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Effects of man on upland vegetation

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1 Introduction
This paper discusses the nature of vegetation in the British uplands, how it is influenced by man, and how it can be managed. It can only skim these subjects, and several later papers in this volume deal in more detail with specific management techniques.

Most available management techniques are, as actions, very simple, eg mowing, burning, fertilizing, draining, planting, applying herbicide. However, their consequences are exceedingly difficult to predict in detail, because vegetation is usually complex in structure and composition, and varies from place to place over even small distances. This variation, in turn, is a result of differences in the many factors that shape vegetation, in particular:

i. topography and location (aspect, altitude, etc);

ii. the chemical composition of bedrocks, and thus of soil parent materials (eg, the calcium content of a granite or gabbro can vary 8-fold, that of a sandstone 80-fold (Clarke 1924));

iii. drainage, structure and lithology of the soil (Beckett & Webster 1971; Lyford 1974), especially in transported materials such as glacial drifts (Robinson & Lloyd 1915; Kantey & Morse 1965);

iv. the chance nature of plant dispersal and the incidence of past catastrophes (eg extreme climatic events, outbreaks of disease or insect attack) (Miles 1979);

v. past management, land use and vegetation cover (Van Goor 1954; Armson 1959; Miles 1985a);

vi. clonal longevity and persistence (Miles 1979, 1981).

There are a number of basic points that every vegetation manager should know.

i. The composition of any patch of vegetation reflects its aggregate response to its past environment. Current environmental factors and events only control its future composition.

ii. No 2 patches of vegetation are ever exactly alike (ie in the combinations, proportions and spatial arrangement of the different species present).

iii. All vegetation is constantly changing in time, for various reasons (Miles 1985b), as individuals die and are replaced, though rates of change do vary greatly. Stability is thus only relative. Figure 1 shows the changes that occurred in the control plots of a grazing experiment, ie where there was no experimental treatment, over a 21-year period. These changes were so large that they would have been gratifying if they had been the results of the experimental treatment!

iv. Vegetation always responds to changes in its environment, whether the change is a single brief event (eg a fire), or of longer duration (eg the imposition or removal of grazing by sheep). Such changes, and the reaction of the vegetation, can vary from the gradual to the abrupt, and from the subtle to the obvious.

2 The nature of upland vegetation
The crucial point about upland vegetation is that, below the natural tree-line, it is almost all man-made, directly or indirectly. After the last Ice Age, man returned to Britain as game recolonized, and has been progressively changing the character of upland vegetation ever since. Burning, felling, and grazing by domestic livestock, and by wild herbivores such as red deer (*Cervus elaphus*) whose other predators had been exterminated, have destroyed all but fragments of the once predominant forest cover. In its place, the familiar moorland landscapes have developed, including the forest-zone

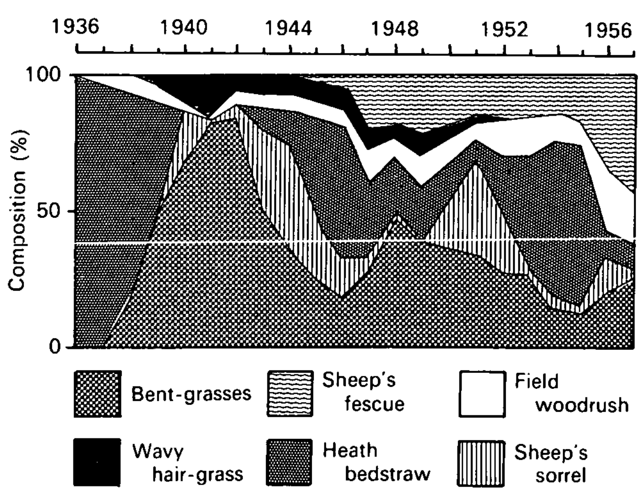


Figure 1. Changes in percentage composition (by cover) of species in a Breckland grass heath, 1936–57 (source: Watt 1960)

blanket bogs (Moore 1973; Merrifield & Moore 1974); even the great peatlands of Caithness may have been initiated by man tipping the ecological balance (Moore 1987). The extent of change to vegetation above the natural tree-line is problematic, but much has been subjected to burning, and all has been influenced by sheep grazing in particular (Thompson 1987). Thus, perhaps only a few cliff ledges, mountain peaks and islets today carry largely natural vegetation.

Man-made vegetation ('plagioclimax') within the potential natural forest zone will revert to forest if it can (a process termed secondary succession). In places with a heavy 'rain' of tree seeds, especially where soils are relatively fertile, this tendency is so strong that it creates severe problems for land managers who do not want the spread of trees (eg on many grouse moors, heathland nature reserves and limestone-dale sheepwalks). Often, however, the vegetation reverts very slowly to woodland, even when not heavily grazed and regularly burnt. This biological inertia results from 3 factors in particular: species poverty (especially light or negligible tree-seed rains), soil infertility (often exacerbated by the effects of the vegetation), and the effects of the vegetation. These points are discussed further because some knowledge of them is needed to understand why the response of upland vegetation to management is so variable.

2.1 Species poverty

As a result of deforestation, and because subsequent repeated burning eliminated fire-intolerant species, large expanses of relatively uniform vegetation in the uplands generally lack successional species, especially shrubs and trees, that can invade and thus change the vegetation, or that give diversity during succession or during regeneration cycles. Thus, heather (*Calluna vulgaris*)-dominant swards often redevelop directly after fire, a simplified course of events associated naturally only with very species-poor vegetation such as that in desert or arctic tundra.

The effects of species poverty were shown experimentally at 3 heather moor sites in north-east Scotland. When ground was bared, recolonization tended to regenerate the surrounding vegetation directly (Miles 1973a). However, when seeds of 107 species, most of which did not currently grow at these sites, were sown on the bared soil, from 28% to 67% of the species established, depending on the soil fertility (Miles 1974a). These new species included many that were probably present at the sites when they were wooded.

