particular issue surrounding peatland restoration through reducing drainage (i.e. 'grip blocking') is the potential for increased methane loss to the atmosphere (Baird *et al.* 2009). Nevertheless, Worrall *et al*. (2009) proposed that land management modification might result in significant net gains in carbon storage and foster greater resilience to external changes in climate. The restoration and effective management of peatlands to safeguard their vast carbon store, and potentially enhance their carbon sequestration potential, thus represent important opportunities.

5.3.2.2 Natural hazard regulation: flood risk mitigation

There is currently limited evidence on whether the UK's MMH habitats act to attenuate or exacerbate flooding (O'Connell *et al.* 2005; Holden *et al.* 2007; Orr *et al.* 2008). Steep areas with thin soils are likely to be sources of runoff rather than temporary water storage areas. Peat soils are capable of storing large quantities of water; saturated peat is commonly 90-98% water by mass (Holden 2005). This has led to the mistaken supposition that peatlands act as a sponge to soak up rainfall and prevent flooding, before gradually releasing water to maintain baseflow (Holden *et al.* 2007). In reality, the water table in healthy peatlands is maintained at, or near, the surface so that available water storage is minimal. Consequently, catchments with a high proportion of blanket bog often exhibit a rapid runoff response, with flashy hydrographs so that stream flow rises quickly during rainstorms and returns rapidly to low-flow conditions (Evans *et al.* 1999; Lane *et al.* 2004; Holden *et al.* 2007). Where bog runoff is routed through fen areas there is some evidence that peak flows may be reduced (Bragg 2002).

The most significant potential gains in flood control from upland systems come from the restoration of degraded systems, for example, through the re-vegetation of bare peat or the afforestation of slope, which both reduce erosion and enhance vegetation cover. Vegetation cover can reduce flow velocities, with *Sphagnum* mosses inducing the most marked reductions (Holden *et al.* 2008). Extensive moorland gripping across the UK has been shown to increase flow in dry conditions, but the impact on peak flows is variable, although more studies exhibit an increase than a decrease (Holden *et al.* 2004). Grip blocking may decrease flow velocities and discharge from drains (Holden 2005; Holden *et al.* 2008). Most land management interventions designed to modify runoff have been carried out at relatively small scales; it is, therefore, unsurprising that flood risk mitigation at a large catchment scale has not been documented and is an area requiring further research. Nevertheless, the potential to modify runoff regimes, even slightly, should be seen as part of a package of benefits that peatland restoration or adaptive management can deliver.

5.3.2.3 Natural hazard regulation: wildfire risk
Sutherland *et al.* (2008) identified wildfire as one of the top 25 priority risks to UK biodiversity. It already causes substantial environmental and economic losses in MMH habitats (Maltby *et al.* 1990; McMorrow *et al.* 2009a; Lindley *et al.* 2009): in 2003, one wildfire on Bleaklow in the Peak District lasted 31 days and fire-fighting costs amounted to around £1million. With predicted climatic changes, wildfire risk is expected to rise as the result of a greater accumulation of potential fuel load following warmer and wetter springs, and a greater ignition risk from increased visitor pressure in hot dry summers (Albertson *et al.* 2009; **Box 5.6**). Wildfires mostly result from arson or carelessness (McMorrow *et al.* 2009a; Haskins 2000) and are particularly frequent and problematic in highly visited areas, such as the Peak District, or in lowland heaths close to urban centres, such as Dorset heathlands. Costs for fire suppression and prevention through habitat management, such as controlled burns for fire breaks (Davies *et al.* 2008), re-vegetation and re-wetting, can be high, but they need to be assessed against the cost of avoiding damage to ecosystem services (FIRES 2010).

INSERT BOX 5.6

5.3.2.4 Water quality regulation: waste detoxification
Perhaps the upland environments most sensitive to the deposition of long-range transported air pollutants are the acidified streams and lakes draining these habitats. Since the middle of the 19th Century, these habitats have suffered loss of salmonid populations, as well as a much wider, overall decline in aquatic biodiversity (Battarbee *et al.* 1990; Chapter 9).

However, plant-soil systems of MMH habitats intercept and retain a proportion of various atmospheric pollutants, including anthropogenic sulphur, nitrogen and heavy metals, which would otherwise contaminate drainage waters. Furthermore, MMH soils have served to buffer the effects of acid deposition on upland stream and lake ecosystems: deposited acid hydrogen ions are exchanged for base cations (such as calcium and magnesium) which are held on soil ion exchange sites and maintained by the long-term process of geological weathering

Growing evidence suggests that the reduction in acid deposition has caused an increase in naturally occurring organic acids in the form of DOC, concentrations of which are the result of the incomplete decomposition of organic matter under conditions of anoxia, low temperatures and low pH (Evans *et al.* 2005; Monteith *et al.* 2007). It is possible, therefore, that DOC concentrations may be returning to pre-industrial (and hence pre-water treatment) levels, which, in turn, could have ecological benefits (for instance, through increased energy supply to freshwater ecosystems, and increased protection of freshwater organisms against potentially harmful ultraviolet radiation). However, an increase in DOC concentrations to levels not experienced since the mid 19th Century also represents a treatment challenge (and a major additional cost) for water companies: DOC must be removed at treatment works prior to chlorination to bring levels below those that risk the formation of potentially toxic by-products.

Elevated points in the landscape receive disproportionate amounts of airborne pollutants including sulphur and nitrogen compounds (Caporn & Emmett 2009), heavy metals and Persistent Organic Compounds (POPs) such as pesticide residues. Intact ecosystems, particularly those with well-developed soils and/or those with extensive moss communities, can retain a considerable proportion of these pollutants (Currey *et al.* 2011), thereby minimising pollution runoff into freshwater habitats and drinking water supplies. Organic soils effectively bind a range of heavy metals and POPs by adsorption to organic matter. However, potential physical or biochemical instability of peatlands driven by climatic and land management changes raises the risk of release of some of these contaminants back into the river system (Rothwell *et al.* 2007; Nizzetto *et al.* 2010). Likewise, increased low flows (due to changes in land management or climate), and subsequent reductions in the dilution of pollutants in downstream ecosystems, could greatly increase pollutant pressures on aquatic ecosystems.

5.3.2.5 Soil erosion: particulate organic matter production

Many areas of upland blanket bog and wet heath are degraded and actively eroding (**Figure 5.9**). Estimates of the affected area vary between 10-30% of peatlands (Evans & Warburton 2007). Causes include a range of cumulative anthropogenic impacts over the last millennium including fire, overgrazing, acid deposition and climatic changes (Evans & Warburton 2007). While erosion is a natural process (and some invertebrate species are associated with open ground), increased soil erosion has a number of negative environmental consequences including the degradation of perceived landscape quality, a reduction in water quality due to release of heavy metals and POPs, and the loss of water storage capacity in reservoirs due to sedimentation of aquatically transported particulate matter. Direct monitoring of suspended sediment outputs from UK upland catchments has produced sediment yield estimates of <1 t/km/yr in intact Scottish moorland (Hope *et al*. 1997), compared with around 260 t/km/yr in heavily eroded peatlands of the Peak District (Evans *et al.* 2006b). Studies on sedimentation in UK reservoirs have produced estimates of sediment yields of 25-200 t/km/yr (Yelloff *et al*. 2005). Soil erosion is also a significant factor in carbon loss from eroding moorlands, both directly through the loss of particulate organic carbon, and indirectly through the drainage effects of widespread gullying which enhances peat decomposition (Evans in press a,b).

INSERT FIGURE 5.9 A & B

5.3.3 Cultural Services

Cultural services of MMH encompass opportunities for recreation, as well as spiritual, religious, aesthetic and educational services. Generally, people value MMH within their landscape context, so cultural benefits also arise from the interactions MMH has with its neighbouring habitats (e.g. grasslands, woodlands and freshwater systems).

Mountains, Moorlands and Heaths are 'socially valued landscapes' as demonstrated by their landscape and biodiversity designations: 28% of the UK's MMH are designated as SSSI/ASSI, and 16% as part of one of the 14 National Parks (**Figure 5.10**). Relatively few people live in, or immediately adjacent to, upland habitats, but areas such as the Peak District, Exmoor, Loch Lomond and the Trossachs are within easy reach for a day trip for many. In stark contrast, lowland heaths are often located close to urban areas and are, therefore, considered to be 'local places' (i.e. places for the daily dog walk).

Engagement with, and appreciation of, landscapes within MMH varies across demographic, socioeconomic and cultural groups (Defra 2008; Natural England 2009b; Hanley & Colombo 2009; Suckall *et al.* 2009a). Some people enjoy escaping to remote, 'wild' locations to achieve a fulfilling connection to nature (Natural England 2009b), while others may find such places inaccessible, dangerous and forbidding (Askins 2004; Suckall *et al.* 2009b).

INSERT FIGURE 10 A TO F

5.3.3.1 Religion and spirituality

Mountains, Moorlands and Heaths can provide a setting for spiritual and religious reflection, particularly as travelling through wild and beautiful terrain, with uninterrupted views, can invoke a sense of meaning and, therefore, spirituality (Natural England 2009b; Frey 1998). These habitats may also contain features prompting spiritual reflection, such as ancient burial mounds and historical sacred places and some pilgrimages involve passing through MMH (e.g. St. Cuthbert's Way in Northumbria).

5.3.3.2 Cultural heritage and aesthetics

Peat soils are of considerable archaeological importance as they can preserve records of species, environment, climate and land use for 10,000 years or more (Olivier & Van de Noort 2002; Simmons 2003). Such records provide fascinating insights into our past environment and culture, and are important in informing us about historic climate changes, sea-level rises, land management and fire regimes (Brunning 2001; Blackford *et al.* 2006; Yeloff *et al.* 2007; **Box 5.7**). Ancient landmarks or burial places, land use remains or other historic artefacts are also conserved in much drier soils, such as those of heaths (Hawley *et al.* 2008).

INSERT BOX 5.7

Not only are MMH habitats shaped by grazing, livestock breeds themselves are valued as aspects of regional agrarian heritage (e.g. Welsh black cattle, Highland cattle and New Forest ponies) for their links to the past, as well as their purported benefits for biodiversity and provisioning services (Davies *et al.* 2004). Livestock farming generates important social and economic benefits for local communities, as well as for visitors and the tourism industry, returns from which are not fully captured through markets (LUPG 2009; Hanley *et al.* 2007). Tourists value seeing livestock and associated farm buildings and boundaries (e.g. hedges and dry stone walls) and, for some, this is part and parcel of 'biodiversity' (Fischer & Young 2007).

Although more localised than farming landscapes, and in long-term decline, 'commons' and crofting landscapes also have high social and cultural importance (Oliver 2005; Crofting Inquiry 2009). While the latter are 'local places' for crofters, crofting counties are nationally significant in terms of species, habitats and landscapes (Redpath *et al.* 2010), with a high percentage of land designated under UK and EU environmental legislation.

Aesthetic features valued by people in MMH uplands include remoteness, bleakness, tranquillity, open space and the special plant and animal life (SAC 2005; CPRE 2006; **Table 5.5).** Mountains, Moorlands and Heaths play an important role in providing a sense of freedom and wilderness. In a survey conducted in the Cairngorms National Park, 70% of the respondents and 82% of the residents stated that it was important for Scotland to have such wild places (SNH 2008).

INSERT TABLE 5.5

Mountains, Moorlands and Heaths also inspire works of art such as Wordsworth's poems (1800s) or Goldworthy's Sheepfolds sculpture project (Cumbria County Council 2007). In turn, this reinforces the position of MMH as socially valued landscapes.

5.3.3.3 Social cohesion and community development

Mountains, Moorlands and Heaths are often considered emblems for both national identity and social cohesion. For example, MMH in Scotland have been promoted as symbols of a popular national identity (McCrone *et al.* 1995; Lorimer 2000), and the two new Scottish National Parks were important symbolic projects for the devolved Scottish Parliament (Rennie 2006; Thompson 2006; Stockdale and Barker 2009). Likewise, Welsh National Parks illustrate the inter-relationship between cultural identity and sense of place (IWA 2009), with the Countryside Commission for Wales describing Wales as 'a land of mountains' (IWA 2009).

These habitats also support local social networks that foster and sustain relationships. Opportunities for environmental and archaeological volunteering (through Non-Governmental Organisations (NGOs), National Parks, etc.) can engender a sense of ownership and reduce problems of anti-social and damaging behaviour (Natural England 2008). For instance, Mountain Rescue UK retains approximately 3,500 volunteers alone.

Mountains, Moorlands and Heaths are one of the few Broad Habitats that involves the management of 'common pool' resources (e.g. deer management and common grazings); this generates important cultural traditions and bonds of reciprocity which are essential to maintain social capital. Such processes, such as the 'heft' in Cumbria, are cultural heritage in their own right, but also important in sustaining fragile and isolated rural communities when other opportunities for face-to-face interaction have declined (Burton *et al.* 2009).

5.3.3.4 Tourism and recreation

Landscape historians indicate that some MMH landscapes (such as the Lake District) were perceived as dangerous places until the Victorian urban elite, and the artists writing and painting for this audience, began to seek out such landscapes as examples of the 'sublime' (Hanley *et al.* 2009).This was the start of appreciating these landscapes for their physical and spiritual recreation opportunities, a trend that now provides alternative livelihoods to the traditional land uses (e.g. sporting estates, extensive grazing). During the 20th Century, outdoor recreation activities, such as hill-walking, increased (Watson 1991; Hanley *et al.* 2002), although broader UK data suggests a recent decline in countryside recreation (Natural England 2006). We have little data on more recent MMH recreation trends, but **Figure 5.11** suggests an increase in contrast to the suggested national downward trends.

INSERT FIGURE 5.11

While no figures exist for visitor use solely of MMH habitats, overall, 35 million leisure visits were undertaken to English and Welsh National Parks and 19 million to English and Welsh 'open access' land during 2005 (Natural England 2006). In Scotland, 44% of the adult population made at least one visit per week to the outdoors for leisure and recreation purposes (TNS 2009).

Most visitors to MMH are attracted by the scenery (Puttick 2004; Atlantic Consultants 2005; Visit Scotland 2008) and tranquillity (Davies 2006). However, relative proximity to home and ease of access may be strong drivers behind visiting patterns (Bonn *et al.* 2010). For example, more people visit Peak District uplands than remote North Pennines uplands, although the latter may provide greater tranquillity (CPRE 2006). Lowland heathlands tend to be 'local places', visited most often on foot or by short car journeys (Underhill-Day & Liley 2007), with many dog walkers attracted by the open space, the views and the wildlife they encounter (English Nature 2006).

Mountains, Moorlands and Heaths provide tourism and recreational opportunities for climbing, mountaineering, rock scrambling, walking, fell running, skiing, orienteering, riding and mountain biking. Since the publication of Hugh Munro's list of mountain summits in 1891, 'Munro-bagging' – i.e. attempting to ascend peaks over 3000 feet (914 m) – has become a popular pursuit among British walkers and mountaineers, with Ben Lomond alone attracting more than 50,000 walkers a year (LLTNPA 2005). Several mountaintops are now directly accessible through private company transport (e.g. Snowdon) or newly created walking paths that allow easier access.

Skiing is largely confined to MMH. The Ski Club of Great Britain reports that there were 159,888 Scottish [downhill] skier days in the winter of 2008/9, generating £11million for the economy; 40% of these were associated with the Cairngorms, NE Scotland, and another quarter with nearby Glenshee. Skier days vary dramatically from winter to winter but were considerably higher between the mid

1980s to mid 1990s than thereafter (**Figure 5.12a**). The wintry 2009/10 season broke the declining pattern, and indeed, a substantial part of the variation in the number of skier days in Glen Shee between 1994/5 and 2009/10 could be explained by average daytime winter temperature between December and March with colder winters generating more skier days (**Figure 5.12b).** Changes in winter climate have thus economic and social ramifications; the variability in notably snow-lie, and the need for large capital outlays, however, makes it difficult to manage this service adaptively.

INSERT FIGURE 5.12 A & B

Unlike skiing, most leisure activities in MMH are largely informal and non-commercial, such as walking and enjoying the scenery. However, there is a considerable potential for visitor-spending in associated settlements before and after these pursuits. For example, day and overnight visitors to Peak District moorlands spend on average £14.97 and £96.40 respectively per trip for food, accommodation, travel, equipment and souvenirs (Davies 2006). The considerable impact of reduced tourism on local economies was illustrated by the outbreak of Foot and Mouth Disease in 2001 which caused losses to the tourism sector of £3.2 billion across all habitats (Curry 2009).

Charismatic species, such as peregrine falcon, golden eagle, nightjar, mountain hare and red deer, are often associated with MMH habitats. Recent work shows that the public has a considerable willingness to pay for the conservation of raptors found in MMH habitats (Hanley *et al.* 2010). Between 1997 and 2002, the Scottish wildlife tourism market was estimated to be worth £57 million, employed approximately 2,000 people, and demonstrated a 50% increase in employment within wildlife tourism business (A&M 2002).

5.3.3.5 Field sports: wild deer and red grouse

Field sports of relevance to MMH include grouse shooting and stalking wild deer. There have been high private investments in establishing and maintaining moorlands and heaths for field sports (PACEC 2006). There are approximately 450 grouse shooting moors in the UK, covering 16,763 km^2 (Richards 2004), i.e. 7% and 36% of the UK and MMH land area respectively (**Figure 5.14**). The majority (296) are in Scotland, with only 10 in Wales, and the rest in England. Furthermore, the average shooting moor in the Scottish Highlands is 40 km^2 – twice the size of those of the Southern Scottish Highlands and English moors. Although few grouse moors return a profit in their activities (Sotherton *et al.* 2009), Fraser of Allander Institute (2010) estimated that, during 2009, grouse shooting supported 1,072 full-time equivalent employees in Scotland. In England, grouse shooting activity increased from 1,560 potential shooting days per year in 2000 to 1,898 in 2009. During that period, the number of gamekeepers also rose from 196 to 253. Overall, it was estimated that 47,000 people in the UK took part in grouse shooting (PACEC 2006).

INSERT FIGURE 5.13

5.3.3.6 Education

Within MMH habitats there are substantial opportunities to learn about the natural world and our cultural heritage. For example, MMH are increasingly valued for their geodiversity, as illustrated by the North Pennines Geo-park and North-West Highlands Geo-park (www.northwest-highlands-geopark.org.uk/) projects, communicating a sense of the permanence of nature (Natural England 2009b). Active promotion of learning opportunities, such as those organised by NGOs and National Parks, takes place through guided walks, visitor centres and school education programmes ‘outside the classroom’. Materials, such as onsite interpretation panels, audio-trails, publications and websites, offer opportunities for individual learning.

5.3.3.7 Human health

Mountains, Moorlands and Heaths provide health benefits through the activities undertaken within them, while also providing more ‘passive’ benefits for mental and emotional health (Pretty *et al.*

2007; Mitchell & Popham 2008). Climbing and walking in MMH, for example, provide both physical and mental health benefits. The openness and remoteness of such landscapes has been linked to feeling calm and relaxed, although other emotions, such as exhilaration, anxiety and fear, can be associated with particular landscape features like high crags (Natural England 2009b). Indeed, MMH can provide spaces for physical and mental recreation that reinforce social bonds of reciprocity. Through memories, inspiring photographs and documentaries, the existence of open, wild spaces may provide important mental 'well-being' for some of the population, even if they do not actually visit them.

