# The Benefits of Woodland
# Unlocking the Potential of the Scottish Uplands

## Part II - Supporting evidence

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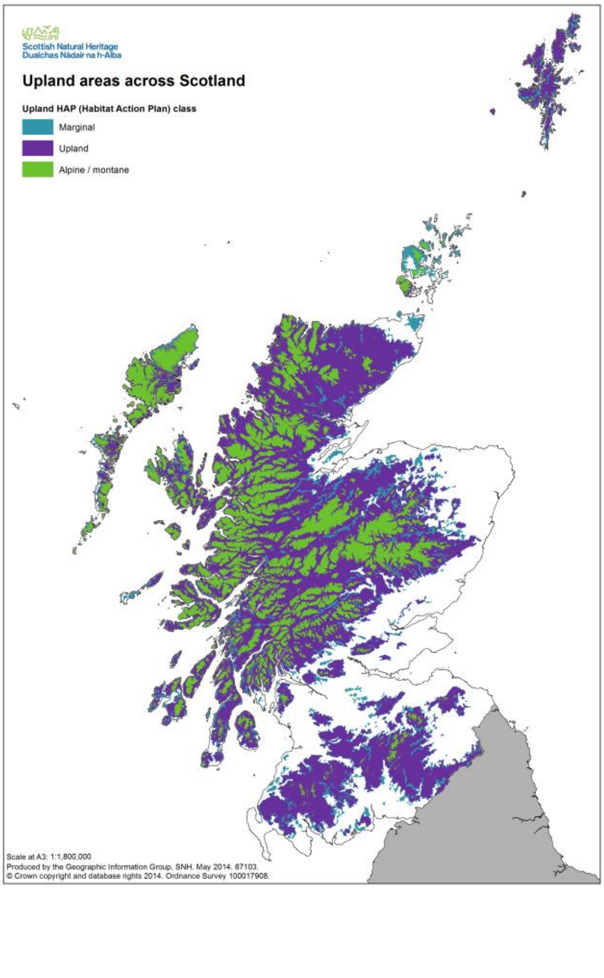
## Contents

### *1. Extent of the uplands*

The extent of the Scottish uplands, as defined by vegetation type, soil type and climate corresponds well with the European Union designation of Less Favoured Area[1]. Scotland's Less Favoured Areas are defined by: (i) The presence of poor land of poor productivity, which is difficult to cultivate and with a limited potential which cannot be increased except at excessive cost, and which is mainly suitable for extensive livestock farming, (ii) lower than average production, compared to the main indices of economic performance in agriculture, (iii) a low or dwindling population predominantly dependent on agricultural activity, the accelerated decline of which could cause rural depopulation[2]. The total area of the LFA in Scotland is 5.38 million ha (68.6% of Scotland's land area and 86% of all agricultural land)[3].

Scottish Natural Heritage (S. Johnson, personal communication) has separately mapped lowland, upland, marginal and montane land types in Scotland using mapped features for the first three categories and a theoretical model of the altitude at which trees would reach no more than 3 m tall to determine the lower limit of the montane zone. This is shown in the map below. The upland and montane zones, which together make up the area above the limit of enclosed farmland, make up 63% of Scotland's land area. This, together with the marginal land, which cannot be classed as lowland, but may be enclosed, makes up 70.8% of Scotland's land area (5.56 million ha).



