3. General issues

3.1 Introduction

Upland blanket bogs and wet heaths provide a nutrient-poor habitat, in fairly inhospitable, cool and wet climatic conditions (see Section 7), particularly in the north and west of Britain. Britain is one of the main world locations for blanket mire, comprising more than 2 million ha of a total global blanket mire resource of *c.* 10–12 million ha (Tallis, 1995). 'Active' blanket bog is considered to be a priority habitat under the EU Habitats and Species Directive (92/43/EEC), comprising such NVC communities as M1, M15, M17, M18, M19 and M20 (see below), and supporting some uncommon plant and animal species (see e.g. Lindsay *et al* 1988; JNCC 1994; Thompson *et al.* 1995c).

Uplands have long been influenced by human activities, and in many places this influence has probably been a key factor in the initiation of blanket bog and heathland (e.g. Dimbleby, 1952; Moore, 1993). It seems likely that all areas of upland blanket bog and wet heath have been affected by human activities to some degree, and at least by grazing by both domestic and wild animals. Although not of such value as their drier, eastern counterparts, some moors have been managed for grouse, but management for sheep has become more common with the trend for an increase in sheep numbers in many areas over the past 50 years under the prevailing economic climate (e.g. in Wales: Bunce 1989). In many areas, much of the moorland (including dry heathlands) has been maintained by rotational burning and grazing over the last 150–200 years, or even earlier, although then rather more erratically (see Thompson *et al.* 1995c). There has also been increasing grazing pressure in some areas from wild herbivores, such as red deer in Scotland (Staines, Balharry & Welch 1995).

It is now generally accepted that some degree of management is usually required for the perpetuation of the *status quo* on 'dry' heaths and moors, but appropriate measures must be carefully considered, as the balance between the main plant species is extremely sensitive, and much depends on the climate, soil type and drainage (e.g. Gimingham 1995). Appropriate management for blanket bogs and wet heath is less clear, as shown by the present review.

3.2 Plant communities

In order to provide a focus for the report, the following NVC plant communities (Rodwell 1991) have been considered to be within its scope. Details are given in Section 7.

Blanket bog

M1: *Sphagnum auriculatum* bog pool
M2: *Sphagnum cuspidatum/recurvum* bog pool
M3: *Eriophorum angustifolium* bog pool
M17: *Scirpus cespitosus–Eriophorum vaginatum* blanket mire
M18: *Erica tetralix–Sphagnum papillosum* raised and blanket mire
M19: *Calluna vulgaris–Eriophorum vaginatum* blanket mire
M20: *Eriophorum vaginatum* blanket & raised mire

Wet heath:

M15: *Scirpus cespitosus–Erica tetralix* wet heath (in upland context)
M16: *Erica tetralix–Sphagnum compactum* wet heath (in upland context)

In addition, consideration was to be given to examples of M25: *Molinia caerulea–Potentilla erecta* mire where related to the above communities, i.e. examples on deep peat or clearly derived from blanket bog / wet heath vegetation.

3.3 Invertebrates

3.3.1 The invertebrate fauna of blanket bogs

There is little experimental or observational work which is directly related to the effects of grazing and burning on the invertebrates of blanket bog. There is, however, a considerable body of work characterising the fauna of blanket bog (although a great part of this work has taken place over a limited area of northern England), which gives some scope for determining the likely effects of burning and grazing on the invertebrate fauna. Accordingly, there follows a brief and selective summary of work which helps to characterise the blanket bog invertebrate fauna, and a brief summary of the chief characteristics.

By far the best-studied area of blanket bog for invertebrates is Moor House NNR. Here there has been research into a wide range of groups over several decades (e.g. Block 1966a, b; Cherrett 1964; Coulson 1959; Hale 1966; Houston 1971; Nelson 1971; Peachey 1963; Springett & Latter 1977; Svendsen 1957; Whittaker 1964). Much of this research is summarised by Coulson & Whittaker (1978). Coulson & Butterfield (1980) undertook a much more widespread survey of upland invertebrates in northern England, including a number of sites on blanket bog. The conclusions from this research are summarised in Coulson & Butterfield (1985), and various detailed aspects of the work are discussed in Butterfield & Coulson (1983), Coulson & Butterfield (1986), Coulson, Butterfield, Barratt & Harrison (1984), Coulson, Butterfield, & Ungpakorn (1984), Disney, Coulson & Butterfield (1981). Work on other areas of blanket bog and wet heath has usually concentrated on more specific groups of invertebrates.

