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The future of the uplands☆

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ABSTRACT

Upland areas provide UK society with many important functions, goods and services, but have experienced a number of disturbing trends and face an uncertain future. This paper outlines historic, current and future drivers of environmental, economic, socio-cultural and policy change in UK uplands, and assesses how these have affected or are likely to affect ways in which land is used and the provision of ecosystem services. Information is synthesised into scenarios summarising a range of possible futures anticipated for UK uplands to 2060 and beyond. Finally, innovations in science, technology, governance and policy are evaluated that could enable uplands to continue providing key ecosystem services under a range of scenarios. The paper concludes that many upland areas will need to be prepared for significant reductions in grazing and prescribed burning. Conversely, other areas could experience agricultural intensification, for example significant increases in grazing or an expansion of arable or bioenergy crops into upland valleys, due to anticipated increases in global demand for food and energy. These scenarios will take place in the context of climate change. Many may take place together and may interact with each other, with complex and unpredictable implications for the upland environment, economy and society. In this context, a number of advances are needed in science, technology and policy to maintain viable upland communities and the future provision of ecosystem services. These may include funding for ecological and hydrological restoration via carbon offsetting or other means. It may also involve advances in ecosystem service modelling, mapping and valuation, which through stakeholder participation could facilitate more integrated rural planning. New forms of environmental governance need to be explored that can empower those interested in developing upland economies to maintain thriving upland communities, while managing the ecosystem services they provide as efficiently as possible.

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Introduction

The uplands (as defined by the European Commission, see this section below) cover a third of the land surface of the UK, and support important land-based industries (notably hill farming, forestry, water industries, field sports and tourism) that underpin the social fabric and economies of many rural communities. Moreover, the UK uplands are of national and international importance for their biodiversity, landscape and cultural heritage, and as a source of crucial ecosystem services (those goods and services from ecosystems that benefit, sustain and support human livelihoods; MA, 2005). They provide food, fibre and timber, climate regulation (through carbon storage or renewable energy supplies), clean water supplies, flood mitigation, and recreation opportunities (Thompson et al., 1995, 2005; Dougill et al., 2006; Bonn et al., 2009a; Hubacek et al., 2009a,b).

Uplands have a long history of change. In the Mesolithic period there was a progressive creation of semi-natural habitats through native woodland clearance (initially to supply timber and assist foraging and stalking, and more recently for hill sheep). This was followed by a progressive intensification of sheep production and, since the 1920s, afforestation with coniferous plantations and a more recent trend towards extensification of production (Simmons, 2003; Davies, 2008). Now and in future, upland areas are subject to a range of significant environmental, socio-cultural and economic drivers which, on top of historic trends, may affect their capacity to respond and adapt to future pressures (Orr et al., 2008; Bonn et al., 2009a; Hubacek et al., 2009b). Growing populations will need to feed themselves under very different climatic conditions on a shrinking land base (as sea levels rise), and compete for food with the rapidly growing middle classes of the developing world. At the same time, upland areas must continue to provide the many other functions and services we have come to expect from them, for example, supplying over 70% of the UK's drinking water (Heal, 2003), without compromising biodiversity and important landscape features. Never before have our uplands been under so many competing pressures, combined with such a legacy of change. In light of these challenges, it is vital to better understand and prepare for the future of the uplands. This paper therefore aims to:

- outline historic, current and future drivers of environmental, economic, socio-cultural and policy change in UK uplands;
- assess how these have affected or are likely to affect ways in which land is used and the provision of ecosystem services;
- synthesise this information into scenarios summarising a range of possible futures for UK uplands to 2060 and beyond;
- identify and evaluate key innovations in science, technology, governance and policy that could enable uplands to continue providing key ecosystem services under a range of future scenarios.

A variety of approaches exist for defining uplands using, for example, elevation, soils or vegetation criteria. Here we use the designation of Less Favoured Area (LFA, under EC Directive 75/276) as the boundary for the uplands[1]. The LFA designation describes areas where farming becomes marginal and less profitable because the productivity of the land is limited, often severely, by physical factors such as harsh climate, short growing season, poor soil fertility and drainage, steep slopes and high altitudes. Although originally a primarily socio-economic designation, it corresponds well with UK upland habitats. The varied nature of UK uplands results from a combination of land use, management and biophysical factors (Holden et al., 2007; Orr et al., 2008). These include: north to south and altitudinal temperature variation; east to west precipitation gradients; vegetation patterns (typically heaths towards the east and acid grass or bogs towards the west and north); wide variations in geology, which have influenced geomorphology, topography and local soil conditions; prescribed fire management (mainly for grouse shooting); wildfires; grazing pressure; other management (afforestation, drainage, peat cutting etc.); acidic atmospheric deposition; proximity to urban areas; legacy effects from historical settlement patterns, particularly the exploitation of natural resources; cultural diversity, typically related to physical isolation in the past; and use for military training.

What pressures are uplands under and how are they changing?

This section will review historic and current drivers of policy, economic, socio-cultural and environmental change in UK uplands, and assess how these affect ways in which land is used and their provision of ecosystem services. The next section will examine possible future drivers and their likely implications. Before this, it should be noted that two underlying challenges make these drivers particularly difficult to address in an upland context.

First, the uplands have perhaps the most wide-ranging set of "economic externalities" found in any land use context in the UK. The beneficiaries of upland ecosystem services are often located in distant urban areas, leading to a mismatch of costs incurred by those who manage uplands and those who enjoy their benefits. Although some costs are borne by tax payers (e.g. through agri-environment schemes) and water customers paying for water treatment costs through their bills, some costs are borne by the landowners. They range from well-endowed private estates to hill-farming communities with declining incomes and declining resources of labour and capital (Hubacek et al., 2009b).