## *2. Loss of woodland*

Between 4000 and 3000 BC all of Scotland except the mountain tops in the Highlands was dominated by woodland or shrubby vegetation of some sort[4]. Scots pine woodland dominated on poorer soils and at higher altitudes in the central Highlands. Deciduous woodland covered the rest of the wooded uplands with oak dominating in the south, oak and hazel in the southern Highlands and birch in the far north and on the northern and western isles[4]. Boggy and exposed areas, as well as areas above the treeline, although not supporting woodland as such, are likely to have had a covering of stunted trees and shrub species, as is commonly found currently in countries such as Norway, where grazing and burning do not limit tree and scrub regeneration[5]. But even though woodland predominated in the landscape it did not have the dense, closed character that has sometimes been supposed but instead is likely to have been a dynamic mosaic of closed woodland, open woodland, woodland glades and larger areas of grassland and heathland together with areas of montane scrub, stunted bog woodland, blanket bog and montane heath. It is quite possible, however, that only the mountain tops were completely, and permanently, free of any trees or scrub. Overall, woodland in 3000 BC is likely to have covered at least 60% of the total land area of Scotland[6,7]. Between 3000 and 2500 BC the climate became colder and wetter. This influenced the distribution of woodland types and Scots pine dominated woodland disappeared from flat, boggy areas in the north Highlands to be replaced by blanket bog. As a result, the total cover of woodland probably shrank to around 50% of the land area[8].

Although there is some debate about whether humans may have contributed, along with the deteriorating climate, to the decline of Scots pine in the north of Scotland around 5,000 years ago, there is little doubt that, since then, most of Scotland's still extensive tree and shrub cover has been lost due to the impact of humans. Up until 1000 AD this was largely due to deforestation to create fields for crops and to grazing by domestic stock preventing woodland regeneration. Between 1000 AD and 1900 commercial timber extraction, burning for sheep and for grouse and heavy grazing by wild deer added to the pressures on woodland and scrub and led to further extensive losses[8]. Currently, native woodland covers only 4% of the land area of Scotland and only half of this is classed as ancient woodland i.e. native woodland that, as far as is known, has not been planted and has been present for at least 250 years on the same site[9]. Timber extraction is now no longer an issue but the other pressures continue to this day to prevent woodland and scrub from naturally regenerating across much of the uplands of Scotland. A recent Forestry Commission Scotland survey of the native woodlands of Scotland[9] found that 87% of our native woodlands by area were subject to herbivore impacts, largely those of deer, that are either preventing or restricting tree and shrub regeneration as well as substantially reducing tree and shrub species diversity. These high grazing pressures may help to explain why, in the last 40 years, about 12.5% of our ancient, semi-natural woodland by area has been converted to open ground, most of this in the uplands[9]

### *3. Woodland and soil productivity*

Birch is a common colonising tree species that will readily spread onto open heathland in Scotland if there is a supply of seeds from nearby trees. This process is prevented by grazing and burning. Ruth Mitchell, of the James Hutton Institute, has led a number of long-term research projects that have documented the changes that occur on moorland soils when birch invades[10]. The results show that invasion by birch causes heather to be replaced by grasses and herbs. Heather leaves, when they die and fall to the ground, create 'litter' that is slow to decompose due to their high content of tannins and other chemicals. This causes an increase in soil acidity. The change to grasses and herbs caused by birch invasion should therefore result in a fall in soil acidity and, consequently, an increase in the availability of soil nutrients to plants. As expected, the researchers found that litter decomposed faster and soil acidity decreased after birch invasion. Nitrogen and calcium also became more available and the amount of soil phosphorus increased, the latter possibly due to the tree roots bringing phosphorus up from deeper layers of the soil. The number and diversity of soil mites, spring tails and earthworms also increased indicating a more diverse soil fauna and a richer soil. The soils also became drier, probably due to the larger amounts of water evaporated from trees compared to open vegetation. Although less carbon was found to be stored in the woodland soil compared to that of the open heathland, this is likely to be more than compensated for by the additional carbon stored in the trees' extensive root systems as well as in their trunks and branches. These studies have, therefore, confirmed the results of several previous studies that birch, like other broadleaved tree species, has the capacity to improve the fertility and productivity of upland soils[11].