However, MMH can be dangerous places, with bogs, slippery rocks, avalanches, rock falls, severe weather and poor visibility among the hazards. Statistics from the Mountain Rescue Committee of Scotland indicate that there were 387 mountain incidents during 2008: 20 of these were fatal and another 60 resulted in serious injury. However, the sense of vulnerability arising from these hazards may well contribute to their attraction, partly through people learning about themselves when undertaking challenging activities in MMH landscapes (Natural England 2009b).

5.3.3.8 Biodiversity

Besides enabling 'life', and thus being a supporting service, 'biodiversity' provides a number of cultural services, which include its conservation. Indeed, Harrison *et al*. (2009) note that often the cultural service aspects of biodiversity conservation have received most attention, with the relationship between biodiversity and provisioning, supporting and regulating services arising at a later date. In other words, biodiversity conservation has often been for moral, ethical or aesthetic reasons, providing spiritual benefits through activating an ethic of care for non-human species and ensuring diversity of life for future generations – these rationales underpin the designations of socially valued habitats (e.g. heathlands). The services arising from biodiversity include the role of species in encouraging an interest in conserving MMH and the role of biodiversity in a landscape setting that provides restorative health benefits.

Although MMH are characterised by their species-poor habitats, they are known for the species indicative to the habitat, i.e. charismatic, flagship species. Visitors include those seeking specific experiences, such as birdwatching for dotterel or Dartford warbler, which links biodiversity with recreation and tourism. It is often an interest in a specific charismatic species, habitat or landscape type that stimulates life-long learning about MMH and the environmental processes therein. For example, many naturalists are inspired by species such as golden eagle or red deer, which are often used as symbols by NGOs such as RSPB or the National Trust to attract new members. Furthermore, biodiversity conservation projects often contribute to community development objectives that combine job creation with environmental education.

The symbolic use of these species highlights the fact that people do not have to visit MMH in order to enjoy and care about them - it is possible that natural history programmes (e.g. Radio Four's World on the Move programme tracking Ospreys returning to nest in the Cairngorms) provide a connection between urban dwellers and the biodiversity found in MMH without visiting. By contrast, it is both biodiversity and geodiversity combined that create a landscape and it is often the individual's experience within this restorative setting that creates the health benefits, rather than species *per se*. Thus, the cultural services arising from biodiversity require us to put the species present in the wider landscape context, understanding both the interconnection between species and also the experiential and cognitive process by which people interpret and derive meaning from these interconnections.

5.4 Trade-offs and Synergies Among MMH Goods and Ecosystem Services

This section will provide a qualitative analysis of the trade-offs and synergies between the provision of the different ecosystem services identified in Section 5.3 (**Table 5.6**; **Box 5.8**). This allows an initial assessment of whether it may be appropriate to prioritise different ecosystem services in different areas for different purposes, and whether multiple delivery of ecosystem services from MMH are likely to provide added value. Certain ecosystem services from MMH are already prioritised in certain locations, but this approach is largely piece-meal (Stockdale & Barker 2009; Reed *et al.* 2009). For example, water quality is prioritised through River Basin Management Plans under the Water Framework Directive, often without reference to likely effects of proposed management activities on other ecosystem services. Similarly, nature conservation is given priority in designated sites such as SSSI's and National Nature Reserves. Although these are multi-functional sites, there is little explicit consideration of the likely consequences of managing land for nature conservation on other ecosystem services such as the provision of food and fibre or carbon storage. It is imperative that trade-offs and synergies between different ecosystem services are more explicitly considered in decisions about the future of MMH habitats.

INSERT TABLE 5.6

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The management of MMH habitats has changed considerably as managers have adapted to a range of past and present drivers (Section 5.2; Section 5.3). Although the majority of those who benefit from MMH ecosystem services perceive that further extensification of land use and management will occur in these habitats in the future (for example, reductions in managed livestock and/or game populations and associated burning practices, or woodland regeneration), it is likely that some intensive land management practices will continue in certain areas, such as heather-burning for grouse, and others may increase in demand, such as the production of biofuels (Reed *et al.* 2009). The rest of this section, therefore, considers likely trade-offs and complementarities between different MMH ecosystem services under a mix of current (and possible future) extensive and intensive management practices.

Extensive management in MMH habitats may reduce their capacity to sustain provisioning services such as sheep and game production. Intensive sheep-grazing and managed burning have been blamed by some for the poor condition of many upland SSSI's (English Nature 2003), and intensive management may threaten water quality and soil carbon storage (Holden *et al.* 2007). However, the significant reductions in sheep stocking densities currently being reported for some MMH areas (SAC 2008) may potentially lead to a short-term increase in wildfire risk due to fuel-load build up and associated change in vegetation structure. In turn, the enhanced incidence and severity of wildfires could damage soils and release the carbon they contain (Tucker 2003; Reed *et al.* 2009). Fires have indeed been found to spread faster in older *Calluna* stands due to a greater amount of fine, available fuel, and increased proportions of dead material (Davies *et al.* 2010). Yet the dynamics of wildfire in MMH are complex and influenced by a wide range of other factors, such as soil humidity and plant chemical content, that are not necessarily susceptible to changes in sheep-grazing pressure (Johnson *et al.* 2001; Bond & Keeley 2005). Combined with reductions in managed burning, reductions in sheep-grazing are likewise connected to changes in biodiversity (both increases and decreases) through habitat modifications as scrub encroaches into MMH, transforming the drier areas over time into woodland.

A loss of livestock from MMH habitats would most likely be associated with a loss of land managers and farm workers. Depending on how land is managed in the absence of livestock, some land managers may remain, but most probably much fewer than is currently seen (based on a cross-section of opinion from stakeholders consulted over possible scenarios for UK uplands; Reed *et al.* 2009). There is growing concern over the effect this may have on the long-term viability of remote communities already under pressure from demographic change, declining access to public services, limited employment opportunities, limited energy infrastructure, low internet connection speeds and poor mobile phone coverage (Commission for Rural Communities 2010).

Reductions in livestock-grazing may also affect cultural services such as the maintenance of cultural landscapes, social cohesion and tourism. Those who visit MMH for recreation tend to value their uninterrupted views and unique habitats and wildlife, which, according to some recreationalists, would be compromised by dense scrub and forest (Reed *et al.* 2009). Conversely, it is well-known that respondents to surveys about landscape scenarios tend to express a preference for the status quo over any alternative scenario (Samuelson & Zeckhauser 1988; Hanley *et al.* 2009). However, relationships with, and appreciation of, different landscapes are likely to evolve, and there is a desire to prevent dominance of a single habitat – for example, balancing the prevalence of heather and woodland (Fischer & Marshall 2010). Relaxation of grazing pressure, by both livestock and deer, in certain areas could foster the provision of a more diverse range of landscapes, thus maintaining open MMH and their associated cultural services, whilst allowing scrub and woodland to regenerate. Such a development would increase biodiversity, help fulfil national and international statutory conservation obligations, and create a more diverse landscape to which people can form emotional attachments (Parsons & Daniel 2002). Where MMH habitats do not occur on deep peats, carbon sequestration objectives may become an increasingly strong driver of such landscape change (Forestry Commission 2009).

Indeed, the large number of potential complementarities between carbon management (which, in the short-term may contribute towards climate change mitigation targets) and other ecosystem services (Bonn *et al.* 2010) may represent important opportunities for future sustainable management of MMH habitats. The re-wetting of peat soils by grip blocking might serve to protect the soil carbon store, not only with respect to reducing losses of particulate carbon, but also by making it more resistant to wildfire; however, the potential benefits of grip blocking for 'climate change mitigation' are less clear-cut because raising the water table has the potential to increase methane production. Nevertheless, ecological and hydrological restoration (**Box 5.9**) involving practices such as re-vegetating bare and eroding peat may have an important role in maintaining the UK's largest carbon store without increasing net greenhouse gas outputs (Worrall *et al.* 2009; Lindsay 2010). If realised, this could provide synergies between carbon management and the protection of upland biodiversity (and possibly the provision of drinking water) in areas where restoration is viewed as required. Conversely, drainage and extractive uses of MMH habitats (e.g. peat for horticulture or fuel) are mostly in conflict with climate change mitigation and biodiversity protection policies.

INSERT BOX 5.9

Mountains, Moorlands and Heaths also have the potential to contribute towards 'climate change mitigation' in other ways. The altitude of many MMH habitats means they have some of the highest inland average wind speeds in the UK (Orr *et al.* 2008), but the potential for generating wind energy is often limited by the infrastructure costs associated with transmitting energy from sometimes remote locations (Orr *et al.* 2008). There may also be trade-offs between the provision of wind energy and the negative impact of wind turbines and their associated infrastructure on soil carbon storage, upland raptors, waders and wintering geese (Barrios & Rodriguez 2004; Percival 2005; Pearce-Higgins *et al.* 2009b), and people's appreciation of perceived 'wild landscapes' and their desire to maintain the status quo (Woods 2003; SNH 2008). It will be important to minimise such trade-offs and the availability of high quality scientific data to inform decision-making will be crucial; for example, the use of bird sensitivity maps may help identify areas where new windfarm developments are least likely to have adverse effects on important bird populations (Bright *et al.* 2008).

The abundance and diversity of different species of plants and animals that depend on MMH may be altered by both highly intensive and highly extensive management of MMH habitats, raising potential for conflicts between groups with differing management objectives and priorities. One such conflict within MMH revolves around conservation issues: the effects of gamekeeping on raptor populations in grouse moors (Thirgood & Redpath 2008). The associated managed burning and predator control of grouse moors creates heather mosaics which favour gamebirds such as red grouse – the distinctive dark-winged race, *Lagopus lagopus scoticus*, is endemic to Britain and Ireland and lives mostly within the UK. Grouse moor management also favours other ground-nesting birds, such as golden plover (Sotherton *et al.* 2009), but other species, such as such as dunlin, hen harrier and golden eagle, are negatively associated with grouse moors (Pearce-Higgins *et al.* 2009a). Redpath and Thirgood (2009) propose various ways in which the trade-off between red grouse and hen harrier populations could be managed to allow hen harriers to co-exist more easily on grouse moors. However, in the absence of alternative forms of management (e.g. grazing), there are concerns that a reduction in grouse moor management intensity may lead to a loss of gamekeepers and subsequent effects on wildlife and landscape (Sotherton *et al.* 2009). Furthermore, the illegal persecution of hen harriers on some grouse moors may produce economic costs for those sectors of the population who care about raptors (Hanley *et al.* 2010). This illustrates how the management of MMH can result in conflicts based on different perspectives and underlying values held by relevant stakeholders (White *et al.* 2009).

As much of MMH habitats are open access country, there seems no shortage of provision of recreation opportunities (Curry 2009). Recreational pressure in MMH can be damaging through a number of factors including: localised disturbance of wildlife, such as nightjar and Dartford warbler in lowland heath (Langston *et al.* 2007; Murison *et al.* 2007) and golden plover in upland heath (Finney *et al.* 2005); excessive erosion through trampling and motorised access; and wildfire (Hewins *et al.* 2007; McMorrow *et al.* 2009b). As a result, lowland heathland managers might find themselves in conflict with local communities over the appropriate management of some sites. Although common ground can be found with early and appropriate engagement of the neighbours and visitors, some management options, such as grazing large animals (due to both fencing and perceived danger from livestock), burning and cutting trees, regularly result in adverse reactions from the public (**Box 5.10**).

INSERT BOX 5.10

The development and expansion of ski resorts have caused local damage to fragile habitats (Warren 2002). There are several upland footpath and motor vehicle management projects aiming to find a balance between tourism and the conservation of protected sites (Phillip & MacMillan 2006). Indeed, access management through footpath improvement can have joint benefits for visitors and biodiversity (Finney *et al.* 2005).

Although deer can be a tourist attraction and increase recreational use of MMH, concerns about the impact of deer grazing on plant diversity, the knock-on effects on other organisms and the costs to society are mounting (Hunt 2003; Defra 2003), and have led to an explicit call for greater control of their numbers. Despite these concerns, an extensive analysis of data on grazer impact gathered from across Scottish uplands (Albon *et al.* 2007) led to the conclusion that sheep, not deer, were most strongly associated to grazer impacts on MMH habitats; evidence for strong negative impacts on vegetation from deer grazing appeared limited to certain habitats such as blanket bog (**Box 5.11**). Whilst biodiversity considerations may be seen as legitimate, a diverse range of competing views characterise deer management across the country, as deer present both threat (e.g. to biodiversity, deer traffic accidents) and opportunity (e.g. employment, venison, enjoyment). Carefully balancing different agendas and cultural positions, and a wider exchange of knowledge, are critical to ensuring the best management strategies are employed for this potentially important rural resource.

INSERT BOX 5.11

5.5 Options for Sustainable Management

5.5.1 What is Sustainable Management?

There is considerable disagreement over what constitutes 'sustainable' management and how it should be achieved. Some landowners and managers believe that current land management is sustainable, pointing to its tradition and the current provision of ecosystem services from MMH. Others argue that current management is too intensive, pointing instead to aspects (e.g. biodiversity) that they believe have been compromised by human activities (English Nature 2003; Reed *et al.* 2005; Dougill *et al.* 2006). Hence, on the basis of equally valid but quite different objectives, stakeholders prioritise the provision of ecosystem services in different ways. These priorities are likely to be dynamic – as stakeholder needs and preferences change over time – and to differ from place to place. Management that might be considered sustainable in one location, at one time, may not be considered sustainable in another location, or a different time, rendering universal definitions of 'sustainable' management virtually impossible. Indeed, the Millennium Ecosystem Assessment (2005) concluded that "arriving at a comprehensive definition of sustainability in mountains, particularly one that is universally accepted, is itself a mountainous task, and not likely to be a productive effort". For the remainder of this section, therefore, we will consider how different forms of management may minimise the trade-offs and optimise the complementarities between the provisions of different ecosystem services from MMH that are described in Section 5.3.

5.5.2 Sustainable Management Options

5.5.2.1 Managed burning

Mountains, Moorlands and Heaths are often burned to provide habitats suitable for the production of sheep and red grouse. The effects of burning are complex, and differ between habitats (e.g. heath versus bog) and substrates (e.g. mineral versus organic soils). Burning is primarily carried out to create a mosaic of different aged stands of heather. On heather-dominated moorland, burning stimulates more palatable new growth and reduces vegetation height (Yallop *et al.* 2006). This creates a habitat suitable for red grouse to feed, shelter and nest in (Lovat 1911; Gimingham 1971, 1972), and also favours several other ground-nesting birds (see Section 5.4). However, managed burning may have adverse effects on other bird species, such as meadow pipit (Smith *et al.* 2001), and on conservation priority plant species, such as common juniper (*Juniperus communis*) which can be killed outright by burning and recovers very slowly from fire damage (Thomas *et al*. 2007). Gamekeepers also conduct predator control to further favour assemblages of ground-nesting birds, thus altering the competitive balance between species in MMH habitats over vast areas (Fletcher *et al.* 2010).

There is relatively little scientific evidence to link managed burning to effects on ecosystem services, and where evidence does exist, it is often contradictory. For example, there is currently contradictory evidence about the relationship between managed burning and carbon accumulation and storage where MMH habitats occur on peat soils. Garnett *et al.* (2000) found that less peat accumulated in North Pennine experimental plots that were burned than in those that were not burned due to the adverse effects of burning on peat-forming species such as *Sphagnum* species; this finding has been supported by peat core evidence from Canada and Finland (Kuhry 1994; Pitkänen *et al.* 1999). Particulate organic carbon is also lost through soil erosion from burned moorland, but most of this is lost during wildfires, rather than through managed burning (Tallis 1987). Controversially, Clay and Worrall (2010 and under review) suggest that long-term soil carbon storage may be enhanced through managed moorland burning because carbon stored in charcoal produced during cool, well-managed burns is highly durable. This is contrary to previous studies, which assumed that there was no surviving biomass after burning (Garnett *et al.* 2000; Harden *et al.* 2000). Clay and Worrall (2010 and under review) show that there is a significant proportion of remaining biomass which needs accounting for in carbon stocks. Assuming well-managed, cool burns can be achieved, this research suggests that current burning practice is already optimised for carbon through char production. Working on blanket bog in the North Pennines, Clay *et al.* (2009) found that water tables were significantly shallower on burned sites versus those that were not burned, and that there was greater runoff following burning. Although a relationship has been shown between DOC and moorland burning in streams soon after burning (Yallop & Clutterbuck 2009), other research calls this into question (Clay *et al.* 2009; Chapman *et al.* 2010). These studies suggest that the relationship between burning and DOC in soil water and runoff is strongest for the first month after a burn, but is not statistically significant when a range of burn ages are considered (Clay *et al.* 2009; Chapman *et al.* 2010). It should be noted that results to date are specific to certain locations, habitats and substrates, so it is difficult to generalise across MMH habitats.

Heather-cutting is used in some locations, notably in lowland heathland, as an alternative to managed burning. This is the case, for example, in urban heaths, where fire could present a risk and the smoke is a nuisance for people in surrounding private properties or on roads. Cutting heather in autumn allows the seeds to mature, so the material can be used to stimulate heather regeneration in restoration sites; such timing would also avoid harm to breeding birds (Symes & Day 2003). There is evidence that repeated cutting may reduce the cover of *Molinia caerulea* (Milligan *et al.* 2004) but it has also been reported to reduce heather vigour over the long-term, leading to slower re-growth rates (Brown 1990). Cutting operations may be limited by topography, stoniness and access, and are perceived by land managers to be uneconomical compared to burning (Tucker 2003; Reed *et al.* 2005).

5.2.2.2 Grazing

Livestock-grazing and the associated efforts of many generations of farmers have contributed to the cultural and environmental heritage of today's countryside. The provision of several ecosystem services other than food production may be dependent on the existence of viable farming systems within upland and lowland areas in the future.

Grazing impacts on MMH habitats vary between grazer species and breed, for example, cattle are less selective and eat a higher proportion of *Nardus stricta* or *Molinia caerulea* than sheep or deer. Heather is a valuable winter food for livestock and (particularly) deer after the grasses have died back. However, heather is sensitive to overgrazing; it only thrives when grazing is below a critical limit, which varies with heather growth rates (Grant *et al.* 1978; Pakeman & Nolan 2009; **Figure 5.4**). The effects of grazing on heather are difficult to disentangle from the effects of burning and atmospheric deposition (Yallop *et al.* 2006). Indeed, there is evidence that the behaviour of grazers is influenced by the spatial distribution of burning (Palmer & Hester 2000; Fuhlendorf & Engle 2004). Heavy grazing, combined with frequent burning, may cause heather to be replaced with *Molinia caerulea* (Stevenson *et al.* 1996), particularly under conditions of high atmospheric nitrogen input; this replacement can be difficult to reverse (Ross *et al.* 2003; Marrs *et al.* 2004). Depending on soil type and drainage, heavy grazing and burning may also cause heather to be replaced by other species such as *Nardus stricta* or *Juncus squarrosus*. Heavy browsing of saplings can prevent the establishment and spread of trees and shrubs. At a smaller spatial scale, heavy grazing pressure is also associated with increased soil erosion, concentrated along sheep tracks and at local depressions in the land (Rawes & Hobbs 1979; Evans 2005). A decrease in grazing pressure will, in many places, enhance vegetation heterogeneity, most notably in its structure, with benefits for several moorland bird species (Evans *et al.* 2006a; Pearce-Higgins & Grant 2006). Destocking is a prerequisite to the re-vegetation of bare and eroding peats, which can, in turn, have benefits for carbon storage. Large-scale removal of sheep from parts of the hills, however, could lead to many unexpected consequences.