2.2 Soil infertility

Most non-calcareous upland soils are relatively infertile, partly intrinsically, because of the prevalence of base-poor rocks, but partly because of the loss of the natural woodland cover, and the subsequent acidifying effects of many moorland plant species, particularly heather (Miles 1985c). This secondary soil infertility now often controls species richness. For example, when soil was bared experimentally at 3 heather moor sites in north-east Scotland, only one species of flowering plant colonized that was not already growing in the surrounding vegetation. In contrast, when the soil was given a dressing of fertilizer, 10 new species colonized naturally (Miles 1973a). Also, in the experiments noted earlier in which seeds of 107 species were sown, 68-86% of the species established on fertilized soil, compared with only 28-67% on unfertilized ground (Miles 1974a).

2.3 Effects of vegetation

Three ways by which plants influence each other are discussed here: competition, the resistance of vegetation to new plants establishing, and the effects of plants on soil properties.

2.3.1 Competition

Competition between plants is the ubiquitous means by which they sort themselves into the assemblages we see. Many examples are of common experience; for example, mowing a lawn close to the ground in autumn tends to result in more moss than grass being present in spring. The main point for the upland manager is that many tall plants such as ox-eye daisy (*Chrysanthemum leucanthemum*) and red campion (*Silene dioica*) will only persist when grazing is light or absent for much of the summer, as in hay meadows. In contrast, intrinsically low-growing plants, such as white clover (*Trifolium repens*) and thyme (*Thymus drucei*), predominate in short swards. Management influences vegetation mainly by changing the competitive balance between species.

2.3.2 Resistance of vegetation to immigration

Many studies have shown that seedlings commonly establish very poorly in undisturbed grassland and dwarf shrub stands (Tamm 1956; Cavers & Harper 1967; Miles 1972, 1974b). Few moorland plant species can tolerate heavy shade; most can establish from seed only

Table 1. Mean percentage establishment after one growing season from seed sown experimentally in heather-dominant vegetation on a brown podzolic soil with different layers of the vegetation removed (source: Miles 1974a)

	Control	Canopy removed	Canopy and moss layer removed	Canopy, moss, & litter layers removed
Common bent-grass (*Agrostis tenuis*)	0	0.5	4	24
Wavy hair-grass (*Deschampsia flexuosa*)	0	0	2	5
Yorkshire fog (*Holcus lanatus*)	0	1	0.8	23
Cat's ear (*Hypochaeris radicata*)	0	2	4	22
Greater woodrush (*Luzula sylvatica*)	0	0.2	0.5	14
Sorrel (*Rumex acetosa*)	0	0	0.5	27
Broom (*Sarothamnus scoparius*)	0.5	4	6	10
Gorse (*Ulex europaeus*)	0	0	10	6

in gaps, though what constitutes a 'gap' varies from species to species. Table 1 shows how the physical structure of a heather stand influenced its receptivity to colonizers. There was negligible establishment when seeds were sown experimentally into the untouched sward, but, when different layers were successively removed, there was a progressive and substantial increase in establishment. This resistance of many vegetation types to colonization by seedlings can make them very stable. Good examples seen in the uplands are stands of rhododendron (*Rhododendron ponticum*) and bracken (*Pteridium aquilinum*), which by layering and rhizome growth respectively can maintain dense thickets that are highly resistant to tree invasion.

Small gaps tend to be filled by vegetative ingrowth rather than by seedlings. When different-sized patches of soil were bared experimentally in a species-rich heather-dominant sward, the cover after 3 years in patches of 25 cm^2 was mainly from plants that had vegetatively spread in from the edges (Figure 2). In contrast, most cover in patches of 2500 cm^2 was from plants regenerated from seed. Not all apparent gaps may be suitable niches. For example, a study of 20 fresh molehills in an alluvial bent/fescue (*Agrostis/Festuca*) grassland showed that, after 2 years, all had 100% cover derived entirely from vegetation regeneration (Miles, unpublished).

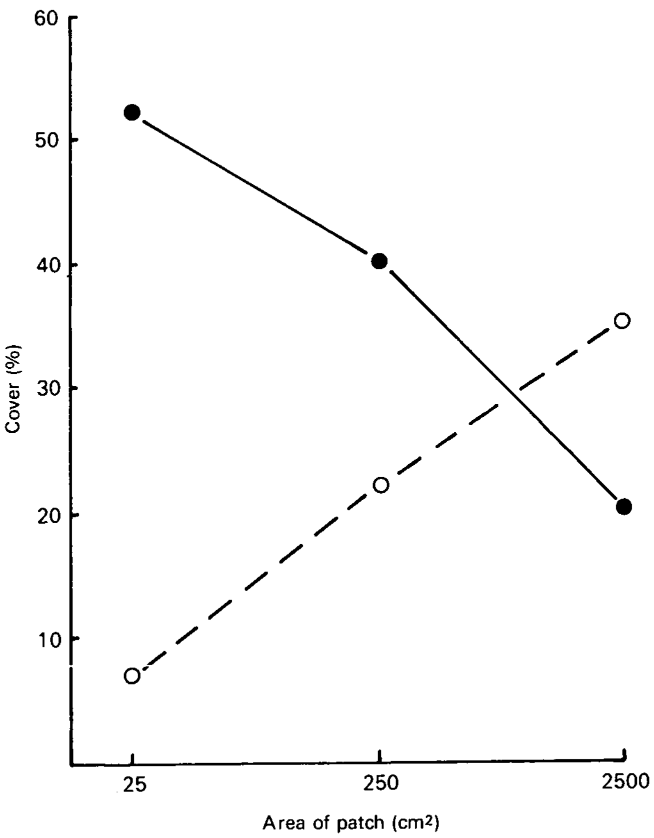


Figure 2. Mean percentage cover after 3 growing seasons of flowering plants regenerated from seed (o– – – – –o) and by vegetative means (•————•) in different-sized patches of experimentally bared ground (source: Miles 1974b)