Birch and Scots pine dominate most of Scotland's upland, native woodland. This type of woodland would cover much of the uplands if allowed to spread. Although Scots pine is a conifer, with needles that decompose slowly, woodlands dominated by this species have similar effects on soils to those of birch[11,12]. The soils under a Scots pine woodland are less acidic than those of open moorland[12]. This is probably because, where grazing is not too high, semi-natural woodlands dominated by Scots pine normally contain some deciduous tree species, notably birch and rowan. The trees are often also quite widely spaced allowing light to reach the woodland floor so they have a well-developed ground vegetation layer. The deciduous trees and the ground vegetation will both help to reduce the potentially acidifying effect of the Scots pine litter. Through the action of their roots they can inhibit, and even reverse, the formation of iron pans[12]. Furthermore, the soils under Scots pine woodlands appear to store more carbon than do those of moorland soils presumably due to the build-up of needles[11]. In addition, Scots pine woodland has higher amounts of nitrogen and phosphorus in the soil compared to the soil of open moorland[11]. As with birch, this is likely to be due to the deep tree roots bringing up nutrients from deeper layers of the soil. The trees may also more effectively 'scavenge' nitrogen compounds from the atmosphere.

Plantations of exotic conifers (North American Sitka spruce is the most commonly planted species in the Scottish uplands) tend to be so densely planted that ground vegetation can only grow where there are wayleaves and tracks. The lack of both ground vegetation, and of deciduous trees, together with the high density of conifers, leads to the formation of thick mats of fallen needles. These decompose slowly leading to further soil acidification and possibly increased podsolization[13]. Dense conifer plantations therefore do not have the beneficial effects that more natural types of woodland have on soils and can, in fact, make them even less productive than they were before afforestation[13].

### *4. Muirburn, soils and water*

Surprisingly little research has been carried out on the impact of burning on soils. Recently, however, researchers at the University of Leeds have published the results of a study of the impact of muirburn on blanket peat soils (with peat depths of >1 m at most sites)[14]. They compared soils and water runoff from ten independent river catchments in the English Pennines: five where muirburn had not taken place for several decades and five where muirburn was used to manage the vegetation for red grouse. On the latter moors there was a mosaic of burnt patches ranging from <1 to 25 years since burning. This sort of burning pattern is typical of managed grouse moors in Scotland as well as in England. The results showed that burning reduces the quantity of plant nutrients in the upper soil layers, makes the soil less able to buffer acidic rainfall and lowers the water table making the peat more susceptible to drying out. It also leads to up to four times more particulate organic matter (mostly peat) being washed off the ground and deposited into rivers. They also found that rivers draining burned catchments had lower calcium concentrations, were more acidic and had higher concentrations of silica, manganese, iron and aluminium than those draining unburned catchments. It is likely that the impacts of muirburn, carried out according to best practice[15], on Scottish moorlands and upland rivers are much the same as those found in this study. Where best practice is *not* adhered to, soil and nutrient losses are likely to be higher than those measured. No national statistics are available on even the total area of the Scottish uplands that is burnt each year, let alone on the proportion that is burned according to best practice. Areas of muirburn can frequently be seen, however, that are larger, at a higher altitude, on shallower soils or on steeper slopes than is recommended.

### *5. Grazing, burning and erosion*

Evidence based advice produced by Scottish Natural Heritage[16] states that:

- high sheep numbers can lead to the creation of bare ground that is then subject to erosion.
- Even where overall stocking rates are causing no effect, localised erosion can be initiated where stock are concentrated, for example around supplementary feeding sites, gates, and well-used pathways.
- By preventing or hindering re-vegetation, sheep grazing may maintain or exacerbate erosion initiated by other causes, such as muirburn.
- Scars on slopes, created by sheep rubbing, may extend annually and may result in considerable amounts of soil erosion.

- Although little research has been carried out on the impact of red deer on erosion, they are likely to have similar impacts when at high densities.

The impact of burning on soil erosion was summarized in the same publication[16]. In some soils, water infiltration is reduced after a fire by clogging of the soil pores with fine ash, the development of a crust of charred organic matter and ash, or the distillation and deposition of organic compounds within the soil during the fire. This can lead to an increased potential for erosion. Hot, un-controlled fires are thought to be particularly likely to result in severe erosion especially if the root mat, which binds and protects the soil, is destroyed and /or the fire burns through the peat layer and exposes the mineral soil below. The resulting bare mineral soil, or peat surfaces, are readily eroded by wind and water and may take many years to re-vegetate. Although hot fires will have a much greater impact than will well-managed, relatively cool fires, even well-managed muirburn results in increased peat erosion (see 5, above).