Although a reduction in sheep-grazing may bring benefits for certain species in areas that are currently under high grazing pressure (Albon *et al.* 2007), the challenge is to find a sustainable stocking level which is adapted to local conditions (Natural England 2010). Indeed, there are a series of 're-wilding' initiatives across the country (e.g. Wild Ennerdale, Cumbria) aiming to allow natural processes, instead of human management, to shape the landscape and ecology. Although some proponents of 're-wilding' may advocate the cessation of grazing by livestock, a minimum level of grazing, ideally by a mix of species (including cattle in some areas), is likely to be necessary if the objective is to maintain the current range of MMH ecosystem services. Indeed, grazers may play a role in the restoration of some MMH habitats and protect them from encroachment by scrub and trees. Thus, the levels of destocking now being witnessed in parts of MMH (SAC 2008) may have negative implications for some ecosystem services. For example, assuming sheep were not replaced with deer (but see DeGabriel *et al* under revision), it is likely that a reduction in grazing would mean more areas become dominated by heather at the expense of grass, but scrub and tree encroachment would occur in most areas except the very wet, coastal, high altitude or shallow soil areas. In turn, this may have implications for the value some recreationalists place on more open landscapes.

Given the likely consequences of destocking and other, more unexpected effects, it may be necessary to consider how minimum stocking densities can be preserved in order to maintain MMH, and the ecosystem services they provide, in the future. Ultimately, decisions about what stocking rates are appropriate have to be taken at a local level – depending on management objectives, these could range from very low (to allow woodland regeneration) to high (to maintain species-rich grassland).

5.2.2.3 Deer management

Besides sheep and cattle, the major grazing animals in MMH are deer. In Scotland alone, over 2 million ha (27% of all privately owned land) are managed for game, including deer-stalking activities; a further 17% is in commercial forestry, which is subject to major deer management programmes and, although outside the realms of MMH, of considerable importance for deer populations in open habitats, particularly during periods of adverse weather (Irvine *et al.* 2009).

Despite increased culling, deer numbers have grown considerably over recent years (**Figure 5.5**), which has a range of social, financial and environmental implications. The increasing rate of road traffic accidents involving deer has implications for public safety, and brings significant costs. These may be felt more strongly in less densely populated areas, which are often the areas with highest deer densities. The UK-wide expansion of deer populations has had a negative impact on the profitability of forestry and agriculture, with damage to the latter being estimated at around £4 million/annum in England (Defra 2003). Also transmission of disease from wild herbivores to livestock, and the subsequent effect on human food safety, is of growing concern. The loss of biodiversity as a consequence of overgrazing by deer is perceived as widespread. For example, deer grazing is known to have a negative impact on invertebrate diversity, the establishment and regeneration of upland birch, *Racomitrium* heath, tall heath, native pinewood regeneration and the diversity of woodland understorey. This has led to the designation of several 'priority sites' where greater control is being achieved by intervention from the statutory authorities. However, evidence for strong negative impacts at the landscape-scale is limited (Albon *et al.* 2007; **Box 5.11**).

Deer also bring benefits in a variety of ways. The presence and role of deer in shaping the landscape has positive effects on tourism and recreation. For instance, the opportunity to see red deer, in itself a cultural icon, is likely to be a significant factor in bringing visitors to the Highlands of Scotland. Deer provide rural employment and income from traditional stalking and hunting activities, as well as for those associated with the downstream venison industry. Yet exploitation of deer to the benefit of rural economies has been limited, partly because of its associated, centuries-old legislative legacy (Phillip *et al.* 2009).

Deer management across MMH habitats is in different stages of development, and faces the challenge of integrating management across neighbouring landowners (since deer are mobile across property boundaries). Most of Scotland has well-established Deer Management Groups to address this issue, whilst in England and Wales these tend to be more recently established and sometimes absent. The regulation of deer populations is contentious given the different objectives of different (often neighbouring) landowners, some of whom reap the benefits that deer bring, whilst others see mostly the costs (Smart *et al.* 2008). Recent research has shown that collaborative and participatory approaches are required to find locally acceptable solutions to perceived deer problems, as well as to develop creative ways to more effectively capture the associated economic and social gains to the benefit of rural economies. The emergence of Deer Management Groups across the UK is an example of a voluntary approach to managing some of the conflicts of deer numbers and distribution.

5.2.2.4 Grip and gully blocking

During the 1960s and 1970s, government grants were provided to landowners and managers to create drainage ditches or 'grips' in many MMH habitats to improve livestock and game production (Ratcliffe & Oswald 1988). They are particularly prevalent in the English Pennines, with more limited occurrence elsewhere, for example, the Brecon Beacons (Holden *et al.* 2007). However, 'gripping' did little to enhance production (Stewart & Lance 1983), leading instead to hydrological and ecological changes favouring dwarf-shrub heath over blanket bog communities, and increasing fire risk. In many areas, upland peatlands are also dissected by erosional gullies, which are significantly deeper and wider than grips, often occurring in dense, branching networks. Recovery of peat requires a very long time: in the Culoegh Plateau, Fermanagh, mechanised peat extraction led to frequent flooding of 'show' caves and, 15 years after extraction ceased, recovery is still far from complete (Dykes & Kirk 2001).

As a result of gripping, soil is lost through erosion, both of the channels themselves and through increased prevalence of soil pipes in drained peats (Mayfield & Pearson 1972; Holden *et al.* 2006). Gullies may present a hazard to both humans and stock, and sediment can cover salmonid gravel-bed spawning grounds downstream, and infill reservoirs. In actively eroding gully systems, the magnitude of the particulate carbon loss can be sufficient to shift peatlands from carbon-accumulating to carbon-losing status (Evans *et al.* 2006b). As the water table is lowered, carbon is also lost as carbon dioxide through the oxidisation of dried-out peat (Clymo 1983; Evans & Warburton 2010).

It has been proposed that lowering of the water table also enhances dissolved carbon loss, which, in addition to the erosional loss of carbon, means that fluvial carbon losses are significant. Worrall *et al.* (2003) showed that fluvial losses of carbon account for a significant component of the carbon budget in moorlands; the inclusion of fluvial carbon flux estimates into the national carbon budget for peatlands decreased the estimated size of the UK sink from 0.7 to 0.32-0.05 Mt carbon/yr. However, effects of drainage on water quality are mixed, and depend on catchment characteristics and timing of peak flows (Moore 1973; Mitchell & McDonald 1995; Hughes *et al.* 1998; Driscoll *et al.* 2003).

Moorland grips and gullies can be blocked using heather bales or dams made from plastic, wood or peat. Bare and eroding channel walls can be re-vegetated through natural regeneration, re-seeding and mulch (Campeau & Rochefort 1996; Price 1997), or through the use of heather brash (see the Peat Compendium for more restoration options: www.peatlands.org.uk). So far, there has been little research into the effects of grip and gully blocking on water quality. In contrast to Worrall *et al.* (2003), Wallage *et al.* (2006) showed that DOC and associated water colour from a site blocked three years prior to measurement was significantly lower than an adjacent drained site, and also significantly lower than that of undrained moorland.

5.5.3 Future Directions

For MMH to continue providing high levels of ecosystem service flows long into the future, the management of these habitats must be sufficiently flexible to allow adaptation to a range of currently uncertain future conditions. **Table 5.7** provides a range of such adaptive management options as suggested by upland stakeholders and researchers. Some adaptations may be taken at the scale of individual holdings or catchments, while changes to policy may be necessary to facilitate other, wider adaptations. For example, by effectively linking agricultural payments to the provision of ecosystem services in the places that can most efficiently and sustainably deliver those services, it may be possible to give landowners and managers more incentive to provide public goods for which they are currently not paid (Reed *et al*. in press). Finally, if ecosystem services are the benefits humans derive from nature (MA 2005), then we may wish to consider how the management of MMH habitats can meet the priorities of the people who use and value them. This would require an understanding of regional differences in demand and preferences for different ecosystem services (Christie *et al.* 2010). Clearly communicating the many benefits MMH bring to society may promote greater care and inspiration for people to find their own ways to engage with these special habitats.

INSERT TABLE 5.7

5.6 Future Research and Monitoring Gaps

Our work on this chapter has brought into focus a range of limitations in our understanding of changes in extent and perceived quality of MMH habitats since the Second World War, the factors underlying those changes, and what they mean to society. Here, we summarise major knowledge gaps under broad headings.

5.6.1 Changes in Habitat Extent and Quality

We have been surprised by the difficulty of obtaining sound, long-term quantitative (and ideally spatially explicit) data on changes in extent and 'quality' of MMH habitats. Therefore, we recommend a UK-wide programme to bring together our existing, heavily fragmented, datasets. The continuation and development of long-term scientific monitoring programmes, such as the Countryside Survey, the ECN and the UK Acid Waters Monitoring Network (that informs on biogeochemical changes to, and fluxes from, upland soils), provide our best opportunities to quantify future changes in pressures and ecological responses. Yet some coverage, most notably for montane habitats, is poor. Furthermore, we recognise that monitoring data needs to be 'fit for purpose' and able to detect subtle changes in biogeochemical processes resulting from often gradual changes in atmospheric deposition, climate and land use. Hence, we call for a spatial extension of current large-scale scientific monitoring capacity in MMH habitats.

Attributing causes to observed major changes in habitat extent and quality has likewise been difficult. For instance, large-scale changes in plant species composition of MMH habitats may be due to a plethora of factors including changes in land management, atmospheric pollution, climate, or, more likely, a combination of such factors. Strong indications of underlying drivers operating at the national or regional spatial scale can be derived from monitoring networks or other large-scale studies, but currently there is little emphasis on incorporating regular measurements that may best facilitate the identification of factors changing habitat extent and quality. These include: more reliable estimates of grazing pressure, burn size and location; better localised estimates of atmospheric pollutant deposition; and stronger co-location of measurements of soils, vegetation and carbon and nitrogen fluxes. Closer integration of upland terrestrial and freshwater monitoring would greatly benefit our understanding of both soil biogeochemical processes and the consequences of changes to the terrestrial environment on the quality and biodiversity of upland waters. This also points to the need to spatially link environmental data with socio-economic data on drivers and status over time.

The current paucity of information in this area prevents us from answering what one could view as simple questions, such as: how are declining numbers of grazing sheep in MMH influencing biodiversity (e.g. changes in populations of insects, scavenging and predatory birds, vegetation composition, etc.)? Or what will happen to deer numbers and the grazing pressure they exert? Likewise, we still have only a rudimentary grasp of the nature of ecological change in response to seasonal and longer-term variation in temperature, precipitation, wind and cloud cover – all factors that are part and parcel of 'future climate change' and fundamental to MMH and mountain habitats in particular. In addition to ongoing monitoring programmes, there is an urgent need for complementary targeted field experimental approaches to take place at the smaller scale to help determine cause and effect. Such experiments also allow the investigation of interactions between drivers of change, which is one of the largest knowledge gaps we have observed. Regarding climatic changes in particular, we need to develop our horizon-scanning across time periods spanning decades, and to take our thinking beyond basic species range shifts, into understanding how combined pressures from land uses and practices (including the expansion of renewable energy such as wind and hydro-power), atmospheric pollution and climatic changes impact on MMH habitats and their spatial configurations. Better understanding of how multiple pressures lead to changes in habitat extent and condition, and influence ecosystem services, should be a key focus for future research – this should involve both interactive and cumulative effects.

5.6.2 Changes in Ecosystem Services

Most biological monitoring has been driven by ecological and/or nature conservation interests and, during the last two decades, has primarily been conducted from a 'biodiversity' perspective: much information concerns either species or habitats of conservation interest. The more recent 'ecosystem function' approach that formed the precursor of the even younger 'ecosystem services' approach adapted by the UK NEA requires information to be available at multiple levels. It is clear that there has not been sufficient time to allow the development of 'methods' to detect and adequately interpret change in biological, physicochemical, economic and social processes combined, which is required to interpret changes of the 'value' of MMH habitats to society. The development of a more interconnected 'systems approach' in the near future would thus be an important step forward.

5.6.2.1 Provisioning services

Relatively good information is available in terms of provisioning services, although crude recording of, for instance, livestock-grazing (at the parish level) or deer density (at the deer management unit) clearly hinders interpretation of ecological and societal change.

5.6.2.2 Regulating services

A series of large knowledge gaps appear when focusing on regulating services. Regarding land management options that impact on carbon sequestration, we have been struck by the variability of evidence and opinion over the effects of burning practices, grazing intensity, blocking of drainage channels and re-vegetation of actively eroding blanket bog. A range of catchment management responses have been proposed and indeed implemented, at the local scale, including grip blocking and controlling intensity of burns, with the stated aim of controlling losses of dissolved and particulate carbon particularly. However, the scientific justification for such management actions is often thin, while mounting evidence that increases in dissolved organic carbon represent a regional return to more natural water quality, has not been sufficiently acknowledged by those that offer catchment management advice. There is thus a pressing need to better understand the consequences of moorland and heath management in terms of greenhouse gas emissions across a wide scale of conditions, and identify the mechanisms involved. Importantly, such studies need to be at sufficiently wide scale and take into account both short- and longer-term release of greenhouse gases through various pathways.

From hydrological and geomorphological perspectives, we have an insufficient understanding of the current importance of nitrogen deposition for the processing of carbon within MMH habitats. Improved knowledge in this area is fundamental to developing more accurate predictions of how MMH carbon budgets will respond to future changes in air pollution and climate. Furthermore**,** there is a need to better understand the fate of fluvial carbon losses from peatland systems, most notably the extent to which particulate and dissolved organic carbon are transformed into climatically active carbon in rivers and other water bodies downstream. A large proportion of the highly organic soils of

MMH are impacted by grazing, burning, drainage, air pollution and erosion; thus there is an urgent need to better understand their influences on both carbon stocks and greenhouse gas fluxes.

Likewise, there is a need to develop a much wider evidence-base to understand the influences land management practices have on the provision of water quantity and quality. This includes furthering our understanding of the relationships between vegetation composition, drainage of upland areas and flood risk further downstream. For example, there are currently great uncertainties regarding the effects of blanket bog restoration on stabilising water runoff under conditions of weather extremes. Such knowledge needs to be both mechanistic and spatially explicit as relationships are likely to be highly variable.

While the deposition of sulphur has fallen massively since the 1970s, nitrogen deposition continues to threaten MMH ecosystems. Hence, long-term effects of airborne pollution remain an important area of research, especially for mountain areas which receive disproportionate amounts and are generally susceptible due to their shallow, nutrient-poor soils. Indications are that MMH habitats with deeper moss and soil layers have played an important role in intercepting a wide variety of components, thereby reducing amounts leaching into waterways. However, this buffering principle is still poorly understood and, with respect to nitrogen, it is unclear whether upland soils may ultimately reach a point of saturation and cease to provide this 'service'. Furthermore, the implications of climate change for the continued storage of atmospherically deposited heavy metals that would otherwise be released to drainage waters remains unclear. The potential for land management to mitigate pollutant impacts through interception by the plant and soil system, and factors that regulate pollutant release, requires attention; this includes the currently poorly studied impacts of diffuse pollution. Importantly, such studies need to take into account multiple drivers of change, notably land use and climatic changes.

There are significant gaps in our understanding of disease regulation (e.g. the tick-borne Lyme Disease) and the prevalence of pest insects (e.g. midges and mosquitoes), both of which may be influenced by the numbers of herbivores in MMH, as well as changes in climate (Gilbert 2010), and could have major impacts on recreation and the enjoyment of some areas. The spread of other wildlife diseases, such as Cryptosporidiosis, could also have serious economic impacts on aquatic and terrestrial ecosystems.

5.6.2.3 Cultural services

Given the overwhelming importance of cultural services, and the immense diversity of issues, it is no surprise that our understanding of even the most critically important issues is still in its infancy. Hence, we only touch on a few areas that we view as worthwhile to address in the near future.

The value of nature. We need to develop a richer conceptual and practical understanding of the 'value of nature' which includes people's individual and collective relationships to MMH or its components. Whilst we have impressive lists of habitat, species and site priorities, science and policy groupings articulate these in a language and currency that appears 'alien' to many interest groups. Hence, we need to develop a more effective language and set of instruments to allow greater engagement with the diversity of MMH nature, its intrinsic value, and its importance to certain provisioning services such as water quantity and quality, energy provision, enjoyment, health and general 'well-being'.

Human health and well-being. Whilst the extent of the benefits of the MMH landscape for health and emotional welfare might be clear to those working, for instance, in ecology, attributing engagement with MMH, or any other form of nature, to human health and 'well-being' (which in itself is a highly contested concept) is notoriously difficult, and is in conflict with the 'positivist' outlook related to much of quantitative science. Therefore, we call for a different way of tackling this issue: collaboration between scientists from a range of disciplines with fundamentally different paradigms, and partnership working with members of the public, conservation bodies and other interest groups. This enables the unravelling of the rich relationships between MMH landscapes and human health and well-being in meaningful and mutually accepted ways. Some recent studies report on important 'quality-of-life benefits' which society derives from the MMH landscape, and which go well beyond the notion of relaxation. This area of science is huge and currently poorly understood.

Protected areas. We have been surprised by the national and operational inconsistencies in approaches to evaluating the values and management objectives of protected areas such as SPAs, SACs, National Parks, SSSIs and regionally designated sites. Whilst we recognise the diversity of national and international statutory requirements, it is surely time to harmonise the conservation and land management objectives for protected areas in order to rationalise the development of the evidence base that underpins our understanding of change and the practices and policies needed to bring about improvements. Importantly, such reform would require the realigning of multiple objectives of those impacted by the designations.

In line with the above, there is a need to better understand the ecological, economic and societal implications of (and diversity in views on) conservation initiatives both within and out with protected areas (e.g. 'rewilding', development of corridors). A careful balancing of different agendas, cultural positions and a wider exchange of knowledge is critical to managing such future developments.

Managing biodiversity conflict. We have reported on a wide range of 'biodiversity conflicts', i.e. issues where the interest of two or more parties towards some aspect of biodiversity compete, and when at least one of those parties is perceived to assert its interest at the expense of another party's interests (White *et al*. 2009). Notably, activities in moorland and heath related to grouse management have been, and continue to be, a strong influence on biodiversity. Likewise, a lack of deer management has been blamed for reduced diversity in plant species abundance. A future conflict is likely to be woodland expansion versus the conservation of open habitats, and, in lowland heaths, controlled grazing against recreation. It is now time to find ways to manage MMH in a manner that encourages the re-establishment of more natural gradients of habitat to the benefit of biodiversity, whilst allowing people to live in, work in, visit and enjoy the countryside.