2.3.3 Effects on the soil

Excluding peats, upland soils can conveniently be classed as having either mull or mor humus, or humus transitional between these 2 forms. This distinction is of fundamental importance. Mull soils have pH values 4.5–5 or greater, are biologically active, with rapid turnover of nutrients, and usually support species-rich vegetation. In contrast, mor soils are acid ($pH<4.5$), have lower rates of nutrient cycling, and are typically associated with species-poor vegetation. In the poorly buffered sandy soils prevalent in the uplands, mull and mor conditions are often interchangeable. Heather and other ericaceous species, pines (*Pinus* spp.) and spruces (*Picea* spp.) tend to produce acid mor soils, and can accelerate podzolization. In contrast, bracken, bent/fescue grassland, birch (*Betula pendula* and *B. pubescens*), aspen (*Populus tremula*), and juniper (*Juniperus communis*) typically produce mull or mull-like humus, and may in time bring about depodzolization through the greater biological activity in the soil (Miles 1985c). When one vegetation type gives way to another, the pH of the surface soil may increase or decrease by 0.5–1.5 units in 10–50 years from initial values between 4 and 6. Changes of this order can markedly influence the species composition and richness of vegetation (Miles 1985a, 1987). For example, when birch colonizes heather moorland, the number of flowering plant species growing under the canopy can more than double as a result of increased pH and associated changes in other soil properties (Miles & Young 1980).

3 *Effects of management*

Most upland vegetation has changed markedly in the past, much is changing now, and, for biological, political and socio-economic reasons, much will inevitably continue to change. Although there are many gaps in our knowledge, we do know a good deal about how to create and maintain the main vegetation types in the uplands. If land managers say what kind of vegetational landscapes they want, vegetation scientists at any point in time can, just like the agricultural advisory services, always advise how to create and maintain what is wanted, on the basis of the best available information. For most of the uplands within the forest zone, the range of potential vegetation types that can exist at any given place is very broad. Most upland soils, apart from areas of limestone and blanket peat, have pH values within the range 3.8–5.5, which accommodates most of the common vegetation types (Figure 3). There is thus considerable scope for creating vegetational diversity.

The most important management practices influencing plagioclimax vegetation in the uplands are grazing and burning. The former is ubiquitous, the latter confined to combustible material (dwarf shrub and shrub stands, bracken and grasslands with an accumulation of dead material), but both have had major and widespread effects. Other practices have been used only locally, though their effects can be equally or more profound. The sections that follow discuss the effects of different management techniques that influence vegetation.

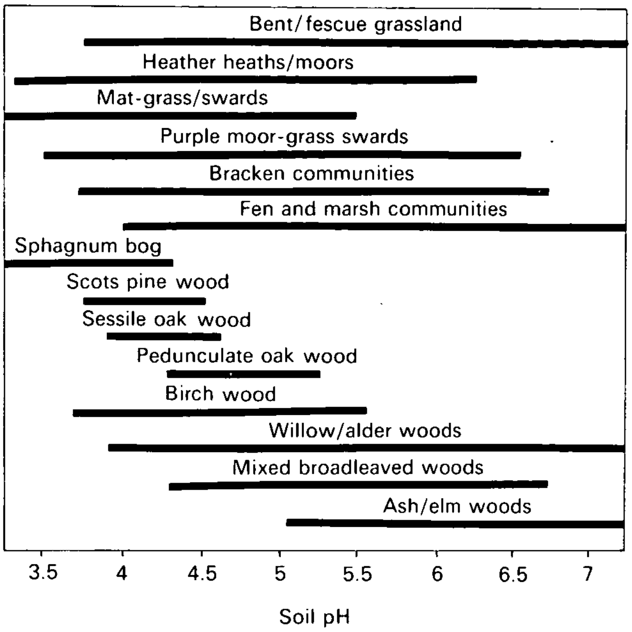


Figure 3. Distribution of vegetation types in relation to pH (source: Miles *et al.* 1978)

3.1 Grazing

Grazing by domestic livestock in the uplands, mainly sheep and cattle, is superimposed on a varying background level of grazing by wild herbivores. Under free-range conditions, the effective grazing intensity on any patch of vegetation depends on the general stock density and the attractiveness of that vegetation, and thus varies widely. One study in the north Pennines showed that the effective density of sheep varied from 5 ha^{-1} on bent/fescue grassland to 3 on mat-grass (*Nardus stricta*)-dominant grassland, one on heath rush (*Juncus squarrosus*)-dominant swards, 0.3 on cotton-grass (*Eriophorum* spp.) bog and 0.1 on heather-dominated bog (Rawes & Welch 1969).

Grazing has a critical effect on the composition of plagioclimax vegetation. All grasslands within the forest zone in Britain are maintained by grazing (or by artificial defoliation, eg mowing). Sheep, in particular, and also red deer in the Highlands, prevent tree regeneration over much of the uplands. Away from moorland, rabbits (*Oryctolagus cuniculus*) and roe deer (*Capreolus capreolus*) also often prevent woodland regeneration. Small rodents eat seeds and seedlings, and sometimes debark and kill saplings, while molluscs also kill seedlings, including those of trees (Howells 1966; Scarratt 1966; Miles & Kinnaird 1979b). Stands of mature trees can be killed by caterpillars, eg birch by those of the moth *Operinia autumnata* (Kallio & Lehtonen 1975), and lodgepole pine (*Pinus contorta*) by those of the pine beauty moth (*Panolis flammea*) (Stoakley 1977). Grazing by heather beetle (*Lochmaea suturalis*) can kill heather plants. On lowland Dutch heaths, death of heather stands from this cause rather than old age seems the rule, and has led to replacement of heather by wavy hair-grass (*Deschampsia flexuosa*) and purple moor-grass (*Molinia caerulea*) (de Smidt 1977; Diemont & Heil 1984). Extensive dieback of heather certainly occurs in the south of England, but further north in Britain only small patches ever seem to be killed.