### *6. Woodland and landslips*

In a report on the potential of planted woodland to reduce the incidence of landslides above the A83 in Glen Croe[17], Bill Rayner and Bruce Nichol from Forest Research reviewed previous publications and concluded that 'there is considerable evidence that trees and shrubs can reduce soil loss and rock fall from vulnerable slopes' and that 'the roots of woody species provide a much stronger, and commonly deeper, matrix in the soil, that allow the soil to be held together and anchored better to deeper layers and underlying rock than would be the case with herbaceous vegetation alone'. They further concluded that a mix of tree and shrub species, with different rooting depths, would stabilise soil better than would one tree or shrub species planted on its own. They quoted the results of a study in New Zealand that found that erosion rates under grazing land were 5 to 6 times higher than they had been under scrub and 8 to 17 times higher than they were under native forest[18]. They advised that planting the currently open slopes above the A83 in Glen Croe with a mix of tree and scrub species with different rooting depths would stabilise the soil and help to prevent future landslips.

### *7. Woodland, water and fish*

In 2011, Tom Nisbet and others at Forest Research reviewed the evidence that woodlands created on previously open land can provide many public benefits[19]. They found that planting woodlands adjacent to rivers and streams, or on floodplains, can:

- Reduce the likelihood of flooding downstream
- Protect river banks from erosion
- Improve water quality by reducing the amount of silt washed off the land and into streams and rivers
- Improve water quality by reducing run-off of nutrients and pesticides /herbicides from agricultural land that has had fertiliser and /or other chemicals applied to it.
- Reduce the maximum, and increase the minimum, water temperature in streams.
- Increase the underwater shelter for fish provided by tree roots.

- Increase pool formation and habitat diversity through an increase in the amount of large woody debris.
- Enhance low river flows from water stored in pools, side channels and wetland soils.
- Provide increased food for fish directly via invertebrates falling from over-hanging branches and indirectly via input of deciduous leaves.

All but the first of these improve conditions for fish and other biota (see 11 below). Planting woodlands in other parts of a river catchment can:

- Improve water quality by reducing the amount of silt washed off the land and into streams and rivers
- Slow down the rate at which water flows off the land and into streams so potentially reducing downstream flooding.
- Improve water quality by reducing run-off of nutrients and pesticides /herbicides from agricultural land that has had fertiliser and /or other chemicals applied to it.

The authors note that broadleaved woodland provides the greatest benefits to water quality. This is due to the lower propensity of broadleaved trees to 'scavenge' acid-causing sulphates from the atmosphere and the higher cover of ground vegetation protecting river banks from erosion. In addition, ploughing at the time of woodland establishment, fertilising during the growth phase, aerial spraying of pesticide and clear felling as a means of harvesting timber can lead to increased erosion, siltation and pollution. It is therefore preferable to use other means to establish and manage woodland.

### *8. Woodland and carbon sequestration*

James Morison and others at Forest Research have also recently reviewed the impact of afforestation on carbon stocks and greenhouse gas production[20,21]. They concluded that, on mineral soils, the carbon stored in woodland vegetation, both above and below ground, as well as in woodland soils, is generally far in excess of that stored in non-wooded vegetation and soils. On peaty soils the carbon stored in both vegetation and soil is also likely to be higher under woodland once the woodland is fully established. When woodland is initially created, however, any disturbance from, for example, ploughing, that results in increased erosion or drying out of soils is likely to result in an initial net loss of carbon and other greenhouse gases (methane and nitrous oxide). This is much more likely to happen on peat soils than on mineral soils since peat stores large amounts of carbon that will be lost as carbon dioxide if the peat dries out. There has been very little research carried out to date on the impact of different afforestation techniques on greenhouse gas emissions from different soil types. Taking the precautionary approach, the Forestry Commission has, however, advised that new planting should not take place on soils with a peat depth of more than 50 cm. Woodland creation techniques that do not require soil disturbance, for example natural regeneration or planting without ploughing, are unlikely to cause any net production of greenhouse gases so need not necessarily be limited to soils with a peat cover of less than 50 cm unless there are other reasons for not creating new woodland on these soils.