In terms of number of species, the most important invertebrate groups in blanket bogs in northern England are the Diptera, Coleoptera and Arachnida (Coulson 1988). The most important of the spiders in upland habitats generally are Linyphiidae. Cherrett (1964) showed that they comprised 78% of spider species on blanket bog at Moor House. In terms of biomass, the most important groups are Diptera (mostly Tipulidae), Enchytraeid worms (which make up an average of 61% of the biomass), and mites and Collembola. A large proportion of the biomass of invertebrates may be made up by a few species: on blanket bog at Moor House, approximately 75% of the total invertebrate biomass was made up of three species: the craneflies *Tipula subnodicornis* and *Molophilus ater* and the enchytraeid *Cognettia sphagnetorum* (Coulson 1988). Hemiptera are quite important numerically (Coulson 1988) but chiefly because of large numbers of a single species, *Strophingia ericae* (Hodkinson 1973, Whittaker 1985). Soil-dwelling nematodes and herbivorous Thysanoptera are also abundant (Coulson, Fielding & Goodyer 1992). Lepidoptera and earthworms are noticeably poor in species (Coulson 1988, Svendsen 1957).

Coulson *et al.* (1992) provide a discussion of the 'key' invertebrates of heather moorland, both in conservation and ecosystem terms, referring the reader to Ratcliffe (1977) and Coulson & Butterfield (1986) for more detailed information.

Coulson (1988; 1989) emphasises the affinity of the fauna of British blanket bogs (and to a lesser extent of British peatlands in general) with that of sub-arctic regions. He finds this affinity not only in the fauna recorded, but also in a well-marked spring flush of emergence of active adult stages (especially of Diptera).

3.3.2 Variations in the invertebrate fauna

Coulson, Fielding & Goodyer (1992) consider that five factors are important in determining invertebrate diversity on moorland: habitat heterogeneity, soil type, habitat isolation and fragmentation, geographical position (but "At the present time, the lack of studies which have considered invertebrate faunas of heather moorlands over a wide geographical range makes the comparison of different areas of Britain difficult") and altitude. Of these, habitat heterogeneity is of most relevance to the current review as the indirect impacts of burning and grazing on invertebrates through changes in habitat (including physical effects, plant species composition and vegetation structure) are likely to be as important as direct effects.

Changes in the invertebrate fauna with altitude have been considered by, *inter alia*, Greenslade (1968), Otto & Svensson (1982), Coulson & Butterfield (1985), Coulson & Butterfield (1986), Coulson (1988).

3.3.3 Comparisons with the invertebrate fauna of other habitats

Coulson (1988) discusses the overlap of species occurrence between blanket bog and other upland habitats. Many species found on blanket bog occur locally on 'northern heath'[1], and some also occur in lowland mires. The extent of overlap with the fauna of upland grasslands on mineral soils varies with group: herbivores tend to show more habitat-specificity than predators. Coulson, Fielding & Goodyer (1992) report a broad overlap between the fauna of blanket bog and that of flush sites on heathland and Gardner (1991) found this true of carabids alone.

Comparison with lowland and upland dry heath is of interest only because there are some habitat similarities, and because the effects of burning on dry heaths have been better studied than those on blanket bog. The relative importance of different invertebrate groups differs considerably between the two habitats. For example, Diptera make up 70% of the insect species recorded from blanket bog in northern England, but only 10% of species on southern heath (Heal 1980). Both Coleoptera and Lepidoptera exceed Diptera in species richness on southern heaths (Richards 1926). Lepidoptera are represented by only a few species on blanket bog, compared with about 30 on northern heaths (Coulson 1988).

3.3.4 Relationship between invertebrate communities and vegetation

Given that rather little work on blanket bog and upland wet heath directly concerns the effects of management on invertebrates, it is worth considering the extent to which available information enables a correlation to be drawn between the nature and condition of vegetation and the invertebrate communities associated with it. Where such a correlation is possible, the

[1] Used in the sense of Gimingham (1972) for 'heath-like moorlands' other than blanket bog, and usually at lower altitude

effects of management may, albeit to a limited extent, be inferred from the effects on vegetation. The importance of vegetation structure to invertebrates is considered in Sections 4 and 8.