Controlling grazing by wild herbivores is at best difficult, and often impossible. However, grazing by domestic livestock can, in contrast, be carefully controlled. Figure 4 shows some results from a classic experiment on a north Cardiganshire hill. Two swards evolved under free-range grazing by sheep were studied: one with dominant sheep's fescue (*Festuca ovina*) overlying a well-drained brown podzolic soil, the other with dominant purple moor-grass overlying peat. When sheep were excluded for 2 years, the cover of heather and bilberry (*Vaccinium myrtillus*) in the fescue sward had increased from 1% to 30%, while the more desirable bent-grasses decreased from 9% to 2%. In the other sward, purple moor-grass increased from 55% to 85%, while the bents neared extinction. In contrast, after 2 years of summer grazing at an annual rate of 2 sheep ha^{-1}, the proportion of bent more than doubled in both swards, and less desirable species declined in abundance. Identical grazing pressures probably have different effects in different parts of Britain. For example, in north-east Scotland, heather-dominant stands begin to change to bent/fescue grasslands when grazing levels exceed 2.5 sheep ha^{-1} (Welch 1984).

Patterns of change between upland vegetation types are complex and multidirectional (Miles *et al.* 1978). Figure 5 shows the known successional transitions between 8 common upland vegetation types, divided according to the 3 broad levels of grazing pressure under which they occur. The available information about rates of change between types is summarized by Miles *et al.* (1978). These sequences are poorly understood, and little is known about regional variations in the frequency or occurrence of particular transitions. The main reason for particular transitions occurring at particular sites at particular grazing levels may be simple proximity. Thus, at low grazing pressures, dying birch woods with grassy field layers seem initially to give way to heather unless bracken is present, in which case dense bracken stands quickly develop and prevent heather colonization.

Grazing animals influence vegetation in many ways other than by defoliation. For example, vertebrate herbivores influence soil nutrient status by their dunging and urination (Wolton 1955; Peterson *et al.* 1956), and thus increase herbage production and change the floristic composition (Wheeler 1958; Weeda 1967), while their saliva stimulates plant growth (Reardon *et al.* 1972, 1974). Trampling creates niches for seedling establishment (Miles 1973b); excluding livestock from grassland leads to loss of species diversity (Watt 1960), and from deciduous woodland can lead to a lack of tree regeneration (Shaw 1974; Miles & Kinnaird 1979a). Equally, soil bared by trampling exposes previously buried seeds. Gorse (*Ulex europaeus*) and broom

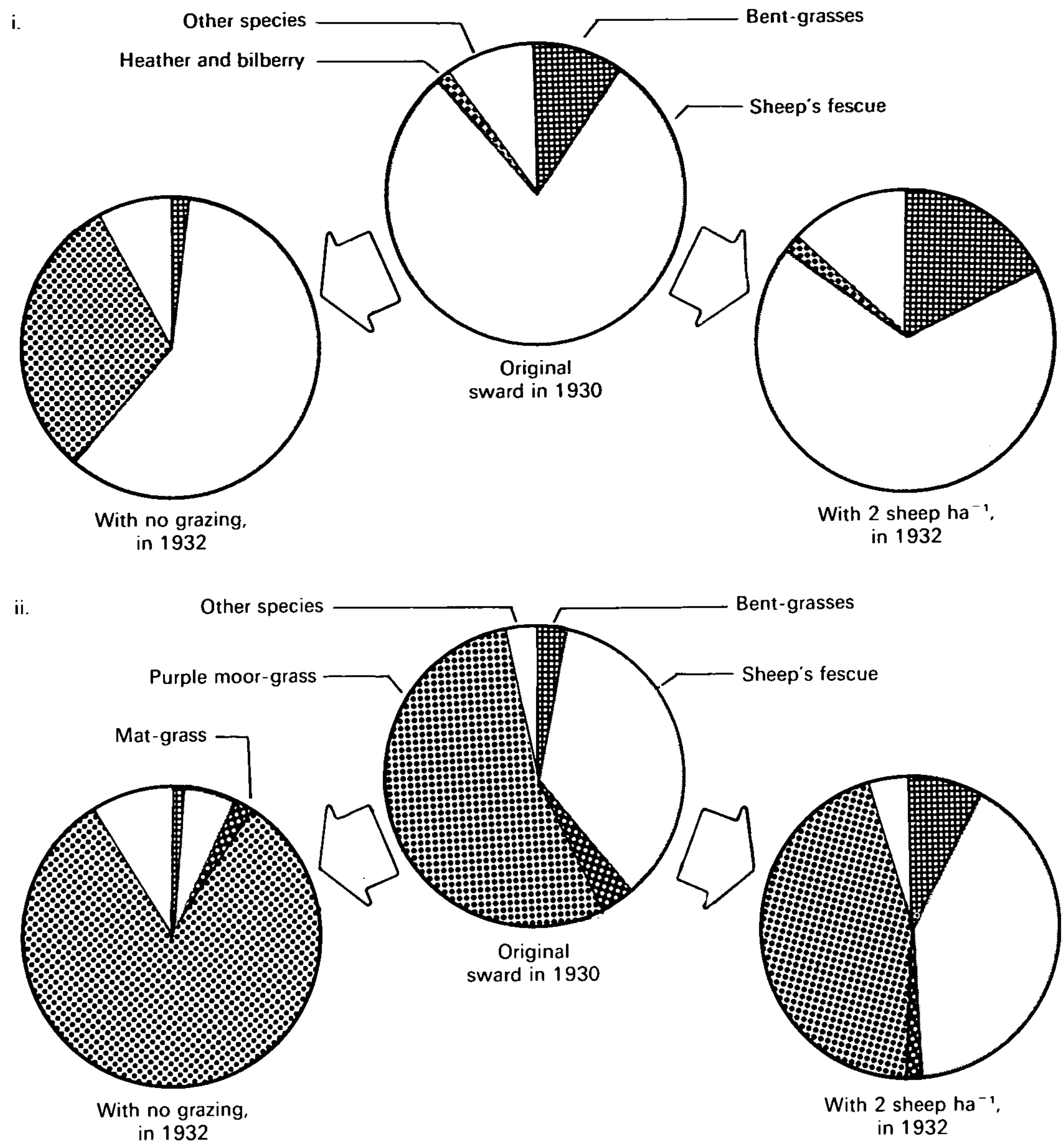


Figure 4. Changes in percentage composition (by weight) of (i) a bent/fescue grassland, and (ii) a purple moor-grass-dominated grassland, at 290 m in north Cardiganshire, after 2 years with protection from sheep grazing and with grazing at 2 sheep ha^{-1} yr^{-1} (source: Jones 1967)