Second, the sheer multiplicity of ecosystem services that are, or could be, provided from the uplands means that there is much competition for land among different stakeholders (Bonn et al., 2009c). Any given parcel of upland may have multiple uses and users at any single point of time. To complicate the situation further, these trade-offs must be negotiated under conditions of uncertainty. The upland system itself is dynamic and is constantly modified by a range of drivers which interact in often unpredictable ways. Partly because of this, the scientific knowledge base upon which to base decisions is never complete (Bonn et al., 2009b). In addition, the complex myriad of overlapping land uses and users has led to complicated land tenure arrangements in the UK uplands, which typically include a high proportion of private land and considerable areas of land owned by NGOs, mixed in with state and common property regimes operating at different scales, with incomplete overlap and sometimes incomplete allocation of rights (McCrone et al., 2008; Quinn et al., submitted for publication).

Finally, it must be recognised that there has been a fundamental change in upland economies over the past 100 years (Slee, 2009). These economies used to be dominated by primary production, including agricultural, forest and mineral products, which provided the exportable products from upland regions. In the 19th century, major demands arose for water to provide for a growing urban population. There were exceptions to this pattern in the Highlands of Scotland and parts of Yorkshire, where sporting land use exercised a powerful economic driver. Particularly since the 1950s, the predominantly land-based economy has shifted to the production of

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[1] It should be noted that they are classified under Article 19 of EC Regulation 1257/1999 as "in danger of abandonment of land-use and where the conservation of the countryside is necessary", not as "mountain" (Article 18) (European Commission, 1999).

secondary and increasingly service sectors with leisure provision and lifestyle migration at its heart. Essentially the uplands have transitioned from an economy built on production to one based on consumption (Slee, 2005). The recent economic crisis and the importance of climate change as a major policy driver raise questions about the sustainability of the consumption-based upland economy and its capacity to respond to calls for more food and fibre to increase national food security in the face of the energy and food demands of a growing world population. The rest of this section will examine possible future drivers and their likely implications, taking provisioning, regulating and cultural ecosystem services in turn.

Drivers affecting provisioning services

Public policy seeks to strike a balance between the many different claims that are made on uplands. Because much upland land use (especially farming) is tied to public policy decisions (regulation and funding in particular), changes in policy can have profound effects on land management (McCrone et al., 2008). After the Second World War, concerns for food security focussed public policy on increasing upland productivity. Efforts under the Hill Farming Act (1946) and the Agricultural Act (1947) were later augmented by the EU, including incentives for LFAs in 1975. Government financial incentives between 1945 and 1980 encouraged farmers to increase the productivity and fertility of upland soils through agricultural intensification. Methods of land quality improvement varied, but generally involved a combination of adding lime and fertilisers, drainage, ploughing and the conversion of native vegetation using more productive grasses to provide improved pasture (Condliffe, 2009). This led to the degradation of upland soils and habitats in many parts of the UK due to changes in the chemical and physical conditions of the soils, land drainage and overgrazing, with stocking density increases of up to 400% in some uplands (Holden et al., 2007; Condliffe, 2009). Today, the reformed EU Common Agricultural Policy (CAP) decouples payments from production, and in response to this policy shift and changing market conditions, sheep stocking numbers are declining rapidly across many parts of the UK uplands (SAC, 2008).

One of the major land use changes in the UK uplands since the 1920s has been the conversion of semi-natural vegetation to plantation forest dominated by coniferous species. This was initially encouraged as part of government policy, through public acquisition and planting of land by the Forestry Commission, and later by the provision of grants, not least to provide a domestic source of timber and reduce reliance on imports. Between the 1940s and 1980s, forestry development became widespread on mineral soils and on peatlands (Forestry Commission, 2000a,b), enhancing soil and water acidification (Carling et al., 2001; Environment Agency, 2004). Since 1990 there has been a steep decline in new planting on deep peat soils, due to a recognition of their importance as a habitat and for carbon storage (Forestry Commission, 2000a,b). Towards the end of the last century, forestry policies began to give prominence to sustainable forest management (Mason, 2007) and, more recently, the contribution of woodlands to ecosystem services. Forest strategies in each of the devolved administrations (Forestry Commission, 2001, 2006; Forest Service, 2006) have aspirations to increase woodland cover while adapting forestry practices to help reduce the impact of climate change. Despite their capacity to sequester carbon and provide timber and wood fibre, there is pressure to change the character of exotic coniferous plantations in many upland areas, and when they are harvested. The intention is to increase the proportion of native trees, both coniferous and deciduous (Gimingham, 2002), diversify structure (Humphrey, 2005) and improve integration with other land uses (Humphrey et al., 2006), notably deer management (Swales, 2009). A critical issue is the optimum location for tree cover to maximise other potential ecosystem service benefits, such as reduced flood risk and increased biodiversity, and to minimise any potential negative impacts (Nisbet and Broadmeadow, 2003).

Finally, minerals extraction and quarrying have been a feature of the uplands for two millennia (Slee, 2009). The underlying geology of many uplands has created reserves of aggregate and of many metalliferous minerals, which have been widely exploited. They were major foci for development at certain periods, notably the Middle Ages and the 19th century. The legacy of these mineral workings now contributes to cultural services. But continued demands for mineral exploitation, particularly of aggregates, are in conflict with amenity-related ecosystem services.

Drivers affecting regulating services

The impressive (but typically unrealised) economic value that uplands provide through “regulating” ecosystem services is highlighted by considering just three of the most prominent: climate regulation through carbon storage and sequestration; water purification; and flood regulation. Protecting these regulatory services and their associated conservation benefits requires significant public investment. Hundreds of millions of pounds are spent each year on water treatment (Defra, 2002), and over £150 million has been spent on peatland restoration in the UK uplands since 2005. Britain’s peatlands (most of which are located in uplands) store around 3 billion tonnes of carbon – more than all the forests of France and UK combined (Worrall et al., 2003). The recent Stern Report (2006) estimated the social cost of carbon at $85 per tonne and carbon has been traded at as much as £20 per tonne in the UK, illustrating the potential value of the UK’s moorland carbon stocks (see next section).