## *9. Woodland, domestic stock and deer*

In much of Europe, farm forestry is a common form of land use with a long history. Farmers own and manage both farmland and forest resources in tandem[22]. By contrast, the integrated use of land for both agriculture and wood products is currently rare in Scotland although it would have been commonly practiced historically[23,24]. Scott Wilson, in a report to the Woodland Expansion and Advisory Group[24], set up by the Scottish Government, concluded that 'shelterbelt woodland can be of very significant advantage to the yield of crops grown on adjoining fields, and the productivity of livestock benefiting from woodland shelter is known to be enhanced, with reduced thermal stress during cold weather, better welfare standards and lower resulting compensatory bought-in fodder demand. Systems with trees and cropping/grazing on the same land area frequently achieve greater biomass production than agriculture or forestry alone, due to complementary resource capture. Greater forestry activity and timber production on Scottish farms would help to develop and diversify individual farm businesses and the wider Scottish rural economy, creating employment and self-employment opportunities in woodland management, harvesting, woodfuel processing and small-scale sawmilling. Many of these opportunities could be available on a seasonal basis that would make them easy to integrate with existing farm work, reducing income vulnerability in rural areas. This would place the Scottish rural economy, especially in our remoter areas, on a comparable basis with that in parts of Scandinavia with established records of farm forestry.'

The Macaulay Institute (now the James Hutton Institute) and the UK Agroforestry Forum produced a Toolbox to help farmers to integrate stock grazing with woodland[25]. In it they state that grazing sheep amongst trees planted at low density has potential advantages for livestock including increased shelter and a longer pasture growing season[26]. These effects will be particularly important at upland sites.

In relation to deer, Wilson[24] concluded that 'Red deer (*Cervus elaphus*) are naturally a forest-dwelling animal and the presence of woodland shelter on their range is likely to significantly improve their welfare, body weight, antler quality and reproductive fecundity. Deer are thought more susceptible to heat loss and hypothermic stress than either sheep or cattle. Access to woodland shelter is likely to reduce incidence of hill deer mortality during severe winter weather episodes.'

## *10. Fuelwood and timber*

In south west Norway, a reduction in stock grazing and muirburning around one hundred years ago has resulted in a large expansion of native woodland[5]. Most of this woodland, though not managed primarily for timber, is exploited in many ways. Some timber is extracted and it is the main source of the fuel wood used in Norway. This has a declared income (much - perhaps most - is in the 'informal' sector) of £37 million in 2009, or 816 kg per Norwegian household and increasing by 9% annually[5]. In Scotland, it has been shown that birch can produce a return in not much longer than the normal 45 year rotation used for Sitka spruce plantations[27]. There are numerous examples in Scotland of the small-scale production and processing of hardwoods and there is potential for expansion in this area[28]. Native and semi-natural woodlands could thus be a major supplier of both fuelwood and other types of timber.

### *11. Woodland and biodiversity*

Phil Shaw and Des Thompson from Scottish Natural Heritage documented patterns of biodiversity in the Cairngorms[29]. They found that woodland in the area appeared to support more than ten times the number of nationally important species than did more open habitats, such as heather moorland and grassland. They noted that this discrepancy probably reflects the fact that upland heather moorland and grasslands are widespread and abundant throughout much of upland Britain so their associated species are more common and so of less biodiversity importance than are those of woodland. Most of the important woodland species (largely fungi, lichens, bryophytes and invertebrates) were associated mainly with native conifers and birch.[29] There was little difference between woodland and open habitats in terms of important vascular plant, bird and mammal species. This may reflect the impact of heavy grazing throughout the area on vascular plant diversity as well as the difficulty of associating many mobile bird and mammal species with only one habitat.