(*Sarothamnus scoparius*) stands, rush infestations and, in woodlands, showy displays of foxgloves (*Digitalis purpurea*) can all originate in this way. Animals also carry fruits and seeds of many plants, internally as well as externally (eg goosegrass (*Galium aparine*) (Ridley 1930)). They are significant agents of plant dispersal in the uplands, depositing many agronomically important species in their dung, eg white clover, bent-grasses, sweet vernal-grass (*Anthoxanthum odoratum*), smooth-stalked meadow-grass (*Poa pratensis*) and rye-grass (*Lolium perenne*) (Welch 1985).

3.2 Fire

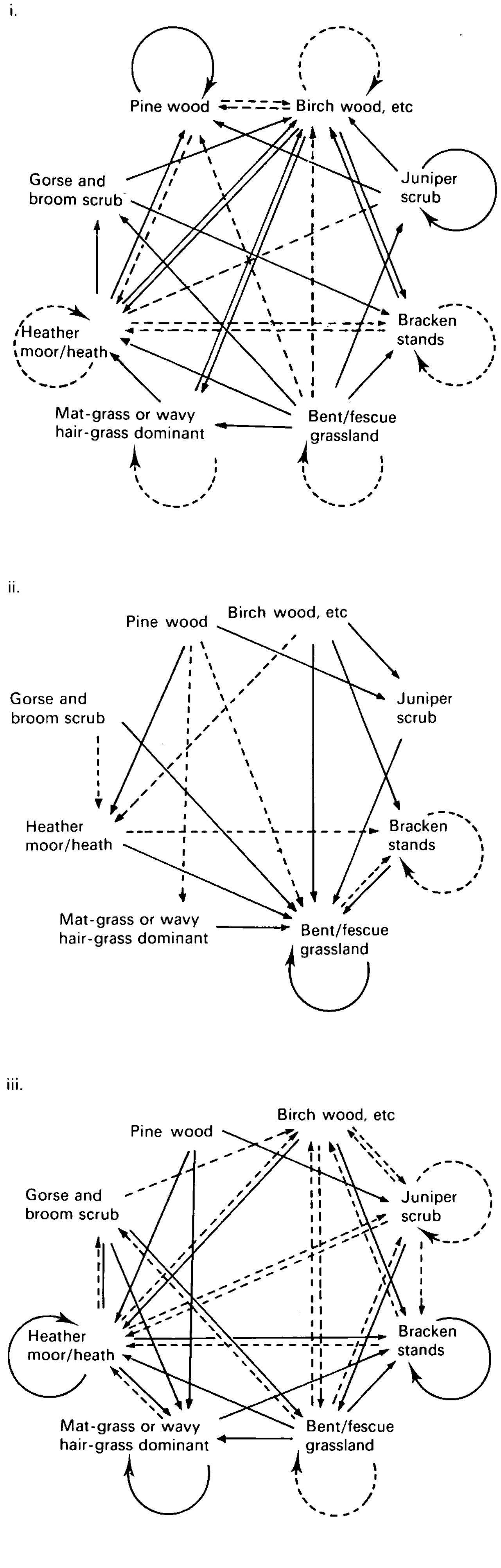
Fires are frequent in the uplands. Some are caused by accident or by lightening (Anon 1970), but most are deliberate acts of management to prevent:

i. the accumulation of old woody stems and litter in heather-dominated dwarf shrub heath, and thus to encourage the growth of new sprouts near the ground for consumption by sheep and red grouse (*Lagopus l. scoticus*) in particular;

ii. the accumulation of dead leaves and surface litter in grasslands, especially where purple moor-grass predominates;

iii. the establishment of trees and shrubs on grazings and grouse moors, and to kill existing scrub.

After a fire, heather and other dwarf shrub stands show a fairly regular pattern of early predominance and changing abundance of many of the associated species. Figure 6 gives an example from north-east Scotland, with a sequence of predominance by grasses, mainly wavy hair-grass, bell-heather (*Erica cinerea*), bearberry (*Arctostaphylos uva-ursi*) with heather, and finally heather with an underlayer of feather mosses. On peatier



soils, bilberry and cowberry (*Vaccinium vitis-idaea*) tend to predominate early on, while on wetter soils cross-leaved heath (*Erica tetralix*) is the more usual early dominant. These sequences occur because many moorland species grow and spread faster than heather after a fire, but are eventually overtopped by the heather and become only minor components of the stand.

Heather regenerates best if it is burnt when about 25-35 cm tall, a height usually reached 8-15 years after the last fire. A well-managed heather moor has a mosaic of small patches (Watson & Miller 1976; Muirburn Working Party 1977). For grouse, a moor should be burnt as small strips about 0.5-1 ha in size, but for sheep or red deer grazings the patches can be bigger. For nature conservation purposes, there should be greater variation in the time to burning, with some patches burnt more frequently than every 8-15 years. This timing increases the abundance of species such as bell-heather that grow rapidly after fire. Equally, some patches should be burnt less frequently than every 15 years to allow fuller development of moss- and lichen-rich layers, but this is not practicable when there is a substantial rain of tree seeds because infrequent burning allows trees to establish.

Lightly grazed areas of hill grassland are also often burnt to remove dead material which would otherwise mask, perhaps for weeks, the spring flush of growth of critical value to livestock. Such grasslands are customarily burnt either annually, as on the purple moor-grass and bent/fescue grasslands of the Exmoor Forest, or every few years, as in the southern uplands and north-west Highlands of Scotland. On mineral soils, repeated burning of grassland can help to maintain species diversity (Lloyd 1968). However, frequent burning favours purple moor-grass when it is present in the sward, and can cause it to become dominant (Grant *et al.* 1963). The difficulty is that purple moor-grass is deciduous, and produces substantial amounts of litter, so that burning it merely further increases the need to burn.