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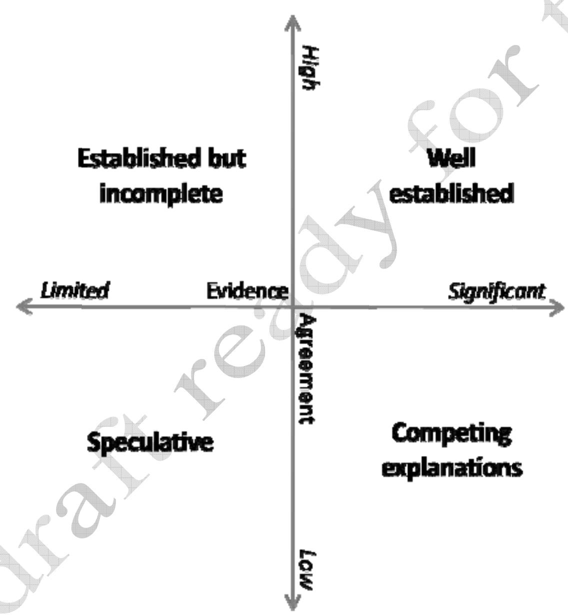
Appendix 5.1 Approach used to assign certainty terms to chapter Key Findings

This chapter began with a set of Key Findings. Adopting the approach and terminology used by the Intergovernmental Panel on Climate Change (IPCC) and the Millennium Assessment (MA), these Key Findings also include an indication of the level of scientific certainty. The 'uncertainty approach' of the UK NEA consists of a set of qualitative uncertainty terms derived from a 4-box model and complemented, where possible, with a likelihood scale (see below). Estimates of certainty are derived from the collective judgement of authors, observational evidence, modelling results and/or theory examined for this assessment.

Throughout the Key Findings presented at the start of this chapter, superscript numbers and letters indicate the estimated level of certainty for a particular key finding:

1. *Well established*: high agreement based on significant evidence
2. *Established but incomplete evidence*: high agreement based on limited evidence
3. *Competing explanations*: low agreement, albeit with significant evidence
4. *Speculative*: low agreement based on limited evidence



a. *Virtually certain*: >99% probability of occurrence
b. *Very likely*: >90% probability
c. *Likely*: >66% probability
d. *About as likely as not*: >33–66% probability
e. *Unlikely*: <33% probability
f. *Very unlikely*: <10% probability
g. *Exceptionally unlikely*: <1% probability

Certainty terms 1 to 4 constitute the 4 box model, while a to g constitute the likelihood scale.

GRAPHICS

FIGURES

Figure 5.1 Illustrations of MMH habitats and societal use for drinking water abstraction and outdoor recreation. a) Craig Goch reservoir overflowing Elan Valley, Wales*; b) Heron Pike, Cumbria†; c) Coulin Forest, Scotland†; d) Dry heath, Cliburn Moss Site of Special Scientific Interest, Cumbria‡; e) Benn Eigh, Scotland†; f) Whitendale Fell, Lancashire¶; g) ptarmigan (*Lagopus mutus*)†. Photos courtesy of *© Stephen Aaron Rees 2011 used under license of Shutterstock.com; †Andrea Britton/The James Hutton Institute; ‡ Peter Wakely/Natural England; ¶David Glaves/ Natural England.

Figure 5.2 a) Distribution of Mountains, Moorlands and Heaths (MMH) habitat by percent cover per 1 km cell; b) Dominant (>51% area per 1 km cell) MMH habitat in relation to the extent of agriculturally Less Favoured Areas* (LFA). LFA data sources: *England and Wales*: Natural England. © Natural England (2010), reproduced with the permission of Natural England; *Scotland*: Scottish Natural Heritage; *Northern Ireland*: Northern Ireland Environment Agency. This material is based upon Crown Copyright and is reproduced with the permission of Land & Property Services under delegated authority from the Controller of Her Majesty's Stationery Office, Crown copyright and database rights, EMOU206.2. Northern Ireland Environment Agency Copyright 2009. *The percentage overlap between LFA and MMH habitat in Great Britain may be an overestimate due to the coarser resolution of LFA data used. By comparison, Northern Ireland LFA data is at a much finer resolution, (and therefore more fragmented). As a result, the coarser MMH data overlies some these gaps in Northern Ireland, reducing the percentage of overlap between the two.

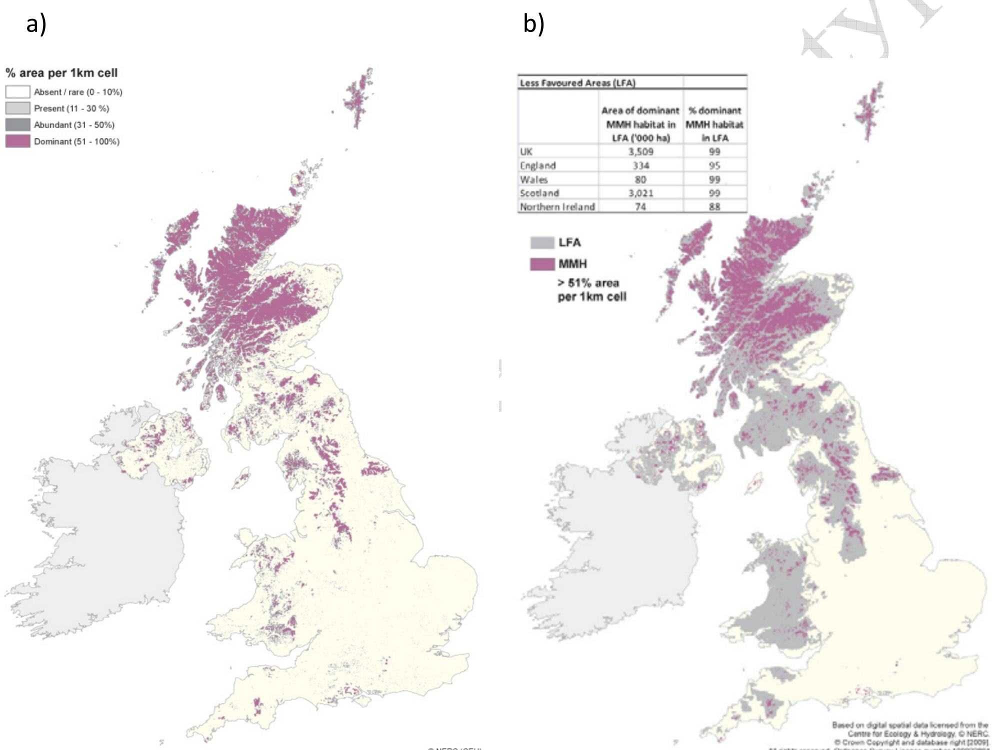


Figure 5.3 The influence of altitude on the duration of snow-lie and, therefore, general opportunities for species, biological processes and human inhabitation. Figures shown are mean and 95% confidence intervals of total snow cover days from October to May on the mountains surrounding Loch Tay, central Scotland, for the period 1954 to 2003. Source: reproduced from Trivedi *et al.* (2007).

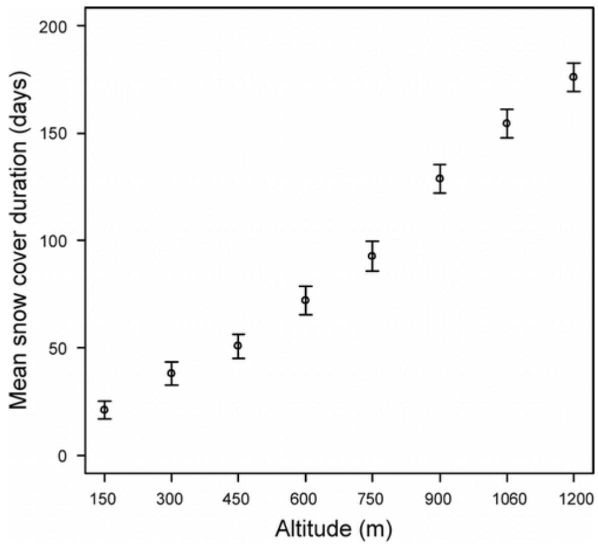


Figure 5.4 Changes in heather cover in relationship to the stocking rate of sheep in north east Scotland. Source: reproduced from Welch *et al.* (1996).

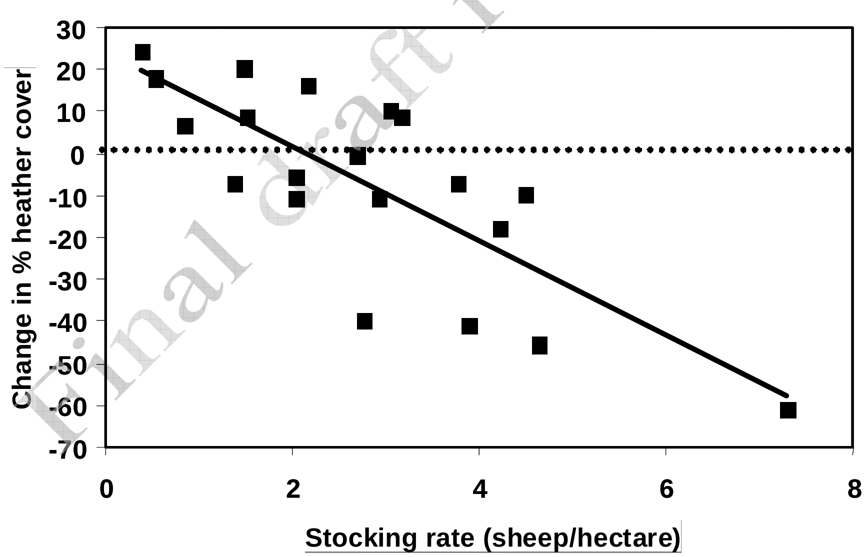


Figure 5.5 The number of red deer in the highlands of Scotland. a) WWF/RSPB estimates of total red deer in Scotland, including (hollow circles) or excluding (filled circles) an arbitrary increase in the estimated number of woodland deer by 70,000 in 2002; **b)** total hill deer numbers estimated from a multiple regression model and corrected for year of count, showing 95% confidence limits; **c)** estimates of annual numbers of all deer (filled circles) culled. Source: Clutton-Brock *et al.* (2004). Copyright (2004), reproduced with permission from Elsevier.

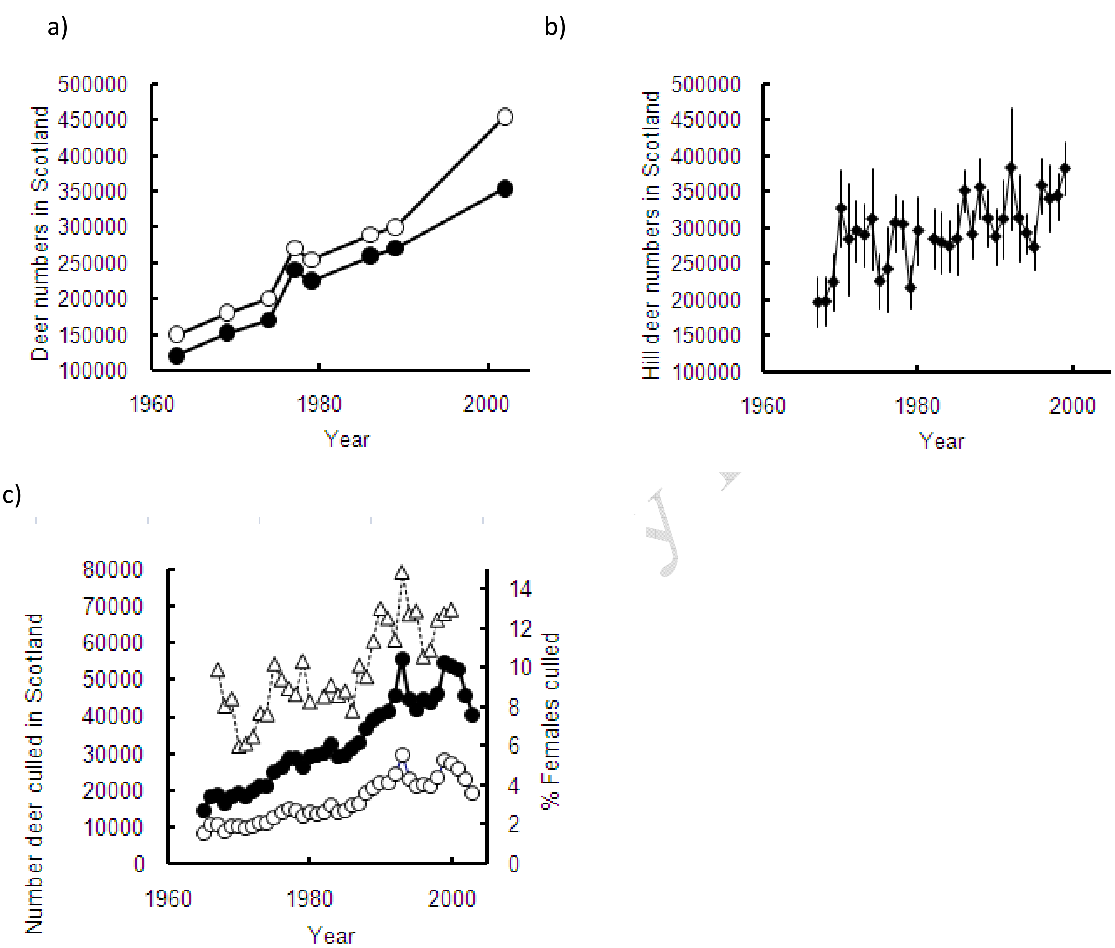


Figure 5.6 Index of red grouse bags since 1900, from the Game & Wildlife Conservation Trust's National Gamebag Census. Source: reproduced from Aebischer & Baines (2008).

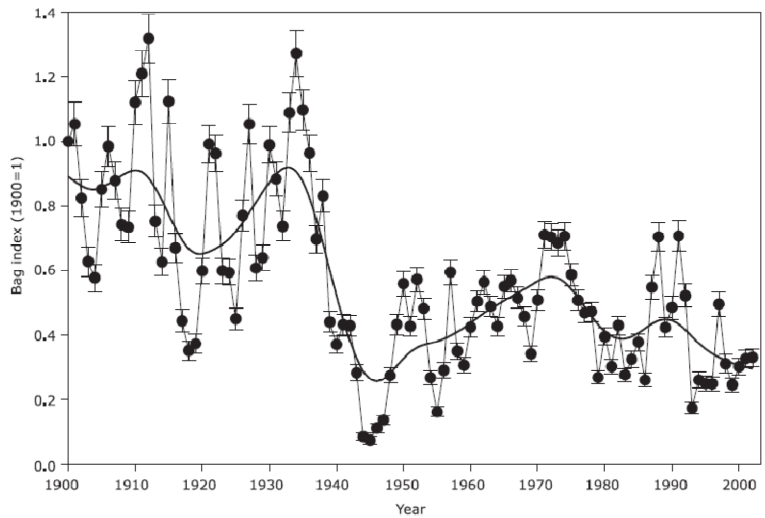


Figure 5.7 Density (kg/m^2) of soil carbon in the UK. Source: Bradley *et al*. (2005). Copyright ©2005 British Society of Soil Science. Reproduced with permission of Blackwell Publishing Ltd.

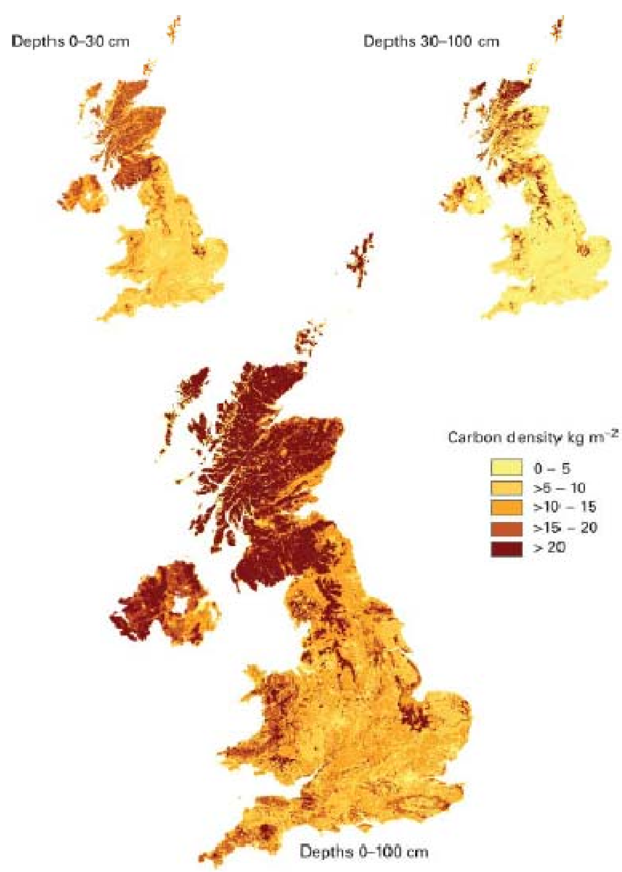
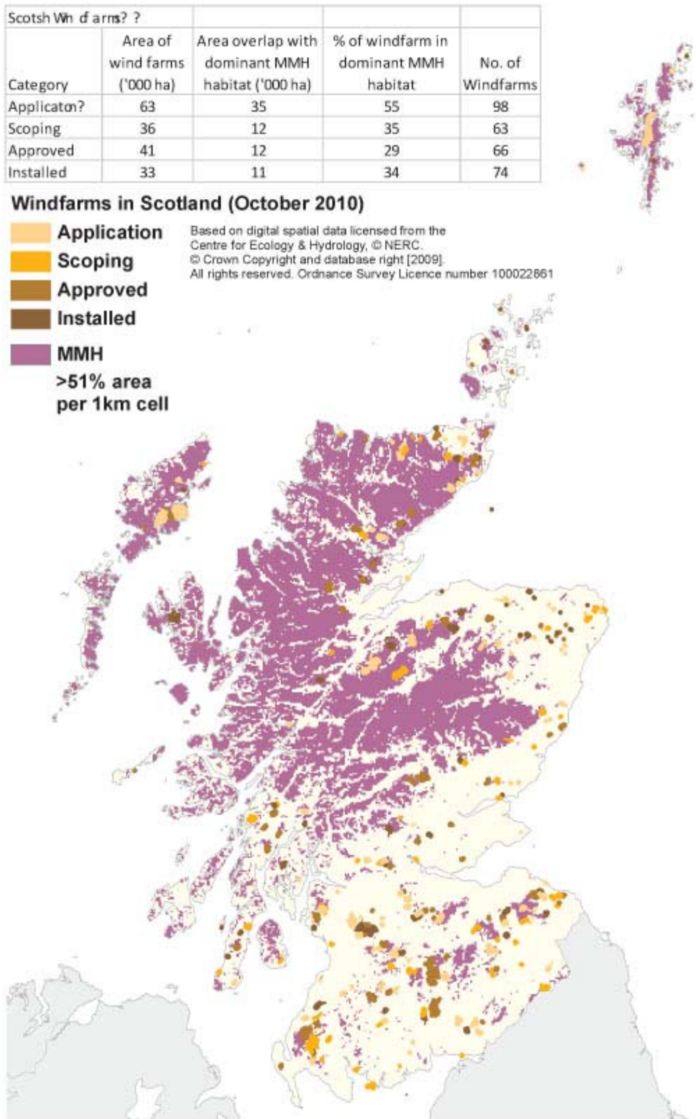


Figure 5.8 Location and number of installed Scottish windfarms, as well as those in the application, scoping or approval phase, in relation to dominate (>51%/1 km cell) Mountains, Moorlands and Heaths habitat.