Since the 1990's, The British Trust for Ornithology has been involved with a number of studies on the impact of increased woodland and shrub cover in the uplands on bird communities. They have found that ' already the shrublands and ungrazed exclosures that have been created are supporting important numbers of some birds such as cuckoo, willow warbler, grasshopper warbler, whinchat, tree pipit and reed bunting. As well as these species, that have declined in many parts of lowland Britain, more typical upland species, for example black grouse and short-eared owl, are found in such areas'[30]. Many other bird species, many of which are currently uncommon or rare in Scotland, are common in higher altitude shrubby and woodland areas in Norway and are likely to benefit from an increase in the extent of higher altitude shrub and woodland habitats in Scotland. These include ring ouzel, bluethroat, mealy redpoll, Lapland bunting, brambling, redwing, fieldfare, wood sandpiper, dunnock and red grouse[31]. The British Trust for Ornithology cautions, however, that although there are many advantages to increasing woodland and shrub cover in the uplands, care should be taken to also safeguard species that require open habitats. One such species is the red grouse. In Norway the willow grouse (of which the red grouse is a sub-species) does well in high altitude shrub habitats and there is no reason to expect that the same would not be true for the red grouse in Scotland if such habitats were available[31]. Furthermore, even if extensive expansion of woodland and shrub habitats did occur, open habitats would always be available above the treeline. Until recently the golden eagle was also thought to need large areas of open habitat over which to hunt. Recent guidance produced by Forestry Commission Scotland[32] concluded, however, that 'available evidence suggests that native woodland expansion, given appropriate design, layout and limits, will not adversely affect golden eagle populations and may, over time, be beneficial by improving the live prey base for the eagles.' By contrast plantations of dense conifers were predicted to reduce golden eagle success by causing a reduction in populations of live prey.

Broadleaved woodland adjacent to streams and rivers provides habitat and food for stream invertebrates and fish as well as reducing water temperature extremes (see 7 above). Stocks of salmon and trout can, therefore, be greater where streamside broadleaved woodland is present[33]. The rare fresh-water pearl mussel which, in its larval stage, needs these fish to act as hosts, can therefore also benefit indirectly from the presence of streamside woodland. Freshwater ussels also benefit from the reduced amount of silt washed into streams in catchments with a higher woodland cover (see 7 above)[33].

The light, or absent, grazing pressure that is needed to allow woodland to expand can, of itself, provide biodiversity benefits. Darren Evans and others, working in an area of upland grassland in Scotland, found that removing, or reducing, sheep grazing pressure resulted in an increase in the height and heterogeneity of the vegetation. This, in turn, led to an increased abundance of arthropods and small mammals; both important food items for predatory birds and mammals[34].

A more anecdotal account of the biodiversity benefits of re-instating native woodland is provided by Alan Watson Featherstone[35]. At Glen Affric, after fifty years of fencing and deer control, he noted that it is not just the Scots pine, and other native trees, that have expanded but also plants such as blaeberry and bog myrtle. These have attracted invertebrates such as moths and sawflies, whose larvae feed on their leaves, and these, in turn, are eaten by birds. Black grouse, a nationally rare species, have spread into areas of young woodland. In West Affric, outside deer fences, the vegetation is short and often dominated by rank grass species such as purple moor grass. Small shrubs, such as heather and bog myrtle, are kept short by grazing and few plants are able to flower or set seed. Areas of eroded peat are common and any trees are present only on rocks or in steep gullies where they cannot be reached by deer. In areas where deer are kept out, bog myrtle and heather replace the grasses, bare peat becomes re-vegetated and birch and rowan trees grow. Plants grow taller, flower and set seed, providing food for invertebrates, birds and mammals. In one such area in Glen Affric flowering bluebells appeared whilst, on the other, deer grazed, side of the fence, none were apparent for miles around. Re-instatement of woodland can lead, he argues, to the expansion and re-colonisation of a wide range of other species due to the cascading ecological impact of the trees. Aspen, for example, is so heavily browsed by both deer and sheep that young trees rarely have a chance to establish anywhere in the Scottish uplands. He relates that woodpeckers prefer to feed, and nest, in aspen trees infected with a species of fungus because the fungus softens the wood. An old woodpecker nest in an aspen tree was observed to be colonised by bees. So more aspens lead to more fungus, woodpeckers and bees.