The UK uplands are important water gathering areas for the predominantly lowland urban population. Around 70% of the UK’s drinking water is derived from upland catchments (Heal, 2003). There has been a shift to higher winter flows in recent decades, with significant implications for flood risk management (Black and Burns, 2002; Orr and Carling, 2006), although much of this is attributable to quasi-decadal climatic variability from the North Atlantic Oscillation (e.g. Barker et al., 2004). In large part this derives from a sharp increase in heavy falls of rain in the uplands (Burt and Ferranti, in press), accentuating patterns seen nationally (Maraun et al., 2008). The extent to which land use changes (e.g. drainage ditches) have added to the problem is not clear (Holden et al., 2006; Orr et al., 2008). Conversely, lower summer rainfall could threaten reservoir supplies, especially in combination with dry winters which, due to continuing climatic variability, will still occur under climate change. This was first seen to be a problem during the drought of 1975–1976 and has recurred regularly since then. Appropriate upland management serves to attenuate peak river flows and maintain supplies to lowland areas under low flow conditions. This is likely to become an increasingly valuable service in the future with climate change (Evans et al., 2004). Furthermore, management can reduce the likelihood of landslides and debris flows that can cause major disruption to critical infrastructure such as arterial transport routes (Winter et al., 2005).

Over the past century, atmospheric acid deposition and land use change have had the largest impacts on upland water quality. Under the Gothenburg Protocol and the EU National Emission Ceiling Directive (UNECE, 2004), emissions of both sulphur and nitrogen are declining. Thus, current large changes in atmospheric deposition chemistry are occurring at the same time as the restoration of peatlands (e.g. by ditch blocking) and changes in climate, which are all likely to affect water quality. Indeed, there is already clear evidence of a long-term upward trend in the concentration and flux of dissolved organic carbon (DOC) and hence water discolouration in the UK uplands (Worrall and Burt, 2004; Evans et al., 2006); evidence for which has also been observed across large areas of NW Europe and NE America (Monteith et al., 2007). This indicates the possibility of large-scale driving mechanisms (Roulet and Moore, 2006), such as recovery from acidification (Evans et al., 2006; Monteith et al., 2007), elevated temperature and the effects of elevated carbon dioxide concentrations, affecting net primary production and soil decomposition (Freeman et al., 2001, 2004; Worrall et al., 2006) and points to climate-driven changes in hydrological processes. In addition, Mitchell and McDonald (1995) suggested that burning could lead to increased stream water discolouration, though the wider environmental implications of burning remain largely unknown (Holden et al., 2007).

Upland stream networks flow through a landscape dominated by a mosaic of peat and organo-mineral soils which support a wide range of vegetation including blanket bog, dwarf shrubs dominated by *Calluna vulgaris*, acid and neutral grassland, improved grassland and forestry. This patchwork of land cover, and its associated management, mean that stream water chemistry has high spatial variability. Disentangling the processes controlling stream water chemistry at a landscape scale is difficult because most of our present process understanding comes from studies of small-scale plots, hillslopes and very small catchments. Yet most questions about the sustainability of water resources and the protection of aquatic ecosystems concern the landscape scale. Knowledge of how different upland landscape units interact, over a range of catchment sizes, is required if we are to successfully implement the WFD in uplands. For example in 2007, the Forestry Commission negotiated an agreement to manage the Loch Katrine catchment (supplying Glasgow) following past outbreaks of Cryptosporidium.

Drivers affecting cultural services

Many UK uplands are iconic landscapes of exceptional scenic beauty, and they are often characterised by distinctive cultural identities related to traditional land use activities (Simmons, 2003). Local buildings and dry-stone walls, and land uses such as hay meadows and common grazing, can represent a rich cultural heritage that is also sympathetic to the natural landscape and resources. In landscape terms, this sustains a strong sense of place and identity for both local people and visitors (Countryside Agency and SNH, 2002). As many UK uplands have not been subject to intensive cultivation and are covered by peat soils with good preservation qualities, they offer a rich source of palaeo-environmental evidence of past landscapes and land uses, settlement and field patterns and vegetation change with respect to land use and climate change (Simmons, 2003).

Furthermore, UK uplands have acted as major inspiration for generations of writers, poets and artists, as well as providing cognitive and educational stimuli as dynamic, living landscapes. The opportunities for inspiration and enjoyment of uplands have been the main social drivers for their protection. The National Parks and Access to the Countryside Act of 1949 and the National Parks (Scotland) Act 2000 led to the creation of National Parks that today cover a significant proportion of UK uplands (9% and 7.1% of England and Scotland respectively, including over 50% of English uplands[2]). Many of the remaining uplands are designated as Areas of Outstanding Natural Beauty (AONB) in England and Wales (e.g. the Clwydian Hills), and National Scenic Areas (NSAs) in Scotland. It is increasingly recognised that upland landscapes can provide considerable opportunities to improve public health and well-being (SDC, 2008), as outdoor recreation and experience of nature provide measurable benefits e.g. for mood (Hartig et al., 1991); symptoms of attention-deficit hyperactivity disorder (Kuo and Taylor, 2004); concentration in school children (Wells, 2000); and mental health (Hartig et al., 2007).

Since 2000, with the implementation of the Countryside and Rights of Way Act 2000 and the Land Reform (Scotland) Act 2003, the public has gained a formal right of access to around 566,300 ha of "mountain, moor, heath and down" and a further 369,000 ha of registered common land (CRC, 2008), as well as undisputed access to all of the Scottish uplands. Uplands continue to be among the most popular tourist destinations, with 92.4 million visitor days per year to UK upland National Parks alone[3]. The economic importance of the upland visitor economy in the UK was critically demonstrated during the Foot and Mouth outbreak in 2001, when access restrictions resulted in estimated losses to the tourism sector of up to £3.2 billion and to the rural economy of up to £8 billion, while farmers received a much smaller sum of £1.34 billion compensation for livestock loss (Donaldson et al., 2006; Curry, 2009).

Socio-cultural shifts in recreational preferences, however, are changing tourism patterns (Suckall et al., 2009; Curry, 2009), with a decreasing appetite for traditional countryside recreation (Natural England, 2006). Demographic trends of upland out-migration by young people may be compounded by increasing numbers of 'amenity migrants' (Moss, 2006), higher income earners and retirees making lifestyle decisions to buy property in the uplands, further weakening the social capital of already fractured and ageing communities (Burton et al., 2005; CRC, 2008; Hubacek et al., 2009a). This trend has created unprecedented rises in house prices and squeezed low-paid local people out of housing markets in some areas (Wilcox, 2003).