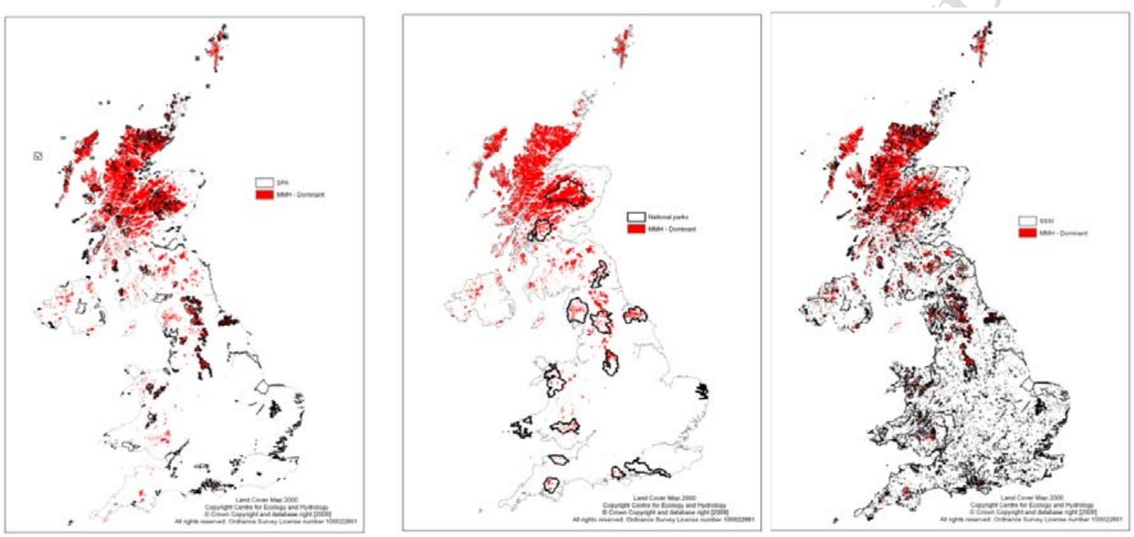
Scotsh Wn d arns? ?				
Category	Area of wind farms ('000 ha)	Area overlap with dominant MMH habitat ('000 ha)	% of windfarm in dominant MMH habitat	No. of Windfarms
Applicaton?	63	35	55	98
Scoping	36	12	35	63
Approved	41	12	29	66
Installed	33	11	34	74

Figure 5.9a Eroding blanket bog in the southern Pennines. Photo courtesy of North Pennines AONB Partnership.

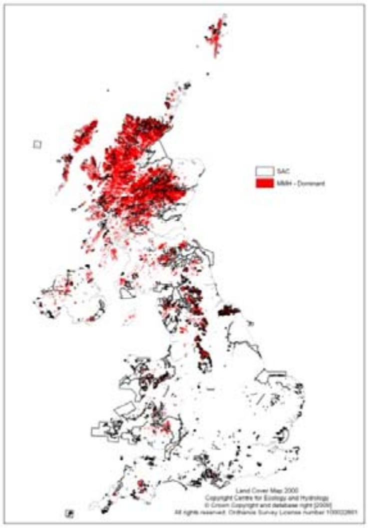
Figure 5.9b Houses encroaching on Parley Common SSSI in Dorset. Photo courtesy of Peter Wakely/ Natural England.

Figure 5.10 Location and size of protected areas in relationship to dominant (>51% area/1 km cell) Mountains, Moorlands and Heath (MMH) area: a) Special Protection Areas (SPA); b) National Parks (NP); c) Area/Site of Special Scientific Interest (ASSI/SSSI)*; d) Special Area of Conservation (SAC); e) Area of Outstanding Natural Beauty (AONB) ; f) National Nature Reserves (NNR). Protected area data sources: *England and Wales*: Natural England. © Natural England (2010), reproduced with the permission of Natural England; *Scotland*: Scottish Natural Heritage; *Northern Ireland*: Northern Ireland Environment Agency. This material is based upon Crown Copyright and is reproduced with the permission of Land & Property Services under delegated authority from the Controller of Her Majesty's Stationery Office, Crown copyright and database rights, EMOU206.2. Northern Ireland Environment Agency Copyright 2009. *ASSI is a conservation designation denoting a protected area in Northern Ireland. SSSI is a conservation designation denoting a protected area in Great Britain.

a) Special Protection Areas b) National Parks c) Sites of Special Scientific Interest



d) Special Areas of Conservation e) Area of Outstanding Natural Beauty f) National Nature Reserves


SAC
MMH - Dominant
Land Cover Map 2000
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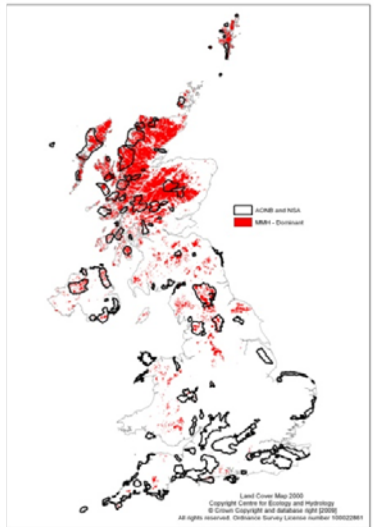
AONB and NSA
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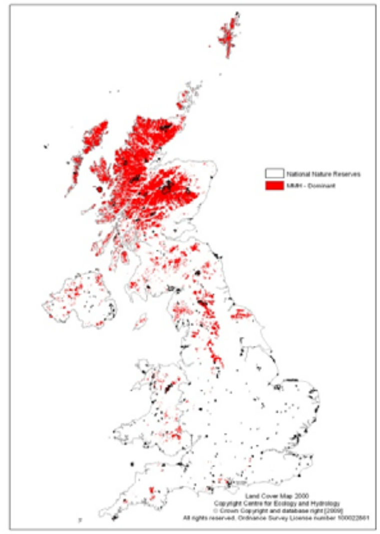
National Nature Reserves
MMH - Dominant
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Figure 5.11 Patterns of visitor use of MMH-dominated areas over time. The main graph (left axis; hollow circles) shows an aggregated index of the number of visitors using three MMH areas in the Northumberland National Park (NNP) on the basis of mechanic counter data; and an estimate of the total number of visitors to the Cairngorms National Park (CNP; right axis; filled circles) based on a wide range of tourism indexes. The little graph (inserted in line with the monitored length of time) shows visitor counts in eight areas in the Cairngorms (mechanic counter data), seven of which generally decline (left axis) and one which steeply increases (right axis). Intriguingly, this relatively chaotic pattern coincides with a temporary slump in visitors to the Northumberland National Park. This clearly indicates that long-term trend data from a range of areas is required to determine directional changes in visitor numbers for MMH. Source: van der Wal (unpublished data).

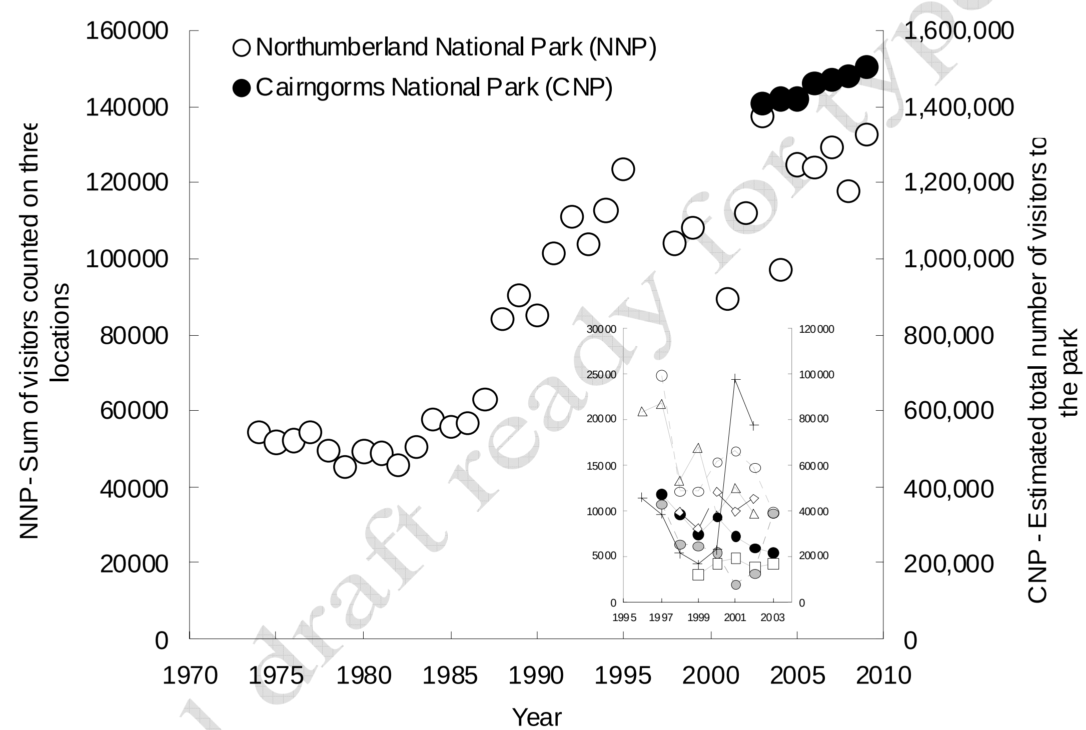


Figure 5.12 a) The trend in skier days across Ski ranges in Scotland between 1994–1995 and 2009–2010; and b) Relationship between Braemar winter temperature (average maximum temperature December to March) and Glen Shee skiers days between 1994–1995 and 2009–2010. Source: a) historical snow data provided by Ski Club Great Britain (www.skiclub.co.uk) and the Cairngorm Mountain Company; b) historical temperature data from Braemar station (www.metoffice.gov.uk/climate/uk/stationdata/); skier days data derived from Audit Scotland (2009); van der Wal (unpublished data).

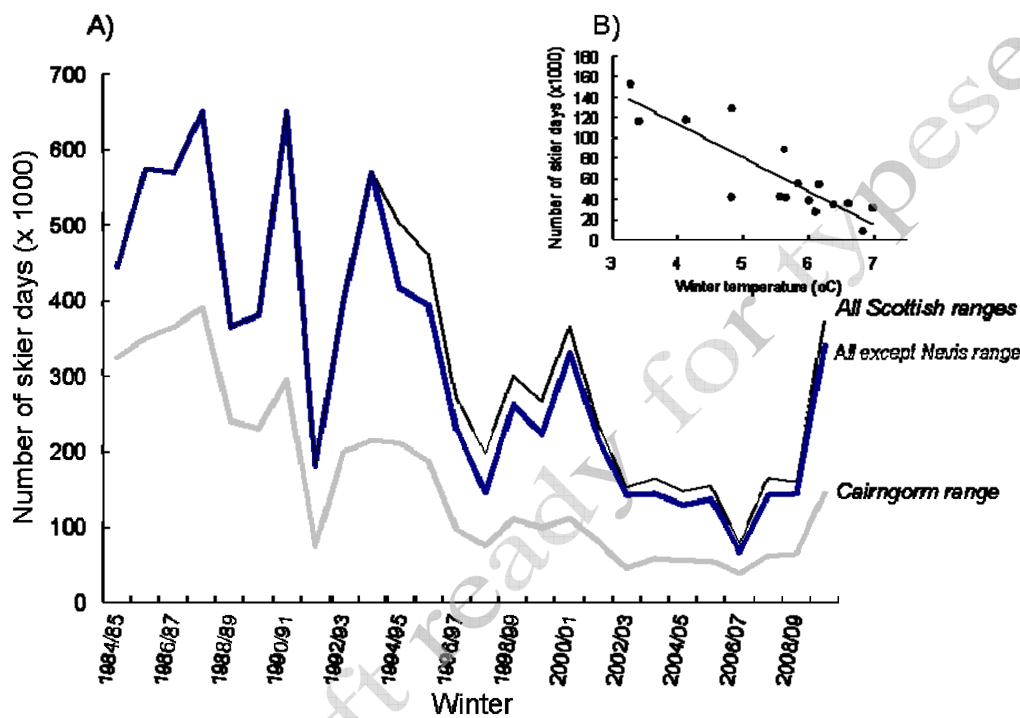
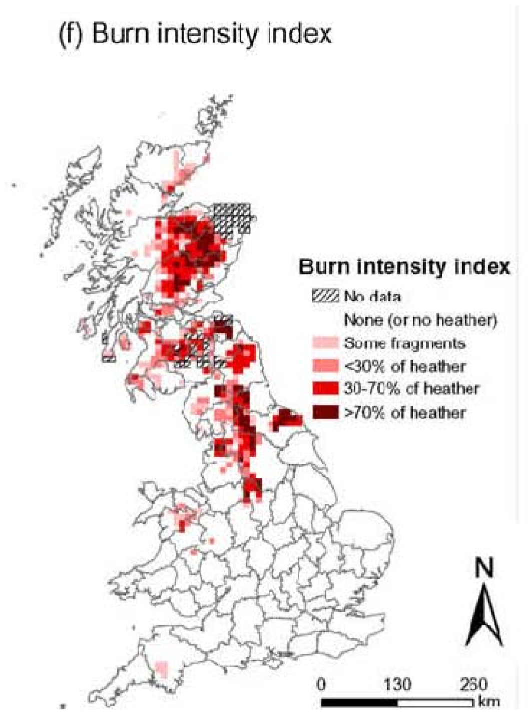


Figure 5.13 Index of heather-burning across Great Britain as a proxy for the spatial distribution of management of MMH for grouse. Source: Anderson *et al.* (2009). Copyright (2009), reproduced with permission from Elsevier.



TABLES

Table 5.1 Estimated surface area ('000 ha) for the six different broad habitats in the UK by country. Percentage of UK land surface each broad habitat occupied in 2007 is displayed in the final column. Data are available for three points in time for GB: 1990, 1998 and 2007; Northern Ireland: 1998 and 2007. Source: data from Carey *et al.* (2008). Countryside Survey © Database Right/Copyright NERC– Centre for Ecology & Hydrology. All rights reserved.

All '000 ha	**England**			**Northern Ireland**		**Scotland**			**Wales**			**UK**	
	1990	**1998**	**2007**	**1998**	**2007**	**1990**	**1998**	**2007**	**1990**	**1998**	**2007**	**2007**	**%**
Bracken	93	109	91	3	3	107	121	132	71	84	37	263	1.05
Dwarf Shrub Heath	309	288	331	14	17	1,007	894	894	120	99	117	1,360	5.42
Fen, Marsh and Swamp	78	124	118	53	47	289	239	239	60	40	36	439	1.75
Bog	98	138	140	164	161	1,922	2,044	2,044	30	45	48	2,393	9.54
Montane	n/a	3.6	3.8	n/a	n/a	n/a	38	38	n/a	0.1	0.1	42	0.17
Inland Rock	16	12.1	9.4	n/a	n/a	53	84	84	7	8	8	106	0.42
Total MMH	**594**	**675**	**693**	**234**	**228**	**3,378**	**3,462**	**3,431**	**288**	**276**	**246**	**4,603**	
Total surface area	**13,180**	**13,180**	**13,180**	**1,774**	**1,774**	**8,012**	**8,012**	**8,012**	**2,121**	**2,121**	**2,121**	**25,087**	
% MMH in each country			5.3		12.9			42.8			11.6	18.3	

Table 5.2 Losses of lowland heath over time. Source: data from Farrell (1993).

	Earliest figure available (ha)	Date	Losses to forestry (ha)
Breckland (Norfolk/Suffolk)	(By 1900) **28,932**	1918	7,326
		1934–1967	4,432
Suffolk Sandlings	(By 1783) **16,470**	1930–1968	3,502
Surrey	(By 1762) **22,780**		No figure available but by 1969 only 39% left. Losses due to afforestation and abandonment.
Hampshire	(By 1792) **46,540**		No figure available but by 1980 only 37% left. Losses due to afforestation, abandonment and urban expansion.
Dorset	(By 1759) **39,960**	1931–1934	No figure available but by 1934 only 45% left. Losses due to afforestation, agricultural improvement and urban expansion.
The Lizard (Cornwall)	(By 1813) **2,270**; (then by 1908) **3,660**	1963	After a reversion from agriculture, about 10% was lost to forestry, agricultural reclamation and infrastructure.

Table 5.3 Exceedance of critical loads for acidification and eutrophication in UK habitats. Shown in percentage of the catchment areas of 1,752 sites sampled across the UK. Source: RoTAP (2011).

Percentage habitat area with critical loads exceeded by deposition data for:								
Broad Habitat	Acidity				Eutrophication			
	1986–1988	1996–1998	2004–2006	2020	1986–1988	1996–1998	2004–2006	2020
Dwarf Shrub Heath	92.7	66.9	46.5	22.4	34.0	36.3	34.2	20.7
Bog	95.9	85.1	67.1	41.8	44.7	45.8	44.7	40.1
Montane	99.9	94.7	96.8	76.5	97.5	92.1	98.0	91.5

Table 5.5 An example of the delivery of cultural services by MMH landscapes. Source: reproduced from Natural England (2009b).

Feature	History	Place	Inspiration	Calm	Leisure/Activities	Spiritual	Learning	Escape
Water, rivers and streams	Low	Medium	High	High	High	High	Medium	High
Bogs and Marshes	Low		Low		Medium	Low	Medium	
Mountains and Hills	Medium	Low	High	Medium	High	High	Low	High
Moorland	Low	High	High	Low	Medium	High	Low	High

Table 5.6 Main goods and benefits derived from MMH broad habitats. Those that require the actual habitat to be removed (such as coal extraction or woodland regeneration, and thereby transfer into a different MMH broad habitat) are not included. Where possible, an indication is given of the relative importance of each habitat for providing the respective service using a four-step scale ranging from negligible (–) to high (+++);○ indicate that attribute on to separate MMH broad habitats is difficult.