### *12. Game animals and birds*

Wilson[24] states that 'Although the sporting tradition for red deer in Scotland is of open-hill stalking, the future opportunity to offer woodland deer hunting, on European and North American models, would diversify the commercial sporting enterprise and offer better scenarios for deer control work through the creation of established deer lawns where stalking is undertaken. '

In Norway a number of game animals are sustainably harvested from upland woodland and areas of montane scrub, including red and roe deer, moose, black grouse, capercaillie and willow grouse (the same species as red grouse)[5,36].

### *13. Non-timber forest products*

A 2003 survey indicated that, within Scotland, 24% of the population had collected non-timber forest products (NTFPs) in the previous five years and around 19% of the Scottish population had gathered NTFPs in the last 12 months[37]. In 2006, Marla Emery and others from Forest Research published a report on the uses made of non-timber forest products in Scotland[38]. They found that participants on the project collected over 200 NTFPs derived from 173 plant and fungal species. Of these, 110 products were edible, 81 were used for crafts (particularly basket making and wool dyeing), 34 were used for making wine and other beverages, 18 had medicinal uses and 10 were used for other purposes, such as garden implements and toys. Most NTFPs were collected for household use.

Many of the most commonly harvested species occur in disturbed habitats, at woodland edges, and in hedgerows. Probably as a result of this, the 42 gatherers who provided information to the study were 'nearly unanimous in their preference for mixed woodlands because, in their experience, these ecosystems produce more NTFP's'. They expressed particular appreciation for mature, mixed species woodlands, expressed pleasure with the trend toward planting more deciduous species and expressed a wish to see more areas managed in this way. An increase in the amount of hazel, and other woody shrubs, would increase the availability of some of the more commonly harvested NTFP's.

Generally NTFPs were not collected for financial profit however they provided a range of other benefits in addition to the products themselves. These included a sense of physical and emotional well-being, reinforcement of regular exercise regimes, the addition of valuable nutrients to collectors' diets and items of beauty to people's homes (from crafts). Collection of NTFPs also helped to preserve cultural heritage and the exchange of information about what to collect, when, where, and how, brought family and friends together. Additionally the authors concluded that there were opportunities for more commercial enterprises, based on NTFPs, to be developed especially if the area of habitat types that support most NTFPs was increased. In particular, they concluded that 'ongoing trends toward mixed species plantings at the edges of plantations, restoration of native woodlands, and continuous cover forestry will increase the biological availability of many NTFP species'. Commercial harvesting would need to be done in such a way as to ensure long term social and ecological viability.

### *14. Resilience to climate change*

In a research note produced for Forestry Commission England[39], Duncan Ray and others concluded that 'a key concept in managing risk is diversification: from broadening the choice of genetic material and mixing tree species in different ways, to varying management systems and the timing of operations'.

Using a case study in Wales, Ray and others at Forest Research modelled the likely impact of different forest management approaches on the output of ecosystem services from plantation forests[40]. They compared the impact of continuing to plant largely one species of tree (Sitka spruce) and harvesting large areas on an approximately 45 year cycle, with other approaches to the management of plantations. In particular, they looked at low impact silvicultural systems. These systems use a wide range of tree species, both conifer and broad-leaved, are managed to maintain a high woodland cover at all times and contain stands of a wide variety of ages, including some that are considerably older than 45 years. They concluded that changing to a low-impact silvicultural system would result in forests of higher biodiversity and recreational value, greater carbon sequestration and a more certain timber return in the face of uncertain future climate change. Such a management system would thus provide a better output of ecosystem services, and be more resilient to climate change, than the system that is generally used currently.