Another important upland activity is field sports (including grouse, deer and fishing). Several million pounds per year of private investment supports game management in the UK, including the provision of local employment (Price et al., 2002). Grouse moor management, along with grazing, has been responsible for shaping heather moorland habitats (Sotherton et al., 2009). In England, 74% of upland Special Protection Areas (SPAs) are managed as grouse moors, which involves the patch-scale burning of the heather, typically with an 8–25-year rotation. A gradual decline in grouse populations (Simmons, 2002) has seen an increase in the area of moorland being burned, particularly in parts of northern England since the 1970s (Yallop et al., 2006; see previous subsection). Predator control is important for improving game stocks for shooting, but the illegal control of birds of prey has led to conflict between game managers and conservation organisations (Thirgood and Redpath, 2008). In Scotland, many upland estates are maintained for deer with their primary income from an annual cull by deer stalking. This has led in some cases to pressures due to unsustainably high numbers of deer, and conflicts with surrounding land uses such as forestry (e.g. Smart et al., 2008). Similarly, the recreational use of rivers by canoeists has led to conflicts with fishing interests[4].

Biodiversity underpins other ecosystem services and has non-use values such as the ethical obligation to protect species from extinction. However, it also provides many use values such as recreation and aesthetic values (Chapin et al., 2000). The UK uplands are the largest remaining tracts of un-fragmented semi-natural

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[2] http://www.statistics.gov.uk/geography/nat_parks.asp.

[3] www.enpaa.org.uk.

[4] See for example the British Canoe Association's Rivers Access Campaign http://www.canoescotland.com/Default.aspx?tabid=717.

habitats in the UK, and host species of national and international importance. Over 50% of the UK uplands are subject to conservation designations due to their biodiversity, geodiversity and landscape attributes. Many of these overlap with sites designated under the European Natura, 2000 network. The 2010 government target of 95% of all upland SSSIs reaching "favourable condition" has led to changed management and investment. Indeed, English upland SSSIs in "favourable" condition rose from 35% to 72% between 2003 and 2007 (Crowle and McCormack, 2009). The largest causes of "unfavourable condition" were reported as burning, over-grazing and drainage, while the impacts of atmospheric deposition are acknowledged but not yet fully understood (Crowle and McCormack, 2009). However, many uncertainties remain. For example, while prescribed patchwork burning that avoids degenerate stage heather can maintain floristic diversity in sub-montane, dry dwarf-shrub heath habitats (Stewart et al., 2004), there is currently contradictory evidence about the effects of burning on blanket bog habitats (Stewart et al., 2005).

What might the future hold and how can we prepare?

Scenarios are useful for investigating relatively long time horizons, and in systems that are highly complex, unpredictable and cannot be manipulated experimentally to see how structure and function change in response to relevant drivers (Peterson et al., 2003). Rather than attempting to predict the future, scenarios are plausible descriptions of what the future might hold (Kahn and Weiner, 1967). Scenarios offer a systematic method for thinking creatively about dynamic, complex and uncertain futures, and identifying strategies to prepare for a range of possible outcomes (c.f. UKCIP, 2001; Berkhout et al., 2002; Peterson et al., 2003; Madlener et al., 2007). Given the dynamic complexity and unpredictability of the upland system over the long term, this article takes a scenario-based approach to assessing the future of the uplands to 2060 and beyond.

Reed et al. (2009b) reviewed all the scenarios developed for UK uplands to date, and following this, the Sustainable Uplands project of the Rural Economy and Land Use (Relu) Programme developed its own scenarios through participation with a wider range of upland stakeholders and incorporated insights from natural science models of the upland system (Reed et al., in press). Two contrasting groups of scenarios emerge from these studies: intensification of land use and management in UK uplands; and extensification or cessation of land management in UK uplands. The following text examines the evidence for each group of scenarios, where possible examining their plausibility and their likely consequences for the upland system. It uses a combination of evidence from the literature and ranking by stakeholders during workshops carried out in 2007 and 2008 by Reed et al. (in press) in the Peak District National Park, Nidderdale AONB in Yorkshire, and Galloway, Scotland. It uses a two-by-two matrix to indicate their relative likelihood and the magnitude of their impact; Fig. 1). These workshops were supplemented by interviews with stakeholders in the Peak District National Park and Nidderdale AONB ($n = 66$, Termansen et al., 2009; Quinn et al., in preparation).

Any of this group of scenarios is likely to take place in the context of climate change. The future UK climate is projected to have hotter drier summers, warmer wetter winters, and a greater frequency of heavy falls of rain (Hulme et al., 2002). It seems likely that a 1.5–2 °C increase in temperature will occur by the 2050s (Hulme et al., 2002; IPCC, 2007), with dramatic consequences for upland ecosystems (e.g. Ellis and Good, 2005). In uplands, there is already evidence of rapid warming (Holden and Adamson, 2002) and stronger seasonality in heavy rainfall (Burt and Horton, 2003). Summer temperature changes are already having detectable effects on the ecology of food chains which are critical in supporting upland breeding bird populations (Pearce-Higgins et al., 2009). The greater potential for crop growth and for reduced soil moisture levels, allowing longer access to the land, suggest that the capability for agriculture of many upland and currently marginal areas will be enhanced, allowing additional land uses beyond those that have been prevalent in the past (Brown et al., 2008). This could allow arable land or agriculturally improved grassland to expand into the uplands, especially at the margins, or the spread of energy-related crops such as short-rotation coppice or short-rotation forestry.

In this context, it should be noted that many of the processes described in the scenarios that have been identified could occur together, for example with extensification in some areas and intensification in others. Different elements of these scenarios may also interact. This is something that is rarely considered in scenario development, but modelling of scenarios may help clarify some of these interactions (Prell et al., 2007; Reed et al., 2009b; Nelson et al., 2009). We must also be prepared for potential feedbacks. For example, Worrall et al. (2007) present evidence that many current peatland carbon sinks (predominantly situated in uplands) may become sources of carbon due to climate change in as little as 10 years, potentially creating a positive feedback to the climate system.