Scrub, particularly gorse stands, is frequently burnt as an attempted control measure. However, burning gorse is usually quite ineffective. Like most broadleaved woody species, gorse bushes, unless very old, sprout vigorously from the base after burning or cutting, thus regenerating the plants. Many other woody species are also burnt,

Figure 5. Successional transitions between common types of semi-natural vegetation on well-drained, acid mineral soils that occur with (i) low grazing pressures (<1 sheep equivalents ha^{-1} yr^{-1}) and without burning, (ii) high grazing pressures (>2-3 sheep equivalents ha^{-1} yr^{-1}) and frequent burning, and (iii) intermediate levels of grazing (1-2 sheep equivalents ha^{-1} yr^{-1}) and burning. Solid lines represent the most frequent transitions, dashed lines less common transitions (source: Miles 1985c, courtesy of the British Society of Soil Science)

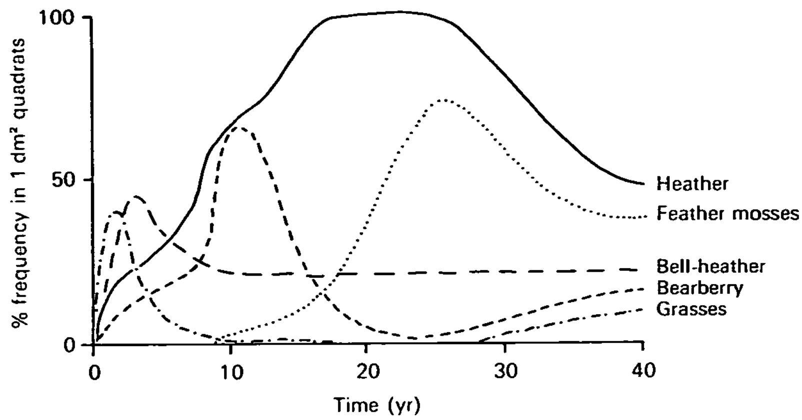


Figure 6. Generalized sequence of vegetation change with time after fire in Dinnet Moor, Aberdeenshire (source: Hobbs *et al.* 1984)

usually during heather, bracken or grass fires. In the uplands, bushes of broom, and saplings and young trees of birch, rowan (*Sorbus aucuparia*), willow (*Salix* spp.), hawthorn (*Crataegus monogyna*), and oak (*Quercus robur* and *Q. petraea*) are often cut back in this way, but generally resprout. Bushes of juniper and saplings and young trees of Scots pine (*Pinus sylvestris*) and other conifers naturalized in Britain are fire-sensitive, however, and are almost always killed by fire.

Carefully planned and executed fires are a useful and positive management tool. Although there was probably a general loss of soil fertility as Britain's moors developed from fires, and when burning began, these losses may now have reached an asymptote, so that careful burning now causes little if any net loss of nutrients from the system. In contrast, inappropriate burning can have serious negative effects on both vegetation and soil (McVean 1959; Gimingham 1985). Burning dwarf shrub heath, too, frequently reduces, and can eliminate, heather and *Erica* spp., and instead causes increases in:

i. wavy hair-grass, fescues, bent-grasses and bracken on well-drained mineral soils;

ii. purple moor-grass and deer-grass (*Trichophorum cespitosum*) on wetter and peatier soils;

iii. cotton-grasses (*Eriophorum vaginatum* and *E. angustifolium*) and, where present, cloudberry (*Rubus chamaemorus*) on blanket peat (Taylor & Marks 1971; Miles *et al.* 1978; Currall 1981; Hobbs 1984).

For example, too frequent burning over much of north-west Scotland has greatly reduced the cover of heather, and thus the amount of green forage available in winter.

Burning heather produces a good seed bed for a few years until a heather canopy redevelops. A heather fire close to trees capable of colonizing moorland is inviting tree invasion, especially by birch. Seedlings of birch are never found in abundance more than 50–100 m from seed-bearing trees (Sarvas 1948; Brown 1984) because most seeds are not dispersed far. The problem for managers, though, is that even an unburnt cordon of heather beside woodland will be invaded eventually by trees, unless the heather is maintained as a vigorous stand by, for example, periodic mowing. This is because gaps otherwise appear in the heather canopy with old age which allow colonization.

Burning on very steep slopes is inadvisable, as even temporary removal of the stabilizing cover of vegetation can allow the onset of gulley erosion, a phenomenon which can happen anyway during periods of prolonged heavy rainfall (eg the summer of 1985) even on wooded slopes. However, perhaps the most important, though commonly overlooked, result has been when burning too frequently or during drought conditions has either destroyed the surface covering of humus or peat, or allowed its loss by erosion, on infertile soils where this layer comprised a high proportion of the readily available nutrient capital. Such devastated areas are particularly common in the north-west Highlands of Scotland, the result of traditionally uncontrolled burning over poor soils in a high rainfall region. They also occur too frequently elsewhere, at least in the Highlands, especially on higher and steeper ground. Peat erosion in the Pennines and on the North York Moors has also been attributed to injudicious burning (Imeson 1971; Tallis 1973).

3.3 Fertilizing

The addition of nutrients to vegetation acts to swing the balance of composition towards dominance by species with high relative growth rates. While the nature of any change depends on the nutrient status of the soil in question, addition of either nitrogen or phosphorus to upland soils with plagioclimax vegetation invariably causes considerable floristic change, while liming causes lesser changes.