***15. Resilience to diseases and pests***

Richard Ennos, from Edinburgh university, recently reviewed the factors affecting the resilience of forests to pathogens[41]. He noted that some pathogens that do not cause a problem when the host tree species is growing at low density in a mixed species woodland, become a problem when the species is grown at high density. Trees growing in a mixed-species woodland, where each tree species occurs at a low density, are likely to suffer less damage from tree diseases than those grown in dense mono-cultures. Ennos considered pathogens but the same is also true of invertebrate pests[42]. There is therefore likely to be a good commercial argument for increasing species diversity in managed plantations. Since climate change is likely to allow novel pests and diseases to spread to, and survive, in Scotland this issue is becoming increasingly important.

***16. Potential for woodland expansion***

In a recent analysis, researchers from Forest Research and the James Hutton Institute concluded that nearly 2.7 millions ha of land in Scotland could potentially be available for woodland expansion[43]. Much of this is in the uplands. Excluded from this area is prime agricultural land, land that is biophysically or biologically unsuited to woodland e.g. built-up areas, areas above the treeline and areas where the surface peat is more than 50 cm deep. Also excluded from the assessment of potentially wooded land is 1.6 million ha that is affected by national designations and policies. Much of this land is designated for the nature conservation value of its open heathland and /or associated species. Although this habitat can be argued to be a degraded landscape, under current legislation, protected heathland areas cannot be converted to woodland. The nature conservation value would not be adversely impacted, however, and may even increase, if the cover of shrubs, scattered trees and small patches of woodland on these areas were to increase. The Scottish uplands therefore have a huge potential for an increase in woodland and shrub cover. Experience from south west Norway, where the climate, topography and previous land use are very similar to the west Highlands today has shown that woodland can regenerate surprisingly quickly given a reduction in burning and grazing pressure[5]. In Scotland, widespread tree regeneration has resulted from removing sheep grazing, reducing deer numbers and restricting burning at several sites in the Highlands including Abernethy[44,45], Creag Meagaidh[46], Glen Affric[35] and Glenfeshie[47,48] . At some of these sites, natural tree regeneration has been augmented by planting. At Carrifran, in the Southern Uplands, where there were few mature trees to provide seed, removing sheep and controlling deer have allowed planted trees to thrive, and a new woodland to be established, without the need for fencing[49].

***17. Deer, ticks and Lyme disease***

Ticks feed off a wide range of small, and large, mammals and birds but females need to feed off a large mammal, such as a deer, to successfully reproduce. This may be because large, adult ticks are detected by smaller mammals and birds and groomed off before feeding. Lucy Gilbert and others at the James Hutton Institute and Aberdeen University looked at the relationship between deer density and tick density at 55 open moorland and woodland sites. They found that 'areas with fewer deer had fewer ticks, and fenced exclosures had dramatically fewer ticks in both large-scale forest and small-scale moorland plots'[50].

There was an elevenfold increase in the number of reported incidences of Lyme disease in Scotland between 2001 (28 cases) and 2010 (308)[51]. The chance of a person being bitten by an infected tick is the result of the balancing effects of the density of ticks, which affects the chance of being bitten, and the chance of a biting tick carrying the Lyme bacterium. Currently, on average, 5% of ticks in Scotland are infected with the Lyme disease bacterium[52]. Although tick densities increase with deer density, the bacterium that causes Lyme disease is killed when it enters a deer's bloodstream [50]. High deer densities may, therefore, result in a reduced incidence of the Lyme bacterium in ticks. The magnitude of this potential 'dilution effect' is not yet known. However, since the Lyme bacterium is harboured by many other species of mammal and bird on which the younger stages of the tick feed, it may not be large. If the 'dilution effect' is indeed small then reducing deer densities, by causing a reduction in tick densities, will reduce the chances of countryside users contracting Lyme disease..

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(Forestry Commission Scotland), Hugh Chalmers (Tweed Forum) and Jeremy Roberts (Royal Society for the Protection of Birds).

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