Scenarios about intensification of land use and management in uplands

Emerging economic incentives from carbon offsetting driving the restoration of degraded peatland

People have modified many peatlands via drainage in order to improve them for agricultural use, and through exploitation of peat for fuel and horticultural purposes. This modification of peatlands alters the net carbon balance of these systems from sinks to sources of carbon dioxide to the atmosphere. The restoration of degraded peatlands is now being advocated as a potentially important mitigation measure for climate change, by reducing carbon losses to the atmosphere. It has been estimated that, if all UK peatlands were restored and in pristine condition, they could soak up 2% of current UK vehicle emissions every year (Worrall et al., 2003, 2009; Worrall et al., in press), significantly improving the UK's carbon economy. Using the Durham Carbon Model[5], Worrall et al. (2003, 2009; Worrall et al., in press) show that, under appropriate management and with a price of £26 per tonne (Defra, 2008), peatland restoration[6] could save enough carbon to pay back its restoration costs within 30 years, making it a good alternative to forestry-based schemes. This scenario was deemed highly plausible and likely to have a significant impact by stakeholders (Reed et al., in press). However, in some areas the restoration of peatlands may lead to an increase in methane emissions at least in the short term. Methane

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[5] All available results from the Durham Carbon Model (Worrall et al., 2003, 2009; Worrall et al., in press) have been examined to evaluate likely effects of scenarios on the carbon budget of peat soils. Data were sorted by management types that can be considered by the model (presence/absence of: burning, grazing, drainage, bare soil or forest plantation) and the predicted budgets were then assessed relative to management using altitude as a covariate. On the basis of the significant differences found, linear models were constructed. In total 4544 model runs were considered covering 1309 km^2 grid squares of upland where peat soil represented at least 10% of the soils in the grid square. The areas chosen covered the Peak District, Lake District, the Forest of Bowland, and the Water of Cree catchment in Galloway.

[6] This considered removing three types of management: sheep-grazing, managed burning of heather and drainage. Any erosion gullies were considered as a (particularly damaging) type of drainage.

Fig. 1. Likelihood/impact matrix showing examples of the categorisation of scenario components by Nidderdale stakeholders (top left) and Peak District stakeholders (top right); and likelihood/impact matrix showing the categorisation of full scenarios by Nidderdale (bottom left) and Peak District stakeholders (bottom right) (from Reed et al., in press).

is a more potent greenhouse gas than carbon dioxide[7], therefore it is important that the long-term impacts of peatland restoration be fully considered. There is an urgent need for research that investigates how much methane is emitted from pristine, degraded and restored peatland sites, in order to evaluate the effect of peatland restoration on greenhouse gas fluxes.

Global food shortages leading to the expansion of arable crops into upland valleys

Food prices are volatile, but rose sharply in 2008 (FAO, 2008). Recent research suggests that projections of food production are overly optimistic because they over-estimated increases in yield due to carbon dioxide fertilisation (Long et al., 2005); that the higher temperatures projected by global circulation models will decrease agricultural productivity (Battisti and Naylor, 2009); and that climate change will reduce food security (Lobell et al., 2008). One solution is to bring land that is currently considered marginal for intensive agriculture (e.g. upland valleys), into production. Many uplands have not been tilled since before the 14th century and have been mostly used since then for grazing (Rimas and Fraser, 2008). The expansion of tillage for food or biofuel crops into upland valleys would be expected to have significant onsite and downstream impacts. For example, the increasing usage of fertilisers could lead to increased loss of nutrients from land to watercourses. This could increase the erosion of mineral and organic soils, with damaging effects on water colour and reservoir sedimentation. The loss of significant amounts of upland peat soil to the atmosphere as carbon dioxide or methane could also significantly influence the climate system (Worrall et al., 2007; Labadz et al., 1991; Johnes and Burt, 1993). Although it was initially suggested by stakeholders, this scenario was not deemed to be particularly plausible during workshops (Reed et al., in press).

Incentives to be self-sufficient in energy driving an expansion of bioenergy production into upland valleys and wind farms on higher ground

The development of international carbon markets, and new renewable energy and greenhouse gas emission targets, may result in the production of renewable energy through bioenergy, wind power and hydro-power in some uplands. The uplands often comprise the wetter parts of the UK and with their steep gradients offer largely unrealised potential for micro-generation of hydro-power by upland communities (Forrest et al., 2008; Slee et al., 2009). They also have the highest average inland wind speeds in the UK, with high potential for wind energy production, although this potential is weakened by the costs of infrastructure and the distance from uplands to the lowland centres of electricity consumption (Orr et al., 2008). The expansion of wind farms is already underway and gaining pace in uplands in response to Government targets and incentives, and aided by amendments to planning regulations (Planning etc. (Scotland) Act, 2006; Planning Act, 2008). Perhaps for these reasons, the expansion of wind energy production in uplands was deemed to be a highly plausible scenario by stakeholders (Reed et al., in press). However, concerns remain about the

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[7] The Global Warming Potential of methane is 24.5 times higher than carbon dioxide.

impacts of wind turbines (and their associated tracks and infrastructure) on upland carbon stores, as well as upland raptors, waders and wintering geese (Barrios and Rodriguez, 2004; De Lucas et al., 2004; Percival, 2005) and on upland landscapes. As a consequence, applications for new turbines are increasingly focusing on lowland sites[8]. In response to this, the John Muir Trust has highlighted the need for a national strategy to counter the current case by case approach (John Muir Trust, 2008), and RSPB has developed bird sensitivity maps to guide decisions over the location of onshore wind farms in Scottish uplands to reduce conflicts with sensitive species (Bright et al., 2006).