Light dressings of nitrogen fertilizer can increase heather growth and flowering (Miller 1968; Miller *et al.* 1970; Helsper *et al.* 1983), but heavier or repeated dressings result in its gradual replacement by other species. Which species replace heather depends on the soil type, and on what species are present and thus able to take advantage of the changed nutrient availability. The sparse available information suggests that additions of nitrogen and/or phosphate in the absence of imposed grazing tend to cause increases at the expense of heather in:

i. mosses and lichens respectively on the poorest podzols, where graminoid species are sparse or absent, while lime also favours mosses (Helsper *et al.* 1983; Miles 1968);

ii. fescues and bent-grasses on more fertile soils (eg brown podzolic soils), which usually support relatively species-rich stands (Jones 1967; Heil & Diemont 1983);

iii. purple moor-grass on soils that are poorly drained or have high water tables (Jones 1967; Vermeer 1986; Miles, unpublished).

In one experiment, addition of nitrogen, phosphorus and potassium at agricultural rates increased the percentage of purple moor-grass in 2 grassy mires from 44 and 62 to 97 and 95 respectively (Miles, unpublished).

The effects of fertilizer interact strongly with grazing, and can be speeded up. Figure 7 shows the dramatic changes that occurred in 5 years, with rotational grazing to maintain short swards, from a single addition of 800 kg ha^{-1} of ground limestone, and from annual additions of nitrogen, phosphorus and potassium at 80, 67 and 27 kg ha^{-1} respectively, with bents and sheep's fescue becoming dominant in place of purple moor-grass.

Patches of hillside in northern England and the southern uplands of Scotland were in the past irrigated with lime-rich water to improve soil fertility, a practice begun by Cistercian monks and continued into the 19th century. The effects on vegetation composition were similar to those from liming (Heddle & Ogg 1936).

3.4 Draining

It has never been economic to install tile or other buried drains on unimproved ground, but there was an earlier vogue for making open drains on moorland (moor gripping) to try to improve grazing values, including improving heather growth on grouse moors. However, draining any but the wettest ground has little effect on vegetation, except immediately beside open drains (Stewart & Lance 1983). Of the common and abundant upland species, *Sphagnum* mosses and cotton-grasses are the most drought-sensitive. Open drains do increase sediment runoff, a phenomenon particularly associated with modern afforestation. Thus, deep ploughing of land for drainage in part of Galloway prior to tree planting was shown to cause a 20-fold increase in sediment runoff (Battarbee *et al.* 1985). Such pulses of soil erosion last for about 10 years, and can damage the stream spawning beds of salmon and trout and interfere with the water industry.

Over much of the uplands, buried drains are an essential part of creating improved pastures. In recent decades, the increasing availability of mechanical diggers, coupled with Government subsidies, has markedly increased the areas of reclaimed moorland, and thus changed landscapes. One consequence has been the spread of tall rushes. These rushes naturally occur on marshy and boggy ground, especially on acid soils, but stands are never extensive on unreclaimed moorland. Several species occur, with similar ecology, though soft rush (*Juncus effusus*) is generally the commonest. However, rush infestations are common in grasslands on intrinsically poorly drained soils, especially in the high-rainfall areas in the west of Britain. These sites commonly give the 2 factors needed for rush germination and

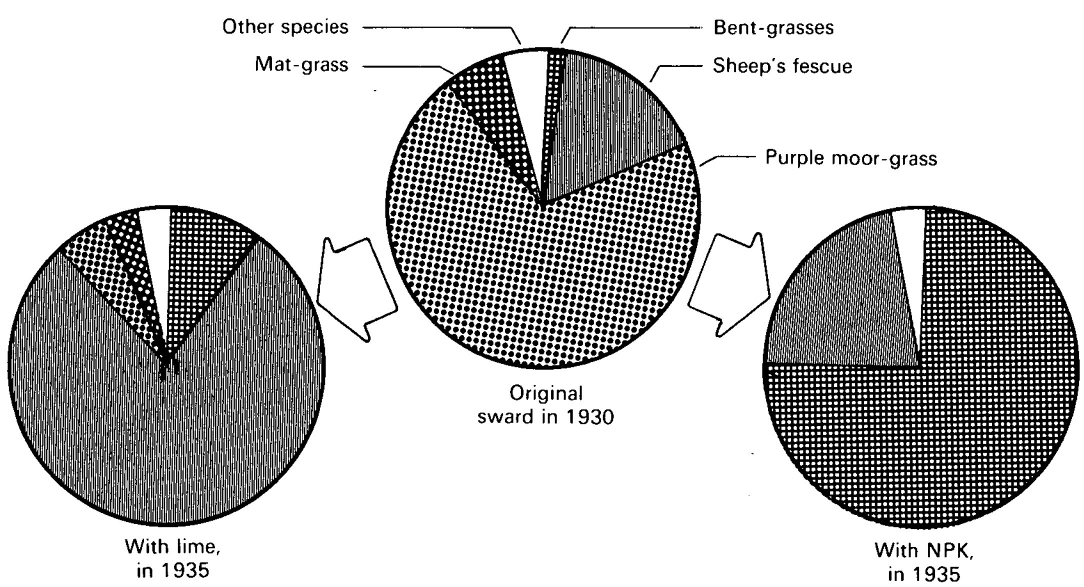


Figure 7. Changes in percentage composition (by weight) of a purple moor-grass-dominated grassland after 5 years, following a single application of ground limestone and annual additions of NPK (source: Jones 1967)

establishment: wet surface soil (Lazenby 1955) and, because of poaching by livestock, small patches of bare soil (Agnew 1961). On many soils it is likely that no drainage system will ever reduce surface moisture enough to prevent rushes establishing from seed. Seed production is prolific, and seeds are dispersed by wind when dry, and by various animals when wet because their seed coats become sticky (Richards & Clapham 1941). Further, seeds can stay dormant in soil for decades; over 15 000 seeds per square metre of ground may be present (Milton 1948). Thus, on unsuitable soils, prevention of rush infestations means either not reclaiming the ground in the first place, or else mowing the grass crop. When livestock grazes reseeds on such ground, it is usually only a matter of time before some poaching occurs and the first rushes colonize.

3.5 Weedkiller use

Selective chemical weedkillers (herbicides) have been developed and used since the 1940s. With the range of selective and total weedkillers and ways of application now available (Fryer & Makepeace 1978; Marrs 1981; Johansson 1985), there is no upland weed that cannot be controlled in principle.