	MMH goods and benefits	Bracken	Dwarf shrub Heath	Upland Fen, Marsh, Swamp	Bog	Montane	Inland Rock
Provisioning Services	**Food provision – livestock and crops:** - Livestock products from sheep and some beef cattle	+	+++	+	++	+	–
	Food provision – deer and game birds: - Wild harvest products including venison and grouse meat	–	+++	+	++	+	–
	Fibre from sheep wool	+	+++	+	++	+	–
	Traditional lifestyle products including honey and whisky	–	+++	+	++	+	–
	Peat extraction for fuel and horticultural use	–	+	+	+++	–	–
	Freshwater provision for domestic and industrial use	○	○	○	○	○	○
	Alternative energy provision: - Opportunity for wind energy schemes - Generation of water flows for hydro-energy in freshwater habitats	+ ○	+++ ○	– ○	+++ ○	++ ○	– ○
Regulating Services	**Climate regulation:** - Carbon storage; maintenance of plant and soil carbon stores - Carbon sequestration potential	++ ++	++ +++	+++ +	+++ ++	+ +	– –
	Natural hazard regulation: - Potential for flood risk mitigation - Opportunities for wildfire risk mitigation	○ +	○ +++	○ +	○ ++	○ –	○ –
	Pollution mitigation: - Interception and retention of airborne pollutants by plants and soil - Regulation of particulate matter and pH buffering - Dilution by water from uplands of pollutants in downstream locations	+ ○ ○	++ ○ ○	++ ○ ○	+++ ○ ○	++ ○ ○	– ○ ○
	Disease regulation: - Disease transmission through ticks - Disease regulation of waterborne bacteria (e.g. Cryptosporidia)	++ ○	++ ○	+ ○	++ ○	+ ○	– ○

Cultural Services	**Religion and spirituality:**						
	- Sense of awe; connection to spiritual powers	+	++	++	++	+++	+++
	- Opportunities for solitude and reflection	+	++	++	++	+++	+++
	Cultural heritage and aesthetics:						
	- Preservation of natural/environmental history and cultural practices	+	++	+++	+++	+	+
	- Socially-valued (‘natural’ and ‘cultural’) landscapes	+	++	+++	++	+++	++
	- Source of inspiration to works of art	○	○	○	○	○	○
	Social cohesion and community development:						
	- Development and maintenance of social networks through management of ‘common pool’ resources	+	++	++	++	+	–
	- Landscape as symbols of a popular national identity	+	+++	+	++	+++	++
	Tourism and recreation:						
	- Outdoor active tourism and recreational opportunities	+	+++	+	++	++	+
	- Tourism and recreation based on watching wildlife	+	++	++	++	++	+
	- Field sports (e.g. grouse shooting and deer stalking)	+	+++	+	++	+	–
	Education:						
	- Opportunities to learn about the natural world and cultural heritage	+	++	+	+	+++	+
	- Opportunities to learn about oneself when undertaking challenging recreation in MMH landscapes	+	+	++	++	+++	++
	Security and personal freedom:						
	- Land used for Military purposes	○	○	○	○	○	○
	- Existence value (i.e. knowing that MMH and their attributes are there)	○	○	○	○	○	○
	Human health:						
	- Mental and physical benefits from experiencing MMH	○	○	○	○	○	○

Table 5.7 Options for upland policy and practice to adapt to a scenario where future land use and management in uplands is extensified. Based on a combination of facilitated site visit discussions, an expert workshop as part of the Sustainable Uplands Project, and interviews using the Delphi technique from the Sustainable Estates Project. Source: a) Reed *et al.* (in press b); b) Reed *et al.* (2009) and c) Glass *et al.* (2009).

Themes	Adaptation strategies	Example	Source*
Restructured financial support: an ecosystem goods and services approach	Provide incentives for management of ecosystem goods and services	Use financial incentives e.g. to ensure the appropriate combination of moorland burning and grazing	a, b, c
		Include carbon storage/management payments in Environmental Stewardship grant schemes	b, c
	Regulate management	Penalise inappropriate or damaging management outcomes	a, c
	Develop innovative tax/trading systems	Individual ‘carbon allocations’ and collection of ‘carbon tax’ or ‘offsetting schemes’	a, b
Resilient rural businesses that can withstand future shocks	Plan long-term management visions	Draw up long-term, integrated spatial plans for future change e.g. rewetting peat soils, woodland regeneration etc.	a, b, c
	Diversify income streams and add value to products	Focus on quality rather than quantity e.g. specialised local food products, diversify livestock, create tourism opportunities	a, b, c
		Inject more cash into non-agricultural economic activity to maintain upland economies (private and public sources)	a, b, c
		Develop biomass and carbon storage opportunities e.g. small scale wood pellet enterprises, willow plantations etc	b, c
	Encourage innovation	Exemplify innovative land managers that make changes rather than allowing change to dictate practices	a, b, c
Integrated management that delivers environmental and other benefits	Environmental risk management	Wildfire risk control, ensure designated sites are in favourable condition, maintain viable populations of appropriate species	a, c
		Ecological restoration projects e.g. gully and grip blocking to reduce erosion, riparian improvements to mitigate flooding	a, c
		Reduce impacts of upland management resource use e.g. increase energy efficiency/sustainable building design	c
	Link into local communities	Release land for development and play a role in housing provision to reduce upland depopulation	c

		Develop local food markets and encourage self-sufficiency	c
	Manage increasing upland recreation	Manage footpaths and access points to reduce impacts, increase ranger provision for education and monitoring	a, c
	Manage visual impacts of management	Heather burning, grazing levels, tree planting, bracken control, renewable energy developments, cultural heritage etc.	b, c
Productive knowledge generation and exchange	Join up thinking and dialogue among stakeholders	Find common ground between interest groups and encourage understanding of the needs and wants of different users	a, c
		Partner across the region e.g. develop habitat linkages, manage increases in recreational activities etc.	a, b, c
	Share best practice	Exemplify successful management practices e.g. disseminate moorland restoration techniques/technology	a, b, c
	Raise public awareness of upland management	Educate about the multiple uses of moorlands and the role of managers/gamekeepers/farmers/rangers	a
	Improve scientific evidence, understanding and monitoring	More research e.g. relationship between water quality and local conditions; the effects of grouse moor management on ecosystem services	a
		Integrate local experience and knowledge into management	a, c
		Well-designed, structured and standardised monitoring e.g. changes in moorland diversity/restoration progress	a, c

BOXES

Box 5.1 Summary characterisation and biodiversity value of the six broad habitats identified to make up Mountains, Moors and Heaths. Lowland raised bog and Lowland fen, marsh and swamp are covered in Freshwaters – Openwater, Wetlands and Floodplains (Chapter 9). Source: modified after www.jncc.gov.uk/page-2433; see also Jackson (2000).

Montane Habitat

These make up the UK's most extensive near-natural habitats. A range of vegetation types occur exclusively in the montane zone, lying above or beyond the natural tree-line. The lowest altitudinal limits occur towards the north and west of Britain, where the compression of life zones is exceptional. Most communities occur on thin soils, which may be acidic or calcareous. Some communities are characteristic of very exposed ridges and summits, whereas others are restricted to sheltered situations where there is late snow-lie. A range of important rock outcrop and scree types, including tall herb ledge vegetation, often occur in close association with this habitat, along with high-altitude springs, flushes and other mire types, and alpine calcareous grasslands.

Characterisation: Exclusively montane habitat types can be recognised by their floristic composition and their physiognomy (prostrate vegetation). It includes dwarf-shrub heaths, grass-heaths, dwarf-herb communities, willow scrub, and snowbed communities. The most abundant vegetation types are heaths dominated by *Calluna vulgaris* and *Vaccinium myrtillus* typically with abundant bryophytes (e.g. *Racomitrium lanuginosum*) and/or lichens (e.g. *Cladonia* species) and siliceous alpine and boreal grasslands with moss and *Carex bigelowii* sedge heaths. Rarer vegetation types include snow-bed communities with *Salix herbacea* and various bryophytes and lichens, and sub-arctic willow scrub.

Biodiversity value: The invertebrate fauna is diverse, with mountain specialists such as the burnet moth (*Zygaena exulans*), the beetles *Stenus glacialis* and *Phyllodecta polaris*, the flies *Alliopsis atronitens* and *Rhamphomyia hirtula*, and the spider *Micaria alpina*. Several UK Biodiversity Action Plan (BAP) priority species are found here: three vascular plant species, *Salix lanata*, *Artemisia norvegica* and *Juniperus communis*; six bryophyte species including *Herbertus borealis* and *Andraea frigida*; eight lichen species; and two moths, the northern dart (*Xestia alpicola*) and the netted mountain moth (*Macaria carbonaria*). Many other rare and local arctic-alpine plants and invertebrates occur. Notable birds include the montane specialists; dotterel (*Charadrius morinellus*), for which the Scottish Highlands is a significant western outlier of the north European population, and ptarmigan (*Lagopus mutus*), which like the dotterel breeds in some parts at higher densities than recorded anywhere else in the world.

Component priority habitats[1]**:** Mountain heaths and willow scrub

[1] Full descriptions of UK BAP priority habitats can be found at www.ukbap.org.uk/library/UKBAPPriorityHabitatDescriptionsRevised20100730.pdf

Figure 1 Montane: *Racomitrium* heath on Creag Meagaidh, Scotland. Photo courtesy of René van der Wal.

Figure 2 Montane: *Racomitrium lanuginosum*. Photo courtesy of Andrea Britton, The James Hutton Institute.

Dwarf Shrub Heath

The UK is the worlds' stronghold of *Calluna vulgaris* – dominated heaths, with extensive tracts managed by strip burning (muirburn) or cutting to sustain high densities of red grouse (*Lagopus lagopus scoticus*) – an internationally distinctive habitat.

Characterisation: Vegetation that has >25% cover of plant species from the heath family (ericoids) or dwarf gorse (U*lex europeus*). It generally occurs on well-drained, nutrient-poor, acid soils. Heaths do also occur on more basic soils but these are more limited in extent and contain herbs characteristic of calcareous grassland. Dwarf shrub heath includes both dry and wet heath types and occurs in the lowlands and the uplands. This vegetation is found mainly in the Atlantic biogeographical region in Europe.

Upland heath is typically dominated by a range of dwarf shrubs such as heather (*Calluna vulgaris*), bilberry (*Vaccinium myrtillus*), crowberry (*Empetrum nigrum*), bell heather (*Erica cinerea*); additional characteristic species are western gorse (*Ulex gallii*) in the south and west and northern juniper (*Juniperus communis*) in some northern areas. Wet upland heath is most commonly found in the wetter north and west, and is dominated by mixtures of cross-leaved heath (*Erica tetralix*), deer grass (*Scirpus cespitosus*), heather (*C. vulgaris*) and purple moor-grass (*Molinia caerulea*), over an understorey of mosses often including carpets of bog moss *Sphagnum* species. Lowland heathland consists of dwarf shrubs, some gorse, scattered trees and scrub, with areas of grassland and bare ground and is generally found below 300 m in altitude.

Biodiversity value: Although generally species poor, an important assemblage of birds is associated with upland heath, including red grouse, Eurasian golden plover (*Pluvialis apricaria*), black grouse (*Tetrao tetrix*), merlin (*Falco columbarius*), hen harrier (*Circus cyaneus*), and short-eared owl (*Asio flammeus*). The habitat is also home to high densities of meadow pipit (*Anthus pratensils*) and skylark (*Alauda arvensis*). Charismatic mammals such as red deer (*Cervus elaphus*) and mountain hare (*Lepus timidus*) are widespread in Scotland. Among the few species of reptiles and amphibians are slow worm (*Anguis fragilis*), adder (*Vipera berus*), common frog *(Rana temporaria*) and common toad (*Bufo bufo*). Some forms of heath also have a significant lower plant interest, including assemblages of rare and local mosses and liverworts that are particularly associated with the wetter western heaths. The invertebrate fauna is especially diverse.

Lowland heathlands are more species rich than upland heaths. Among the more high-profile heathland species are the birds nightjar (*Caprimulgus europaeus*), Dartford warbler (*Sylvia undata*) and woodlark (*Lullula arborea*), the reptiles sand lizard (*Lacerta agilis*) and smooth snake (*Coronella austriaca*), many invertebrates including silver studded blue butterfly (*Plebejus argus*), heath tiger beetle (*Cicindela sylvatica*) and solitary wasps, and plants such as early gentian (*Gentianella anglica*), pale dog violet (*Viola lacteal*) and spring speedwell (*Veronica verna*).

Component priority habitats: Upland heathland, Lowland heathland

Figure 3 Dwarf Shrub Heath: View of Holt And West Moors Heaths Site of Special Scientific Interest, Dorset. Photo courtesy of Peter Wakely/Natural England.

Figure 4 Dwarf Shrub Heath: Bell heather (*Erica cinerea*) Kaerloggas Downs heathland restoration site, Cornwall. Photo courtesy of Paul Glendell/Natural England.

Fen, Marsh and Swamp (Upland only)

<u>Characterisation</u>: A variety of vegetation types that are found on minerotrophic (groundwater-fed), permanently, seasonally or periodically waterlogged peat, peaty soils, or mineral soils. Fens are peatlands which receive water and nutrients from groundwater and surface runoff, as well as from rainfall. Flushes are associated with lateral water movement, and springs with localised upwelling of water. Swamps are characterised by tall emergent vegetation. The Upland Fen, Marsh and Swamp Broad Habitat is typically dominated by sedges and their allies, rushes, grasses (e.g. *Molinia caerulea*, *Phragmites australis*), and occasionally wetland herbs (e.g. *Filipendula ulmaria)*, and/or a carpet of bryophytes (e.g. *Sphagnum* species, *Cratoneuron* species). Vegetation is generally short (<1 m, often <30 cm) but sometimes taller, for example in swamps.

<u>Biodiversity value:</u> The habitat supports a rich flora of vascular plants with many rare species e.g. scorched alpine-sedge (*Carex atrofusca*), bristle sedge (*C. microglochin*), sheathed sedge (*C. vaginata*), mountain scurvy grass (*Cochlearia micacea*), alpine rush (*Juncus alpino-articulatus*), two-flowered rush (*J. biglumis*), chestnut rush (*J. castaneus*), three-flowered rush (*J. triglumis*), false sedge (*Kobresia simpliciuscula*), Iceland-purslane (*Koenigia islandica*), yellow marsh saxifrage (*Saxifraga hirculus*) and Scottish asphodel (*Tofieldia pusilla*). Also exceptionally important for bryophytes with notable species including *Sphagnum lindbergii*, *S. riparium*, *Hamatocaulis vernicosus*, *Bryoerythrophyllum caledonicum* and *Campylopus setifolius*. It also forms an important nesting habitats for waders, such as curlew (*Numenius arquata*) snipe and redshank (*Tringa tetanus*), and supports a varied invertebrate fauna, notably flies and midges (e.g. *Clinocera nivalis, Pseudomyopina moriens*), beetles (e.g. *Gabrius scoticus*, *Elaphrus lapponicus*), spiders (e.g. *Maro lepidus*) and molluscs (e.g. *Vertigo* species), which in turn provide an important food source for upland breeding birds.

<u>Component priority habitats</u>: Upland flushes, fens and swamps

Figure 5 Fen, Marsh and Swamp: Spring on Ben Avon, Scotland. Photo courtesy of Andrea Britton, The James Hutton Institute.

Figure 6 Fen, Marsh and Swamp: *Drosera rotundifolia*. Photo courtesy of Andrea Britton, The James Hutton Institute.

Bog (Upland only)

Characterisation: Wetland vegetation that is usually peat-forming and receives nutrients exclusively from precipitation rather than ground water is referred to as ombrotrophic (rain-fed) bog. Two major bog types are identified, namely raised bog and blanket bog. They are for the most part fairly distinctive but at the same time considered extremes of an ecological continuum. Peat depth is highly variable; an average of 0.5 – 3 m may be typical but depths in excess of 5 m are likewise not unusual.

Blanket bog is the dominant bog, and the north of Scotland has some of the largest single expanses of this priority habitat (e.g. the Peatlands of Caithness and Sutherland Special Area of Conservation (SAC) and Special Protection Area (SPA); the 'Flow Country'). It often forms complex mosaics with other vegetation, such as flush, fen, swamp and upland heathland, reflecting differences in geology and topography. Blanket bog also includes modified bog vegetation that resembles wet or dry dwarf shrub heath but occurs on deep acid peat which would have once supported peat-forming vegetation. Modified bog also includes impoverished vegetation dominated by purple moor-grass (*Molinia caerulea*) or hare's-tail cotton-grass (*Eriophorum vaginatum*). Peat depth, although somewhat arbitrary, is used as the primary criterion to separate types of modified bog vegetation from the 'Dwarf Shrub Heath' and 'Fen, Marsh and Swamp' broad habitat types.

Several of the bog moss *Sphagnum* species occur throughout much of the habitats' geographical range, although their relative abundances vary across the UK. Species that are typically part of blanket bog include heather (*Calluna vulgaris*), cross-leaved heath (*Erica tetralix*), deer grass (*Trichophorum cespitosum*) and cotton grass (*Eriophorum* species). Some other species have requirements that limit their distribution. For example, cloudberry (*Rubus chamaemorus)* is largely confined to high altitude bogs, alpine bearberry (*Arctostaphylos alpines*) to northern bogs, and the black bog rush (*Schoenus nigricans*) to ombrotrophic bogs in the west. *Sphagnum* is a constant element of most blanket bog communities, and is indeed 'habitat forming'. Yet, in the north and west, particularly in the Western Isles, woolly hair moss (*Racomitrium lanuginosum)* can also reach high cover over extensive areas.

Biodiversity value: Blanket bogs support a very wide range of terrestrial and aquatic vertebrates and invertebrates. As with plant species, some of these are widespread and common, others are much more local. Yet, a considerable number of species is of international interest for either their rarity or for the densities on blanket bogs. For birds this includes the breeding populations of red-throated diver (*Gavia stellata*), Eurasian golden plover (*Pluvialis apricaria*), dunlin (*Calidris alpine*) and in the north and west of Scotland, the greenshank (*Tringa nebularia*).

Component priority habitats: Blanket bog

Figure 7 Bog: Blanket bog, Flow country, Caithness. Photo © Steve Moore/SNH.

Figure 8 Bog: Sphagnum moss. Photo ©Lorne Gill/SNH.

Figure 9 Bog: Norton Bog, part of Chasewater Heaths, Staffordshire. Photo © Isabel Alonso/Natural England.

Inland Rock

This broad habitat includes areas such as inland cliffs, caves, and screes and limestone pavements, as well as various forms of excavations and waste tips such as quarries and quarry waste. The habitat covers a wide range of rock types, varying from acidic to highly calcareous. It occurs throughout the uplands, and is particularly characteristic of high altitudes, but is also found at low altitudes.

<u>Characteristics</u>: Natural rock exposures support a wide range of communities. Screes are typically dominated by ferns (e.g. *Cryptogramma crispa*), lichens and bryophytes. On cliff ledges, tall herbs such as *Sedum rosea* and *Angelica sylvestris* are generally abundant. Chasmophytic (i.e. growing in rock crevices) vegetation is usually dominated by ferns such as *Asplenium viride* and small herbs including *Thymus polytrichus* and *Saxifraga* species. Bryophytes and lichens also occur in crevices but

are able to flourish on the open rock surfaces where there is sufficient light but a lack of competition from vascular plants.

Biodiversity value: The inaccessibility of rock habitats to grazing animals, especially of rock ledges, provides a refuge for many vascular plants that are sensitive to grazing, including numerous localised and rare species. Notable species of that kind found in upland rock and scree habitats include *Athyrium distentifolium*, *Woodsia ilvensis*, *Carex rupestris*, *Cicerbita alpina*, *Artemisia norvegica*, *Hieracium sect. Alpestria*, *Salix lanata*, *Saxifraga cespitosa* and *S. cernua*.