Heaton et al. (1999) found that short-rotation coppice (SRC) production in the uplands was more profitable than sheep production without subsidies, and so may become a realistic option if agricultural subsidies decline in future. The landscape effects of the widespread growth of arable biofuels[9] in upland valleys would be broadly similar to the effects of adopting arable agriculture (see above). However, the production of woody biomass[10] would probably involve the ploughing up of improved or rough grazing, and would require fertiliser inputs to produce adequate yields. Although SRC and *Miscanthus* can both be grown in areas that would be considered marginal for agricultural crops, many areas of the uplands are unsuitable (Wildlife and Countryside Link, 2007). In addition, the cost and carbon footprint of transporting bulky biomass crops within the UK is relatively high, encouraging production to be clustered close to processing and generation plants, which currently tend to be located far from most uplands. Perhaps for these reasons, stakeholders questioned the plausibility of scenarios based on the expansion of bioenergy production in uplands during workshops (Reed et al., in press). Interviews conducted as part of the Sustainable Uplands project explored the factors influencing farmers' decisions to adopt bioenergy crops and concluded that the majority of farmers were unlikely, at this time, to consider bioenergy production even with the potential for high returns (Termansen et al., 2009; Quinn et al., in preparation). Most rough grazing or improved pasture was deemed inappropriate for bioenergy production, either because it was too steep, because the soils were unsuitable, or because it was too waterlogged for much of the year. In addition, farmers were deterred from considering bioenergy crops by their distance from biomass markets, a lack of examples nearby, low levels of knowledge about bioenergy crops, and the failure of some existing schemes (Termansen et al., 2009; Quinn et al., in preparation).

Expansion of upland conifer plantations driven by global commodity prices, increased demand for sustainable wood, or policy targets for afforestation in Scotland

The expansion of forestry in uplands (particularly on low carbon content soils) may be necessary in Scotland if the Scottish Government's aspiration to increase woodland cover to 25% is to be met (Forestry Commission, 2006, 2009). Mid 20th-century afforestation was associated with negative effects on soils, water quality, and both aquatic and terrestrial biodiversity (Harriman and Morrison, 1982; Hughes et al., 1994; Ormerod et al., 1989; Waters and Jenkins, 1992; Harriman et al., 1987; Rees and Ribbens, 1995; Wright et al., 1994; Puhr et al., 2000; Dunford, 2008). However, there has since been substantial progress in the development of principles and practice to improve the environmental contribution of forests (Forestry Commission, 2000a,b, 2004), and a growing appreciation of the benefits of new habitats (Humphrey et al., 2003a,b). There are aspirations to increase mixed woodland cover in other parts of the UK too (Forestry Commission, 2001, 2006; Forest Service, 2006), but changes in forest area are also likely to be dependent on changes in global commodity prices and increased demand for sustainable wood.

Although tree planting does offer a means of sequestering atmospheric carbon, rates of sequestration depend on tree species, site-specific growing conditions and management prescriptions (Badeck et al., 2005; Hyvönen et al., 2007), which also influence habitats, water quality and landscapes. Tree planting on peat soils is highly controversial, and is now actively discouraged (Forestry Commission, 2000a,b), because soil carbon losses due to drainage can often exceed gains in tree biomass, producing a net increase in carbon emissions (Cannell et al., 1993; Hargreaves et al., 2003). However, it is important not to over-generalise. Using uplands in the Bladnoch, Cree, Fleet and parts of the Dee catchments in Galloway as a case study, the Durham Carbon Model (Worrall et al., in press) shows that, although planting coniferous forest turns the soil from a sink to a source of carbon and prevents perpetual peat growth (and hence long-term carbon accumulation), this effect is more than offset by tree biomass in the short- to medium-term, with the combined average carbon sink increasing from 59 ton C/km^2/yr for land before planting to 253 ton C/km^2/yr afterwards.

Extensification or cessation of land use and management in uplands

Reduced levels of hill farming based on reduced financial support, cross-compliance with environmental measures and diversification

The first scenario in the extensification group focuses on reduced levels of hill farming based on reduced financial support, cross-compliance[11] with environmental measures and diversification. Given the current downward funding trajectory and the growing prominence of environmental concerns in policy-making, this scenario was thought to be the most likely to occur by stakeholders who were consulted in the studies reviewed by Reed et al. (2009b), and deemed highly plausible and likely to have a significant impact by those consulted by Reed et al. (in press). These studies suggest that, despite reducing hill farm production, this scenario would contribute to the provision of ecosystem services: for example, contributing towards the minimisation of diffuse pollution from agriculture and emphasising the multi-functionality of upland landscapes. However, there could be significantly fewer farms, with some amalgamation into larger farms, and only a limited number of family farms would remain viable. It is also assumed that large tracts of land (concentrated in the highest and most remote areas) could cease to be grazed or managed in any way for agriculture, and that some afforestation, reafforestation and management for nature conservation might occur here. The demand for agricultural inputs and services would probably decline, offset to an extent by demand for new goods and services to support diversification. Many studies assume that if financial support for upland farming is reduced, more funding would be made available for diversification (Matthews et al., 2006; Gardner et al., 2009). New sources of income could include tourism, recreation and leisure

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[8] http://www.bwea.com/ukwed.

[9] Biofuels refer the production of liquid bioethanol from (e.g.) wheat or biodiesel from (e.g.) oil seed rape, as direct substitute for petrol and mineral diesel.

[10] Woody biomass usually refers to short rotation coppice or short rotation forestry, but other more traditional woodland management systems and other types of material can be used.

[11] Cross-compliance creates a link between the receipt of direct payments by farmers and their compliance with rules designed to be in the interests of society as a whole (based on http://ec.europa.eu/agriculture/glossary/index_en.htm).

activities; direct processing and marketing of local produce (e.g. “fell-bred” lamb); alternative crops or other products (e.g. planting bioenergy crops in upland valleys); and new business ventures (e.g. wind farms).