All trees and shrubs (including gorse, birch and rhododendron) can be killed by either foliar spraying or stump treatment. The most commonly used effective chemicals are 2,4,5-T, glyphosate ('Roundup'), ammonium sulphamate ('Amcide') and fosamine ammonium ('Krenite'); all except the last are recommended for stump application as well as foliar sprays.

Bracken control was revolutionized by the discovery in 1967 that asulam ('Asulox'), a non-persistent weedkiller of low toxicity marketed 2 years earlier to control docks (*Rumex* spp.), was very effective at killing bracken (McKelvie & Scragg 1972). Spraying following the manufacturer's recommendations will give a 95–96% kill in the first year, and respraying in the second year can give 99+% control (Miller *et al.* 1984). Follow-up spraying or cutting is essential; otherwise the 4–5% of fronds that reappear after a single treatment will regenerate a dense stand in a few years.

Purple moor-grass and deer-grass can be controlled by the selective weedkiller dalapon. Using it, heather dominance has been recreated experimentally in part of Wester Ross where too frequent burning had resulted in these species becoming codominant (Miller *et al.* 1984).

3.6 Mowing and cutting

In the absence of grazing, grasslands can be maintained by mowing, which need not be more often than once a year. Indeed, this is how species-rich hay meadows have traditionally been maintained, sometimes for centuries. Road and railway verges and river banks are also commonly managed by periodic mowing or cutting.

Cutting woody vegetation rejuvenates the stand, which is the basis of woodland management by coppicing. Heather stands can also be maintained by cutting, though if the brash is left where it falls regeneration is impeded. Roadside gorse stands are often cut by local authorities, apparently as a control measure, but unless the plants are very old the stands are merely rejuvenated. To eliminate broadleaved scrub after cutting, stump treatment with an appropriate weedkiller is needed.

3.7 Soil disturbance

Ploughing and/or harrowing or discing are routinely done during agricultural reseeding. Ploughing kills many grassland species. Usually these species will quite readily recolonize small ploughed patches that are still surrounded by intact grassland. However, the larger the disturbed patch, the slower this process is.

When large areas are ploughed, there can to all intents and purposes be an absolute loss of species diversity, especially if adjacent seed sources are minimal. Soil disturbance can nevertheless be used to positive effect for nature conservation purposes, because it allows short-lived, ruderal species to establish from buried seed, which, if not controlled, increase the species diversity of the swards for 2-3 years. Soil disturbance has been used by nature reserve managers to maintain early successional species in chalk grassland (Duffey *et al.* 1974). Crofters in South Uist still practise shifting cultivation of small plots of machair grassland to grow potatoes and forage crops. This practice results in scattered patches of successional grassland of different ages and species composition, which enhance the floristic diversity of the machair.

Historically, heather-dominated heathlands in Flanders, the Netherlands and north-west Germany were maintained largely as a result of periodic sod removal (deturfing), with the heather regenerating from buried seeds. Sods were used as bedding and litter for inwintered livestock, and the resulting muck was used to fertilize arable fields (Gimingham & de Smidt 1983). Today, sod removal is a practical way of regenerating heather or *Erica*-dominant stands in heathland that has changed to grassland, eg as a result of grazing (Bakker 1978). Heather seed populations persist for decades in acid soils, so that, provided seeds remain in reasonable numbers, sod removal is a useful tool for nature reserve managers.

3.8 Planting and sowing

The advantage of transplants is that they generally establish under conditions in which seedlings would fail. Tree planting is done routinely throughout Britain, for production, amenity and nature conservation purposes. Shrubs and herbs can also be successfully planted in the wild, as was shown even in the last century (Bonnier 1890, 1920; MacDougal 1921). It is quite feasible to establish a wide variety of species in upland areas where the species in question grew, or probably grew, in the past (Park *et al.* 1962), or even where they may never have grown, at least not for centuries (Miles 1974a, 1975). However, introducing uncommon species to sites outside their putative natural range is a debatable activity, and may cause ill-feeling among nature conservationists and students of plant geography!

Planting can use individual plants or turves (Park *et al.* 1962; Humphries 1979; Gilbert & Wathern 1980); Miles (unpublished) has successfully established heather-dominant stands in patches of felled birch wood in a long-term experiment on the effects of heather on soil fertility. Eighteen-month-old heather plants were spaced at 25 cm intervals after the field layer had been killed with 2,4-D and dalapon, and the stand achieved >95% cover in 4 years.

Species diversification can also be achieved by direct seeding, both of trees and shrubs (McVean 1966) and of herbs (Wathern & Gilbert 1978; Wells 1979, 1980, 1983). Slot-seeding can be used to give a linear seed bed, and thus minimize the damage to the vegetation (Haggar 1980).

3.9 Fences, walls and hedges

The chief use of fences, etc, is to control livestock movements, and thus only indirectly to influence vegetation. However, boundary barriers, especially fences and hedges, are used as perches by fruit-eating birds, and seeds are voided. Woody species that are commonly dispersed and established in this way are rowan, rose (*Rosa* spp.), juniper, hawthorn, brambles (*Rubus fruticosus* agg.), holly (*Ilex aquifolium*), raspberry (*Rubus idaeus*), gean (*Prunus avium*) and bird-cherry (*P. padus*).

4 Conclusions

Vegetation management has a strong claim to being the oldest profession (Egler 1977)! All of the ways of managing vegetation discussed earlier, with the exception of the use of mineral fertilizers and chemical weedkillers, were known to our Bronze Age, and perhaps even our Stone Age, ancestors. Our advantage is that from systematic study of the ecology of our flora and vegetation, and of the processes of vegetation change, we know more about how the techniques operate, and are thus better able to predict and direct the course of change. Despite the paucity of original management tools, there is great scope for positive management in the uplands. Although precise prediction of the course of change is, from the nature of vegetation, usually impossible, more general prediction, using known principles, is increasingly feasible.

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