There are a number of plants consistently found on limestone pavements throughout their geographic range in Britain. The most frequent species include herb Robert (*Geranium robertium*), maidenhair spleenwort (*Asplenium trichomanes*), dog's mercury (*Mercurialis perennis*), harts-tongue fern (*Phyllitis scolopendrium*), wall-rue (*Asplenium ruta-muraria*), male fern (*Dryopteris felix-mas*), common dog violet (*Viola riviniana*) and wall lettuce (*Mycelis muralis*).

The botanically rich rock habitats support a number of notable invertebrate species. Key groups include beetles (e.g. *Leistus montanus*, *Nebria nivalis*), species of fly (*Tipula* species, *Thricops* species, *Helina vicina*), and spiders (*Pardosa trailli*). Several key species of birds use inland cliffs for nesting, notably peregrine falcon (*Falco peregrinus*), golden eagle (*Aquila chrysaetos*) and raven (*Corvus corax*).

Component priority habitats: Inland rock outcrop and Scree habitats; Limestone pavements

Figure 10 Inland Rock: Black spleenwort (*Asplenium adiantum-nigrum*). Photo courtesy of Andrea Britton, The James Hutton Institute.

Figure 11 Inland Rock: *Cerastrium nigrescens* growing on a Serpentine rock site, Keen of Hamar, Shetland. Photo courtesy of Andrea Britton, The James Hutton Institute.

Bracken

Characteristics: Continuous canopy cover (95%) of bracken (*Pteridium aquilinum*) at the height of the growing season. It does not include areas with scattered patches of bracken or areas of bracken which are less than 0.25 ha. These are included in the broad habitat type with which they are associated. Bracken tends to occur on relatively richer soils of heathland, and can mark out areas formerly with woodland.

Biodiversity value: Bracken can harbour a number of rare plant species. Most of these are considered as woodland plants, which survive in bracken after woodland removal. Likewise, its vertical structure provides opportunities for breeding birds, particularly in the lowlands, such as whinchat (*Saxicola rubetra*) and nightjar (*Caprimulgus europaeus*). In general, however, bracken is regarded a habitat of limited biodiversity value, and over substantial parts of upland heaths management is carried out to suppress bracken growth.

Figure 12 Bracken: Autumn view of bracken from Haystacks path of Crummock Water, Lake District. © S J Francis 2011 used under license of Shutterstock.com.

Figure 13 Bracken: Bracken invading an open hillside. Photo ©Lorne Gill/SNH.

Box 5.2 The control of predators in the hills: an historic account

Predator control has been intensive in the past, as can be seen from the record below which is provided as an example of the sheer scale of such a practise. Identification issues and double counting may partly compromise the data, but do not take away the diversity and number of animals killed.

An abstract from Richard Perry (1946), *Life in the High Grampians,* tells us that "In the 3 years between Whitsunday 1837 and Whitsunday 1840 […] on a single estate south of the Forests of Gaick and Glen Feshie caused his keepers to destroy, among other vermin, and solely in the interests of grouse preservation the following [mammals and birds]":

198 wild cats, 78 house cats, 11 foxes, 246 pine martens, 106 polecats, 301 stoats and weasels, 48 otters, 67 badgers; 15 golden eagles, 27 sea eagles, 285 common buzzards, 371 rough-legged buzzards, 3 honey buzzards, 462 kestrels, 98 peregrine falcons, 6 gyrfalcons, 78 merlins, 11 hobbies, 7 orange-legged falcons, 63 goshawks, 275 kites, 18 ospreys, 92 hen harriers, 5 marsh harriers, 71 short-eared owls, 35 long-eared owls, 3 barn owls, 475 ravens, 8 magpies, 1431 hooded/carrion crows.

A wide range of similar examples can be found in Lovegrove (2007), collectively indicating the past toll of predator control on mammals and birds in Mountains, Moorlands and Heaths.

Grampian Hills viewed from Scolty Hill, Aberdeenshire. Photo by Hilary Gaunt available under a Creative Commons Attribution-NonCommercial-ShareAlike license.

Box 5.3 Synergistic impacts of grazing and nitrogen deposition on mountain habitat.

Racomitrium heath is one of the UK's few remaining near-natural habitats, and is well known for representing the exclusive breeding ground of dotterel, one of the UK's most charismatic and rare wading birds (**Figure 1**). This moss-dominated mountain summit community is found throughout the upland regions of the UK, and in oceanic mountain areas across Europe including Ireland, the Faroes, Iceland, Norway and Greenland (Ratcliffe & Thompson 1988). Despite such a widespread distribution, the habitat has become the focus of conservation concern due to considerable declines in both its condition and extent in the UK, leading to its fragmentation and virtual disappearance in upland regions south of the Highlands (Thompson *et al*. 1987; Thompson & Brown 1992). During the past 50 to 60 years, replacement of *Racomitrium* heath by grass-dominated communities has been observed in North Wales (Tallis 1957), the Lake District (Pearsall & Pennington 1973) and, more recently, in the Cairngorms (Welch 2005). Two anthropogenic factors, high sheep-grazing pressures and increased atmospheric nitrogen deposition, have been implicated in its degradation and decline. Furthermore, there is evidence (**Figure 2**) that nitrogen deposition and grazing interact and cause an amplification of their deleterious effects on *Racomitrium* heath (Van der Wal *et al*. 2003) as well as in other communities such as heather moorland (Hartley & Mitchell 2005).

The current condition (tissue chemistry, growth, depth and cover) of the moss *Racomitrium lanuginosum*, the dominant species of the habitat, was investigated at 29 sites across its geographical range in the UK and at 9 European sites (Iceland, Norway and the Faroes). This extensive survey led to an improved understanding of how nitrogen deposition, grazing and climatic conditions contribute to the loss of *R. lanuginosum* cover and degradation of *Racomitrium* heath. Unexpectedly and contrary to experimental studies on this species, nitrogen deposition was found to stimulate, rather than suppress growth. However, results suggest that elevated nitrogen deposition adversely alters the balance between growth and decomposition of moss tissues, leading to increased shoot turnover and reductions in moss mat depth, with higher temperatures shown to exacerbate these effects. A thinner moss mat is more vulnerable to competition from neighbouring vascular plants and also to the physical damage caused by sheep trampling, resulting in loss of moss cover. The worst levels of habitat degradation, seen in Wales and Cumbria, thus represent the cumulative impacts of all three environmental factors.

Field manipulation experiments showed that *Racomitrium* heath has the potential to recover from the effects of nitrogen pollution (Armitage *et al*. 2010; **Figure 3**) and heavy grazing, despite their long history of impacts. Therefore, reduction of nitrogen deposition must be a key policy goal in order to prevent further loss of habitat, and at the local level, a reduction of grazing by sheep can be a positive action.

Figure 1 Dotterel, the flagship species of *Racomitrium* heath. Photo courtesy of Jens Fischer.

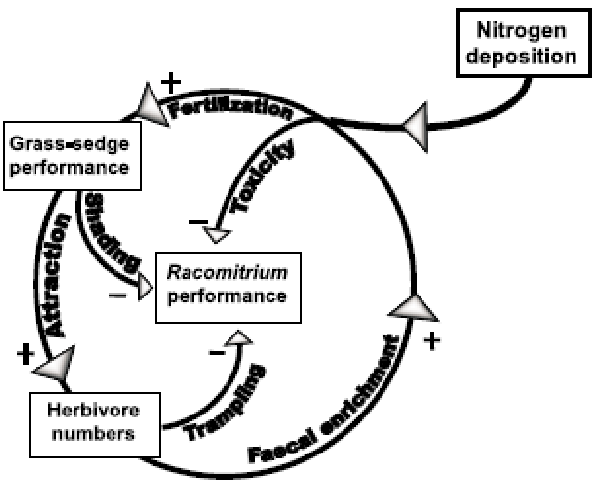


Figure 2 Conceptual model integrating impacts of nitrogen deposition and grazing. This multi-step, positive feedback loop shows how atmospheric nitrogen deposition leads to the replacement of the moss *Racomitrium lanuginosum* by sedges and grasses. Field experimental manipulations showed that nitrogen additions were directly toxic to the moss and indirectly limited light availability through the stimulation of grasses and sedges. These in turn attracted sheep, resulting in greater trampling impact on the moss. Deposition of nutrient-rich faeces enhanced grass/sedge performance and completed this downward spiral of events.

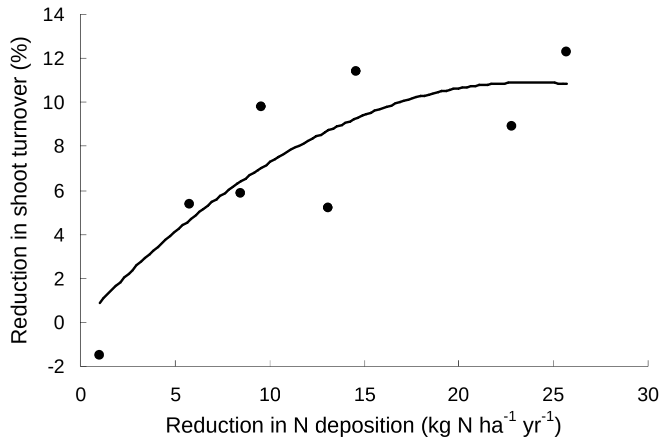


Figure 3 Reduction in nitrogen deposition promotes recovery of *Racomitrium* heath. Greater reductions in nitrogen deposition were associated with lower shoot turnover, indicating recovery of the moss mat. Source: Armitage *et al*. (2011). Copyright (2011) reproduced with permission from Elsevier.

Box 5.4 Landscape values for MMH – evidence from a choice experiment study.

Many of our upland landscapes are highly valued by the general public, as well as by recreational users and those that live in such landscapes. But how can we measure the economic value of such benefits, and determine how these benefits might change under a range of future scenarios?

Economists use a variety of stated preference approaches to value non-market benefits from environmental goods such as a landscape: one such approach is 'choice experiments'. Choice experiments proceed from a characterisation of environmental goods into a number of attributes. One of these attributes is a price or cost. Individuals are asked to make choices between different 'bundles' of these attributes, which reveals the rate at which they are prepared to trade-off an increase in heather moorland protection, for, say, a decline in broadleaved woodland. We can then calculate mean 'Willingness to Pay' measures for changes in each attribute.

Hanley *et al.* (2007) and Colombo and Hanley (2008) report on such a choice experiment applied to upland landscape features in England. **Table 1** shows an example question from their survey, which was carried out with people living in four regions of England with upland areas (the North West, West Midlands, Yorkshire and Humberside, and South West). The landscape features included in the design were:

- heather moorland and bog;
- rough grasslands;
- broadleaved and mixed woodland;
- field boundaries (stone walls and hedgerows);
- 'cultural heritage' – a term describing traditional farm buildings and animals.

People made choices over future possible changes in these landscape attributes, relative to a baseline prediction. 'Payment' for changes in attributes was via an increase in taxes. **Table 2** shows the results for willingness to pay which demonstrates two things:

- there is large variation in how people in different parts of England value changes in a given landscape attribute, such as increased conservation of heather moorland and bogs;
- there is large variation in the values people within a given region place on changes in different landscape features. For example, people living in the North West are willing to pay considerably more for the conservation of heather moorland and bogs than they are willing to pay for conservation of rough grasslands.

Table 1 An example of a choice card used in the survey. Source: reprinted from Colombo & Hanley (2008).

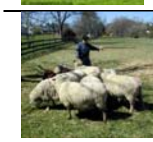
		Current Policy	Policy Option A	Policy Option B
	Change in area of Heather Moorland and Bog	A loss of 2% (-2%)	A gain of 5% (+5%)	A loss of 2% (-2%)
	Change in area of Rough Grassland	A loss of 10% (-10%)	A gain of 10% (+10%)	A loss of 10% (-10%)
	Change in area of Mixed and Broadleaf Woodlands	A gain of 3% (+3%)	A gain of 20% (+20%)	A gain of 10% (+10%)
	Condition of field boundaries	For every 1 km, 100 m is restored	For every 1 km, 200 m is restored	For every 1 km, 50 m is restored
	Change in farm building and traditional farm practices	Rapid decline	Much better conservation	No change
	Increase in tax payments by your household each year	£0	£40	£17
	Which do you like best?	☐	☐	☐

Table 2 Willingness to pay for changes in upland landscape features. All values are in £/household/year. 95% confidence intervals are in parentheses. Source: based on Hanley *et al.* (2007). Copyright © 2007 The Agricultural Economics Society. Reproduced with permission of Blackwell Publishing Ltd.

Attribute	Region			
	North West	**Yorks and Humber**	**West Midlands**	**South West**
Heather moorland and bog % increase	0.23 (*0.09 0.41*)	0.31 (*-0.49 1.05*)	0.81 (*0.40 1.37*)	1.64 (*-5.42 11.10*)
Rough grassland % change	0.09 (*-0.44 0.20*)	0.67 (*-0.76. 2.40*)	0.76 (*-0.15 1.83*)	0.23 (*-4.94 11.50*)
Broadleaved and mixed woodland % change	0.24 (*0.10 0.45*)	-0.13 (*-1.22 0.47*)	0.54 (*0.07 1.03*)	0.73 (*-2.79 6.13*)
Field boundaries; length conserved	0.02 (*0.00 0.03*)	0.04 (*-0.03 0.13*)	0.01 (*-0.04 0.06*)	-0.01 (*-0.32 0.50*)
Cultural heritage no change rather than rapid decline	1.69 (*0.18 3.24*)	5.96 (*0.36 18.64*)	3.23 (*-1.11 9.71*)	16.04 (*-0.91 21.35*)
Cultural heritage much better conserved than rapid decline	0.49 (*-3.14 4.11*)	16.73 (*0.07 48.57*)	23.78 (*13.44 41.67*)	26.75 (*-79.5 134.0*)

Box 5.5 Losing distinctiveness of plant communities in the hills: biotic homogenisation

Biotic homogenisation is the process by which species composition becomes increasingly similar over time. Rarer, more specialised species are gradually replaced by widespread, generalist species – a likely consequence of species invasions and extinctions as a result of anthropogenic activities (Olden & Rooney 2006). In some cases, this is accompanied by a decline in species richness and increased within-community similarity (Ross 2011). In upland vegetation, this process has been recorded in alpine vegetation of the Cairngorm Mountains (Britton *et al*. 2009), and in dwarf shrub heaths, grasslands and alpine heaths of the north-west Highlands of Scotland (Ross *et al*. unpublished). The key drivers of homogenisation vary between vegetation types, and understanding of these remains limited. However, changes in environmental conditions, such as climatic warming and increased nutrient availability, are likely to remove former limiting factors on the distribution of species and allow generalist species to colonise new areas that were previously unsuitable (Britton *et al*. 2009). The homogenisation of vegetation, as illustrated in **Figure 1**, is expected to have ecological and evolutionary consequences for ecosystem properties, including a reduction in community resistance to invasions, compromised ecosystem resilience by decreasing the capacity for environmental change, and limited potential for future speciation (Olden *et al*. 2006).

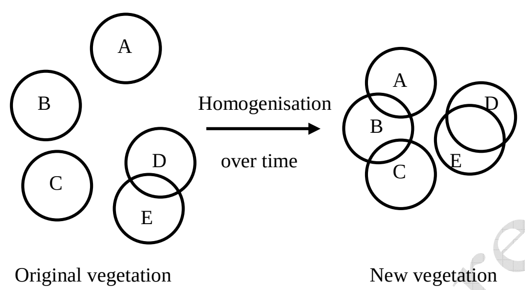


Figure 1 Schematic diagram showing differences in the degree of relatedness between the species composition of plant communities A to E over time. There is less distinctiveness and more overlap in the constituent communities of the vegetation after homogenisation has occurred.

Box 5.6 Environmental risk management: managing wildfire risk and recreation in the Peak District National Park, England.

Wildfires pose a serious threat to MMH habitats, their wildlife and their carbon stores (**Figure 1**). Greatest risk is at its south-eastern climatic range, particularly in the late spring and summer months, when the peat is at its driest and most flammable. Increasing summer temperatures with projected climate change and potential increases in visitors may magnify this threat (McMorrow *et al*. 2009). In the Peak District National Park, there have been over 350 reported incidents of wildfires since 1976, which are commonly started by arson, discarded cigarettes, campfires and barbeques. To tackle this issue, the Peak District Fire Operations Group (FOG) was formed bringing together six different fire authorities, three water companies, the National Trust, private estates and the National Park Ranger Service to help to significantly reduce the impact of wildfires. In addition, the Moors for the Future partnership works in close collaboration with the University of Manchester and other stakeholders to understand the causes and risks of wildfires and raise awareness about them (see www.fires-seminars.org.uk). Risk management measures include: clear protocols and plans for fire fighting; training and use of compatible equipment; predictive mapping of fire risk; and awareness raising programmes with visitors, for example, through the distribution of eco-friendly disposable ashtrays, and the restoration of soils, biodiversity and ecosystem function on wildfire sites.

Figure 1 Fire management on moorland. Photo supplied by Moors for the Future Partnership.

Box 5.7 Biodiversity change and agriculture in the uplands: a long-term historical perspective.

How farmers manage their land is known to have a potentially large impact on species diversity and abundance. But if we look back in time, can we find a long-term relationship between land management in the uplands, and an indicator of biodiversity? Hanley *et al*. (2008) investigated this issue for 11 sites within the Scottish uplands. All sites were chosen to meet two criteria: (i) that they contained suitable undisturbed peat deposits, allowing the extraction of peat cores from which an uninterrupted dating sequence of layers could be obtained; and (ii) that they had farm or estate records which allowed the authors to develop a picture of how land had been managed over the last 400 years (**Figure 1**). Pollen remains were extracted from dated layers of the peat cores and used to establish plant species diversity. Historical records were examined to build up a picture of land use (e.g. grazing patterns), technological change (e.g. the introduction of new breeds of sheep), land drainage, farm amalgamations or divisions, and changes in land ownership or tenancy. Using original sources, a data set of cattle, sheep and barley prices was also developed. The authors then used panel data methods to estimate a relationship between land use, prices and plant diversity over 400 years. The main results were that increases in grazing pressure (measured using changes in prices) led to a statistically significant fall in diversity, while reductions in grazing pressure increased plant diversity. However, land abandonment also reduced diversity. These findings show that the way in which farmers manage land in MMH has had a significant effect on biodiversity over time.