Using an Agent-Based Model[12] of farmer behaviour, based on interviews with farmers in the Peak District National Park, Termansen et al. (2009) showed that a reduction in the Single Farm Payment is likely to decrease sheep stocking densities, and that formerly grazed land is more likely to be managed for grouse, with an associated increase in the area of prescribed burning. This research also indicated that any increase in the Single Farm Payment would probably be used to increase investment in grouse moor management, leading to an increase in the area of heather moorland in the uplands. However, these changes may be offset to some extent by the effects of climate change. The interaction between farmers' decision-making and habitat dynamics is complex. Although sheep production is likely to become more productive under climate change, heather is likely to become more vulnerable to over-grazing at higher temperatures, and land managers are likely to respond to over-grazing by removing sheep from the moor (Chapman et al., 2009). The Durham Carbon Model (Worrall et al., 2003, 2009; Worrall et al., in press) suggests that a reduction in grazing by hill sheep would decrease greenhouse gas emissions by 3.6 ton C/km^2/yr (assuming no drainage or managed burning), both directly through the removal of animals and indirectly through effects on soil carbon budgets.

Withdrawal of agricultural management and re-wilding

The second extensification scenario consists of financial support being withdrawn from upland agriculture, leading to the withdrawal of agricultural management or “re-wilding”. In this scenario, the poorest, highest and most remote land is most likely to be abandoned (Gellrich and Zimmermann, 2007). Most studies agree that any process of re-wilding would most likely consist of some form of active conservation management (including the maintenance of fire breaks) replacing sheep or grouse management, rather than land being completely “abandoned”, and that this would need to be facilitated through some kind of alternative funding, perhaps cross-compliance funding, for current upland managers (Soliva et al., 2008; Reed et al., 2009b). It should be noted that the re-introduction of locally extinct megafauna was not considered as part of this scenario, although this option regularly enters re-wilding debates (c.f. Donlan, 2005; see also ECOS volume 29, issue 3–4 for articles on this topic). This scenario may have negative socio-economic consequences for upland communities due to loss of agriculture, but there may be increased revenue from nature tourism and environmental stewardship management.

The environmental implications of this scenario are currently unclear. Many conservationists favour re-wilding certain upland habitats, particularly blanket bogs (Reed et al., 2005), to enhance biodiversity and landscape aesthetics. Using the HillPlan model, MLURI (2005) predicted that a reduction in grazing pressure under re-wilding might improve the species composition of upland habitats in the short term, leading to an increase in heath communities and a reduction in bracken. In the long term, however, other studies suggest that the reduction in grazing pressure might cause many heath communities to be replaced by scrub and eventually forest unless conservation grazing were introduced (c.f. Hodder et al., 2005) (Reed et al., 2009b). Cessation of grazing and burning, and increased tree cover, may lead to a loss of some potentially important upland ground-nesting birds, while other species may gain, such as black grouse. While a greater tree cover may benefit some forest species, Quine et al. (2007) show that active forest management is more likely to benefit declining woodland birds than the natural forest dynamics under re-wilding.

During the early phases of this change, ecosystems are likely to experience an increase in biomass and hence fuel load, and this may increase the incidence and severity of accidental fires (McMorrow et al., 2009). These would have environmental impacts on water quality, soil carbon and biodiversity as well as economic impacts from the costs of fire fighting. As has been noted above, an increase in tree cover has uncertain consequences for the upland carbon balance. However, any increase in accidental fires which burn into the peat would lead to a significant loss of soil carbon. By contrast, the Durham Carbon model suggests that regular, managed “cool” burns at frequencies of 20–25 years increase carbon stocks on *Calluna*-dominated peat soils compared to unburned systems (Clay and Worrall, submitted for publication).

Perhaps because of the perceived negative implications and likely political unacceptability of re-wilding for most stakeholders, those consulted in the studies reviewed by Reed et al. (2009b) judged this to be the least likely scenario to occur and it was deemed by stakeholders in Reed et al. (in press) to be relatively unlikely, although it would have significant implications. Although many upland stakeholders were not in favour of re-wilding, public opinion places considerable value on “wild” landscapes. For example, although the term was loosely defined, in a recent survey 91% of the Scottish public thought it was important for Scotland to have “wild places” (Market Research Partners, 2008) and findings elsewhere show public preferences for “wild natural settings” over managed landscapes (Arriaza et al., 2004; Van den Berg and Koole, 2006).

Through a combination of interviews and focus groups with upland stakeholders, the Sustainable Uplands project included a range of additional scenarios based on different drivers, which led to the same two outcomes and so are considered within the scenarios above. These included cultural and policy drivers (e.g. the possibility of a future game-shooting ban or regulations to stop the management of blanket bog for game), demographics (e.g. the effects of rural-urban migration limiting the availability of rural labour), and bird disease (e.g. an uncontrolled major disease outbreak that would decimate grouse populations) (Reed et al., in press).

Preparing for the future of the uplands: science, technology and policy advances and needs

Despite the many current and future changes that uplands face, and the associated uncertainties, there are many exciting opportunities as well as challenges to be addressed. Significant innovations in science, technology and policy will be necessary to maintain viable upland communities and the provision of ecosystem services upon which we all depend. Table 1 provides a range of adaptive options suggested by upland stakeholders and researchers for future upland policy and practice. These options focus on adapting to the scenario where future land use and management in the uplands is extensified (Section “Extensification or cessation of land use and management in uplands”, deemed by most stakeholders to be the most likely future scenario). It is based on a combination of facilitated site visit discussions (Reed et al., in press) and an expert workshop (Reed et al., 2009a) as part of the Sustainable Uplands Project, and iterative interviews using the Delphi technique from the ‘Sustainable Estates for the 21st Century’ project (Glass et al., 2009). The remainder of this section explores selected examples from this table.

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[12] A computational model that simulates how the interactions of autonomous individuals (“agents”) lead to actions which affect the wider system in which they are embedded.

Table 1
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 (source a) and an expert workshop (source b) as part of the Sustainable Uplands project and interviews using the Delphi technique from the Sustainable Estates project (source c).

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

(a) Reed et al., in press; (b) Reed et al., 2009a; (c) Glass et al., 2009.

For example, future innovations may come from developing the science necessary to finance peatland restoration through carbon offsetting, using technologies that would otherwise be prohibitively costly at significant scales (see previous section). Critical uncertainties still exist over the role of methane in the carbon balance of restored peatlands, and further research is required to underpin the international accreditation required to launch an upland carbon offset scheme. As well as peatland restoration, various woodland development strategies also have the capacity to sequester carbon, should broad-based offset schemes emerge, and may do so at a lower carbon abatement cost (c.f. Enkvist et al., 2007). Alternatively, advances in modelling may enable us to anticipate how different policy options are likely to affect the decision-making processes of land manager, for example coupling Agent-Based Models to biophysical models of the upland system (Prell et al., 2007; Chapman et al., 2009; Termansen et al., 2009; Quinn et al., 2009; Beharry-Borg et al., 2009). Such advances may also enable us to evaluate the likely effects of potential policies, as they are mediated by the decisions of those who manage the land, across the full range of ecosystem services.

This in turn may open up the possibility of new approaches to rural planning that could make ecosystems more resilient against future change, for example, land use zoning for ecosystem service provision (Reed et al., submitted for publication). The need to move from sectoral approaches to land use policy towards a more holistic ecosystem approach that values all goods and services is increasingly recognised (Natural Environment PSA28 target; Bonn et al., 2009c; Woods, 2009; Swales, 2009). The need to coordinate and optimise current ecosystem service zoning, including for example: incentives to maintain agricultural land, the designation of Nitrate Vulnerable Zones, the designation of protected areas for conservation, open access areas for recreation, and River Basin Management Plans under the Water Framework Directive, is increasingly recognised. As ecosystem service provision affects beneficiaries at different scales (Hein et al., 2006), this approach would involve strategic co-ordination of priorities at national and regional scales (especially for regulating and cultural services) alongside participatory stakeholder partnerships at a local scale. The effective involvement of all relevant stakeholders would be essential during the negotiation of zones and in their effective management (and indeed would be required under the Aarhus Convention). Although this would be a major undertaking, such partnerships are already being developed under the Water Framework Directive to develop Area and River Basin Management Plans, and it may be possible to build on this experience.

There is evidence to suggest that the benefits of maintaining healthy upland ecosystems can become more tangible to land managers, companies, politicians and society at large when portrayed in economic terms and when the number of beneficiaries becomes apparent (Balmford et al., 2002; Naidoo and Ricketts, 2006). Mapping ecosystem services (e.g. Egoh et al., 2007) and valuing them in monetary and non-monetary terms may help provide clarity on a number of current critical uncertainties and support decision making for ecosystem service management (Bonn et al., 2009c). Possible areas include:

- identifying ecosystem service synergies and trade-offs between competing uses of upland ecosystems (c.f. Nelson et al., 2009). This could help target the areas that can most efficiently provide key ecosystem services. The land uses that support these services could then be prioritised over land uses that conflict with their provision, facilitating co-ordinated adaptation to a range of future changes;
- understanding the (economic) gains and losses associated with different policy and management options for upland, and the establishment of (market) tools for sustainable land management (e.g. carbon offsetting);
- assessing the most cost-effective policy options for achieving multiple ecosystem service benefits (e.g. feeding into agri-environment scheme development for payments towards environmental stewardship and ecosystem service provision: see also Goldman et al., 2008).

This approach is made feasible by the development of decision support tools that enable field-by-field management decisions to be supported by fine-scale topographic and hydrological modelling (Holden, 2005). This means that land management policies can be tailored to different land uses in different parts of a catchment: for example, planning for larger stocking rates in some locations within the catchment and stock exclusion on other parts of the catchment, to deliver water quality targets while minimising business impacts on farming. This is in contrast to developing single catchment-scale policies that apply across the whole catchment (e.g. no sheep, or stocking at 3 per hectare) but which may not allow diversity of land use nor have a physical science basis, given that runoff and soil processes vary across the landscape. Such an approach would be consistent with adopting an ecosystems approach to decision making (Natural Environment PSA28 target, Bonn et al., 2009c). However, Woods (2009) suggests that the adoption of such an approach will require a change in mindsets, policies and processes.

To facilitate such an overhaul of rural land use policy, future governments may need to address land tenure arrangements in the uplands to ensure sustainable management across the range of ecosystem services that may be prioritised through such zonation. For example, while private goods such as grouse may be best served by private property regimes, public goods such as biodiversity are more likely to require mixed private-state regimes. Government could use legislation to restrict private property rights, to prevent land management focusing on the production of private goods at the expense of public ones (Lant et al., 2008; Tovey, 2006). As new demands such as carbon storage emerge, tenure arrangements must be able to adapt, to create the most effective mix of regimes for successful and sustainable management (Quinn et al., submitted for publication). However, high costs, inequalities between stakeholders and conflicting objectives can all act as barriers to effective common property regimes (Ostrom et al., 1999; Quinn et al., 2007). In this context, it is necessary to explore the range of emerging approaches to rural governance that align community interests and rural planning. This could potentially be achieved through an extension of the land use planning system, which currently regulates the balance between private property rights and public goods only in the urban or built environment.

Conclusions

The future of the uplands will be shaped by social, economic and environmental forces as well as by policy and science, all of which have the power to mediate outcomes. To future-proof land use policy, it is necessary to be prepared for the widest possible range of likely outcomes. On one hand, we need to be prepared for significant reductions in grazing and prescribed burning. Conversely, other areas could experience agricultural intensification, for example through significant increases in grazing and an expansion of arable or bioenergy crops into upland valleys in response to anticipated increases in global demand for food and energy. Many of these scenarios may play out together and interact with each other, with complex and unpredictable implications for the upland environment, economy and society.

In future, those who manage uplands will be expected to continue providing the many functions and services they provide today, but under very different conditions. This calls for a more sophisticated understanding of biophysical processes, evidence of which is presented in this paper. It also calls for a better understanding of upland economies, of the heterogeneity and cultural distinctiveness of upland communities, and of the links with the lowlands. Here the evidence base is much weaker. Although there is broad awareness of fragility, there is only a modest understanding of how to enhance socio-economic resilience. The evidence base for assessing the trade-offs between public and private goods and services also remains poorly developed. In this context, there is a need to explore new forms of environmental governance, developing policy frameworks that can empower land managers and all those interested in developing approaches to living within our environmental means, both today and into the future.

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