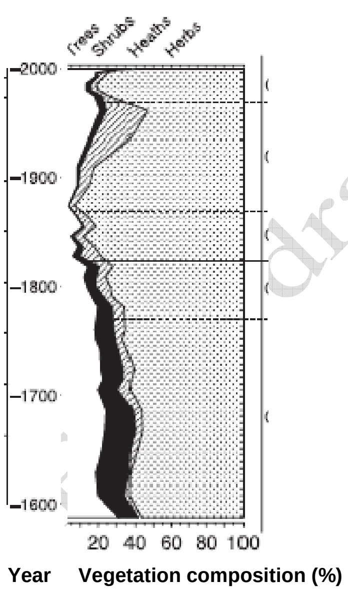
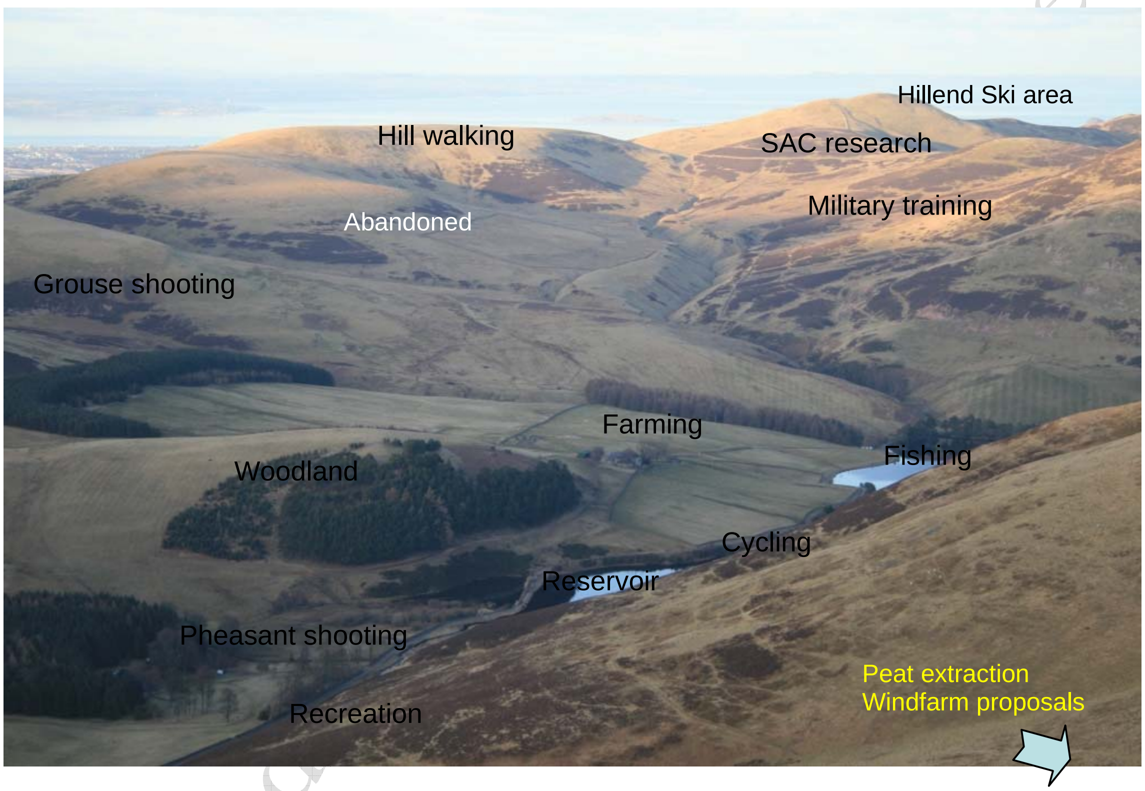


Figure 1 Summary of percentage pollen data for a farm in north-west Scotland, from around 1600 (base of *y*-axes) to the present day (top of *y*-axes). Horizontal lines (zones) depict periods of noticeable vegetation change. Source: based on Hanley *et al.* (2008). Copyright ©2008 British Ecological Society. Reproduced with permission of Blackwell Publishing Ltd.

Box 5.8 Diversity of ecosystem services, goods and benefits provided by the Pentland Hills, 10–12 km south-west of the centre of Edinburgh. Glencorse Reservoir is below the foreground, with Capelaw Hill (454 m) on the left and Allermuir Hill (493 m) on the right, directly overlooking Edinburgh. The challenge for the UK NEA is to cost the range of services provided by a landscape such as this, and to advise on the policies, management practices, connectivity and wider activities needed to ensure that nature is enhanced and wider benefits for society and the environment are identified. Photo courtesy of Des Thompson/Scottish Natural Heritage.



Box 5.9 Ecosystem service recovery through restoration – Bleaklow plateau as case study.

Upland blanket bogs have experienced severe erosion through the last millennium (e.g. Tallis 1997), which resulted in widespread gullying, leading to significant changes in morphology and drainage patterns (Evans & Lindsay, in press b). In addition, land use over the last centuries and especially the last 50 years has exacerbated effects on ecosystem services, such as carbon storage and sequestration, water quality regulation and run-off generation as well as landscape aesthetics and biodiversity (see papers in Bonn *et al.* 2009).

The Bleaklow plateau in the Peak District (53.27.58N, 1.51.09W) has suffered from a legacy of intensive grazing, atmospheric deposition, and a series of large wildfires (Anderson 1997; McMorrow *et al*. 2008), the last one in 2003. This has led to large-scale degradation with extensive bare peat areas, widespread gully erosion covering 34% of the area (Evans & Lindsay, in press a), increased soil acidity (pH between 2.9 and 3.5), severely elevated heavy metal concentrations (Rothwell *et al.* 2005) and very low water tables (26–451 mm below surface, with mean of less than 300 mm in eroded areas [Allott *et al.* 2009]). Vegetation of intact areas in the vicinity is characterised by cotton grass and heather cover (UK NVC classifications M19 and M20, Rodwell *et al.*1991).

The Moors for the Future Partnership is engaging in large-scale restoration of the most degraded areas in the Peak District. Since 2003, bare peat areas over 6 km^2 on Bleaklow have been treated with application of grass nurse crops, heather brash and geojute, including grazing exclusion through fencing. Seed germination and root mat formation is aided by lime and fertiliser to raise pH levels temporarily to 5. This process stabilises the peat soils and enhances soil surface microclimate to allow subsequent colonisation of native blanket bog species by cotton grasses, crowberry and bilberry.

Within three years restoration has achieved an average of 45% in vegetation cover, while control areas have remained bare (Anderson *et al.* 2009). High resolution remote sensing is being evaluated as a tool to monitor this trajectory (Lowe *et al*. 2009). The costs of restoration are £2,900/ha, with costs to date of £1,235,000 (4.3 km) (Walker & Buckler 2009). The effects on ecosystem service recovery and a valuation are summarised in **Table 1** (eftec 2009). The main benefits are clearly derived from improvement of regulating services through greatly enhanced carbon storage, significantly reduced erosion losses, enhanced protection against wildfires and associated damage costs and positive effects on biodiversity and landscape value. Effects on water quality and flood protection are currently areas of further research.

Table 1 Valuation of ecosystem service changes following restoration on Bleaklow.

Ecosystem Services	Pre-restoration (bare peat areas)	Post-restoration (using data from intact sites in vicinity)	Values
Provisioning (food & fibre)	Low or negative value for livestock production after farm cost	Potential to re-establish grazing	Currently no grazing during recovery. Future grazing with low densities of <0.2 sheep/ha = 120 sheep over

			6 km^2 assumed negligible gains after farm costs.
Climate regulation (carbon storage & greenhouse gas sequestration)	POC*: 150–250 t carbon/km^2/yr DOC†: 34–72 tC/km^2/yr GPP‡: -4– -10 tC/km^2/yr NER¶: 44–129 tC/km^2/yr Methane: 0.69 tC/km^2/yr (Modelled average data from Worrall *et al.* 2009, based on Evans *et al.* 2009, Rowson *et al.* in review).	POC*: 6–38 tC/km^2/yr DOC†: 13–58 tC/km^2/yr GPP‡: -48– -386 tC/km^2/yr NER¶: 30–385 tC/km^2/yr Methane: 0.69 tC/km^2/yr (Modelled average data from Worrall *et al.* 2009, based on Evans *et al.* 2009, Rowson *et al.* in review).	Total change over 6 km^2: 152–522 tC/km^2/yr Carbon benefit dominated by avoided losses with carbon budgets on pristine sites of -102–90 tC/km^2/yr (Pawson *et al.* 2008, Rowson *et al.* in review).
Water quantity regulation (flood protection)	Blanket bogs very flashy catchment with little storage capacity. Severe gullying exacerbates channel runoff. Lower water tables under bare peat (Allott *et al.* 2009).	Reduction of overland flow velocities and consequently somewhat reduced peak flows likely with establishment of grass cover and in the future *Sphagnum* cover (Holden *et al.* 2008). Gully network reduction and reversion of morphology unlikely (Evans & Lindsay, in press a).	Assumed negligible, but could be significant by altering peak flow conversions. Flood risk attenuation will relate to wider spatial catchment issues.
Purification – water quality regulation	High rates of DOC† loss, 20–100 t carbon/km^2/yr (Pawson *et al.* 2008; Evans *et al.* 2009). High sediment losses of up to 267 t sediment/km^2.	Currently no measurable benefit of re-vegetation on DOC†, and the trajectory of DOC† development with restoration is unclear. Significant reduction in erosion rates up to an order of magnitude (Evans & Warburton 2007; Evans *et al*. 2009).	Potential for reduced DOC† water treatment cost in the future. Assumed negligible as conservative estimate, but could be significant Reduced impacts on reservoirs sedimentation downstream.
Hazard regulation (wildfire risk)	Bare peat areas identified as high risk areas for wildfires (Lindley *et al.* 2009), especially under climate change scenarios (Albertson *et al*. 2009).	Restoration can mitigate against wildfire risk by reducing ignition hazard (enhanced soil moisture, improved vegetation cover) (McMorrow & Lindley	Avoided costs of up to £210,000, excluding helicopter call-out from fire fighting one incidence in remote moorland location (Aylen 2009).

		2007; McMorrow *et al*. 2009).	
Meaningful places (use and enjoyment, outdoor recreation)	18,000 visits to southern end of Pennine Way.	Some improvement for walkers through stabilised peat surfaces.	Restoration may improve quality of visits.
Field sports	Currently no field sports.	Likely increase in red grouse population, potential to re-establish grouse moor management.	Financial gains of field sports may be marginal after management costs.
Socially valued landscapes (non-use value from historic and cultural landscapes)	Highly degraded landscape.	Improved landscape. Bleaklow is around 0.6% of East Midlands SDA§, around 1.8 million households	National Park designation valued by many people locally and nationally. Based on eftec's (2006) estimate of £8–£23/household (small and large improvement respectively) for SDAs§ in whole region: £0.5–£0.14/household for 6 km^2 on Bleaklow approximately £86,400– £248,400 for 6 km^2.
Biodiversity	Severely degraded with few blanket bog species.	Currently, mean vegetation cover of 45%, moving to 90–100% with pockets of Sphagnum mosses, likely re-colonisation of wading birds.	Bequest values not counted to avoid double counting with recreation and landscape value. Recovery to blanket bog over 15–20 year time span, depends on re-establishment of bog hydrology.

*Particulate organic carbon; †dissolved organic carbon; ‡gross primary production; ¶New Entrant Reserve; §Severely Disadvantaged Areas

Box 5.10 Establishing synergies and trade-offs between ecosystem services: a participatory approach.

During stakeholder meetings synergies and trade-offs were being considered for peatland areas in the Somerset Moors, Thorne and Hatfield as part of a Department for Environment, Food and Rural Affairs project (Defra 2009). The following tables display some of the written comments from the workshop on synergies and trade-offs between ecosystem services for: a) Somerset Moors and Levels (**Table 1**); and b) Thorne and Hatfield (**Table 2**). The different ecosystem services were provided, however participants were asked to include those services that they deemed were missing.

Table 1 Somerset Moors.

		Benefits to people/synergies	**Limitations/trade-off**
Provisioning Services	Food	Livestock-grazing	Nutrient content of natural grass is lower than improved grass. Improved livestock-grazing may mean lower biodiversity.
	Freshwater	Freshwater available	Resource less with higher water levels, more wet grassland and reed area.
	Peat	Fuel and horticulture resource available.	Peat not renewable in the short term; loss of peat results in loss of many other services.
	Withies and teasels	Wetlands provide withies for basket making and teasels for textile production.	More land for withies and teasels may mean less land for grazing and natural habitats.
Regulating Services	Microclimate	Wetlands modify their own climate	Synergy with services supported by high water levels.
	Floods	Flood storage available	Flood water storage assumes low ditch water levels before the flood.
	Carbon	Wetlands have potential to sequestrate carbon.	High water levels reduce carbon dioxide emissions and increase biodiversity but increase methane emissions.
	Diseases		Wetlands can host insects with vector borne diseases, especially if water levels are kept high to support biodiversity.
Cultural Services	Archaeology	Anaerobic conditions preserves organic matter.	Synergy with services supported by high water levels.
	Recreation	Wetlands provide a landscape and birdlife favoured by many people, including anglers.	Synergy with services supported by high water levels.
	Education	Wetlands provide range of scientific, social, economic	Education is supported by archaeology.

		and educational subjects.	
Supporting Services	Biodiversity	Wetlands support unique plants and animals.	Biodiversity may be lower with a higher water table.

Table 2 Thorne and Hatfield.

		Benefits to people/synergies	Limitations/trade-off
Provisioning Services	Food	Low intensity sheep- and deer-grazing.	
	Freshwater	Freshwater available	Standing water encourages reeds in places.
	Peat	Fuel and horticultural resource available.	Peat is not renewable in the short-term; loss of peat results in loss of many other services.
	Energy provision	Coal seams beneath Thorne (previously mined). Gas reserves below Hatfield. Renewable energy - windfarm permission granted.	
Regulating Services	Microclimate	Peatlands modify their own climate.	Synergy with services supported by high water levels.
	Flood risk prevention	Can only store water that falls on site. Cannot take water from off-site and store. Minimum impact of floods downstream.	
	Climate regulation	Peatlands have the potential to sequester carbon.	High water table reduces carbon dioxide emissions and increase biodiversity but may increase methane emissions.
	Drinking water provision/ water quality	No provision of drinking water, although there is a borehole at the edge of Hatfield Moor where water comes from an aquifer below the raised mire.	
	Cultural heritage	Sites of archaeological interest including Mesolithic boats and a rare Bronze age pathway at Thorne and a Neolithic wooden trackway at Hatfield.	Synergy with services supported by high water levels and minimum disturbance to peat.
	Recreation	Peatlands provide a landscape and wildlife favoured by many people. 120 km of tracks, many way marked.	Synergy with services supported by high water levels and minimum disturbance to peat.
	Education	Peatlands provide a range of	Education is supported by

		scientific, social, economic and educational subjects.	Cultural heritage and biodiversity.
Supporting Services	Biodiversity	Peatlands support unique plants, invertebrates, birds and animals.	Biodiversity may be lower with a higher water table.

This allowed identification of key synergies between cultural heritage and carbon storage, and between biodiversity, carbon storage and recreation. Key conflicts were also identified: peat extraction versus carbon storage; and emissions of greenhouse gases, cultural heritage and peat extraction (and resultant arable land) versus biodiversity.

There were also a number of relationships between categories that participants indentified as both a synergy and a conflict depending on specific circumstances and points of view, such as between biodiversity and recreation or flood risk and cultural heritage. Services that were consistently seen to provide high trade-offs with other services were arable food production and peat extraction. Spatial and temporal scales of impact were also important, for example, the scale of impact ranging from global in the case of greenhouse gases to local in the case of flood risk.

To take forward our understanding of how people perceive synergies and trade-offs between services, further focus group discussions were held in the Migneint and Peak District. The participants were provided with the former table and subsequent discussions were used to construct a scoring matrix (**Table 3**): numbers in blue represent votes as a synergy and numbers in red as votes for conflicts.

insert Table 3

For the Migneint and Peak District, generally the conflicts were associated with different forms of land use for provisioning services (wind power, peat extraction). From the scoring matrix, water quality and biodiversity were assumed to have excellent synergy. However, when the detail of this was discussed, it was realised that the relationships are quite complex and attempts to aggregate might be difficult. It may, in fact, be that maintaining monocultures of a particular species (e.g. *Molinia caerulea*) could have synergies with water quality, but trade-offs with aspects of biodiversity.

Nevertheless, both approaches proved valuable in terms of foci of discussion, whilst leaving clearly traceable and concise information. There is a long way to go before we have a sufficient understanding of synergies and trade-offs between ecosystem function, but taking into account stakeholders is likely to provide richer insights that may be shared by the wider community.

Table 3 Scoring matrix.

	Food	Energy (wind)	Energy (peat)	Carbon storage	Greenhouse gases	Water quality	Flood risk	Recreation	Game	Cultural heritage	Biodiversity
Food											
Energy (wind)	1										
Energy (peat)	1										
Carbon storage	11	3	4								
Greenhouse gases		12	2	31							
Water quality	14	1	4	10	1						
Flood risk	1		3	3		1					
Recreation	1		2			21					
Game	13	1	2	2	1	1	2	1			
Cultural heritage	1	1	3					11	1		
Biodiversity	28		3	3	2	7	2	53			

Box 5.11 The impact of different grazers on upland habitats.

Between 1997 and 2003, the Macaulay Institute investigated grazing impacts on seven open-hill habitats in seven out of 11 Deer Management Group (DMG) areas across Scotland. They recorded both indicators of current grazing impact (i.e. percentage of shoots and flowers of dominant species eaten) and indicators of longer-term impacts on the physical structure of the vegetation (recorded as heavy, moderate or light). The presence or absence of red deer, sheep, cattle, rabbits, mountain hares and red grouse was recorded on the basis of various visual signs.

The authors found that sheep were associated with the highest impact across habitats in seven out of 11 DMGs, and their presence increased the probability of observing a moderate or greater impact in most habitats, not only those dominated by grasses, but also heath. After sheep, the recorded presence of cattle was most commonly linked with increased impact on open-hill habitats, although their impact was localised. By contrast, rabbits, mountain hares and red deer had relatively little impact. However, red deer were found to exert clear grazer impact in some habitats, such as blanket bog, in which heather was dominant.

The higher impact associated with sheep presence (**Figure 1)** probably reflects their greater aggregation as a result of their limited ranging behaviour, exacerbated by sheep being herded in places convenient for land managers. Consequently, future reductions in sheep numbers as a result of the reformation of EU farming policies may limit the extent of their impact, but not necessarily the local magnitude. However, reductions in sheep stocks may lead to increases in deer densities, with greater impact, particularly in heather-dominated habitats. Where habitat conservation is a priority this may well require a reduction in deer numbers.

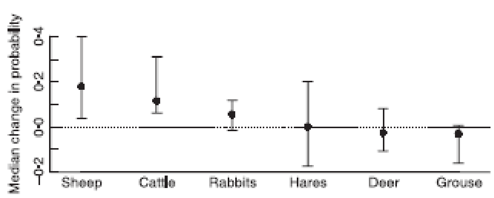


Fig. 2. The median (with 5–95% ranges) grazing and trampling impacts associated with the recorded presence of each herbivore species, averaged across all DMG and all habitats. Results for individual DMG are given in Fig. S1 in the supplementary material.

Figure 1 The medium (with 5–95% ranges) grazing and trampling impacts associated with the recorded presence of each herbivore species, averaged across all DMG and all habitats. Source: Albon *et al.* (2007). Copyright ©2007 British Ecological Society. Reproduced with permission of Blackwell Publishing Ltd.