Buse (1988) found that the diversity of Coleoptera in upland habitats is correlated with plant diversity, even for non-herbivorous species. Gardner (1991) showed a correlation between classifications of plants and ground beetles from the same series of sites, but found that neither could be used to predict the other. Both studies, however, concerned a wide range of plant communities, with blanket bog effectively a single group in the classifications. Densities of invertebrates were found to be higher on peat dominated by *Juncus squarrosus* compared with areas clad in *Calluna* (Coulson & Whittaker 1978, Nelson 1971). Dixon (1984) states that of the 26 moth species found in the Welsh uplands, which contribute significantly to the biomass of flying insects on moorland [in general], 12 are wholly restricted to dwarf shrubs and forbs, and 11 are wholly restricted to dwarf shrub heathland. Clearly, the abundance of these species is likely to be affected by changes in the abundance of dwarf shrubs caused by management practices.

Invertebrate herbivores and pathogens are also known to cause local death of heather, for example the heather beetle *Lochmaea suturalis* (see Watson & Miller 1976) – young plants may recover in 2–3 years, but severely-damaged older plants may be killed (although this is more common at lower altitudes). Fungal pathogens may also be responsible for heather die-back at some sites (see Usher 1995).

3.4 Birds

Before reviewing studies of the effects of burning blanket bog on birds it is necessary to establish the principal bird species that utilise the habitat. There are few specific studies which provide quantitative data on associations between birds and blanket bog.

The British Trust for Ornithology (D. Gibbons & R. Fuller) are currently undertaking an analysis of upland bird distributions using the distribution data from the Breeding Bird Atlas 1993 and the ITE Land Cover data 1990. Overall preliminary analyses suggest that the distributions of few upland birds are strongly associated with upland bog. However the associations for specific upland massifs might be slightly stronger. More details are available directly from BTO.

Studies by Stillman & Brown (1994) and Haworth & Thompson (1990) provide association data between breeding birds and habitat and topography in the South Pennines. Brown & Stillman (1993) provide bird–habitat associations in the Eastern Highlands of Scotland. Stroud, Reed Pienkowski & Lindsay (1987) looked at associations between bird species and land form types in the Flow Country of Caithness and Sutherland.

None of the priority lowland heathland birds (as listed in Brown 1995b), apart perhaps from the raptors, are particularly associated with wet heath. Waders, such as Curlew and Snipe, may use wet lowland heath but this has not been reviewed in this study.

For the purposes of this review we have concentrated on those species which the above studies showed to be reasonably strongly associated with blanket bogs (Table 3.1). The relevant findings are summarised at the beginning of each species account given in Section 8.

Table 3.1 Principal birds associated with upland blanket bogs and wet heath

Waders	**Game birds**
Curlew *Numenius arquata*	**Black Grouse** *Tetrao tetrix*
Dunlin *Calidris alpina*	**Red Grouse** *Lagopus lagopus scoticus*
Golden Plover *Pluvialis apricaria*	**Other characteristic species**
Greenshank *Tringa nebularia*	**Meadow pipits** *Anthus pratensis*
Lapwing *Vanellus vanellus*	**Skylark** *Alauda arvensis*
Redshank *Tringa totanus*	**Twite** *Carduelis flavirostris*
Snipe *Gallinago gallinago*	**Gulls**
Raptors	
Merlin *Falco columbarius*	
Short-eared owl *Asio flammeus*	
Hen Harrier *Circus cyaneus*	
Other raptors	

3.5 Mammals

Coulson *et al.* (1992) provide an account of the mammals (other than domesticated stock and red deer) associated with upland heather moorland (including blanket bog). Information concerning the effects of burning or grazing is limited (see Sections 4.3.2 and 5.3.1), and there is little distinction made between types of moorland. Most of these species are not particularly characteristic of upland moorlands and are commoner at lower altitude where food supplies are better.

Lagomorphs include mountain hare, brown hare and rabbit.

Rodents include short-tailed field, bank and wood vole, wood mouse.

Insectivores and carnivores include common and pygmy shrews, mole, red fox, stoat, weasel, polecat, badger, otter, pine marten, wildcat. Species such as the common shrew and badger may occur in the uplands, but tend to avoid acidic, waterlogged areas, as these lack their main food source (earthworms).

Bovidae: Feral goat

3.6 Amphibians and reptiles

Coulson *et al.* (1992) provide an account of the amphibians and reptiles which may be associated with heather moorland (including blanket bog): common frog, palmate newt and smooth newt (more common in the lowlands), viviparous lizard (favours dry heather moors) and adder. Information concerning the effects of burning or grazing is very limited (although note that the original literature cited by Coulson *et al.* (1992) has not been re-examined).

4. General effects of burning

4.1 Introduction

Fire has been used as a management tool in the uplands for centuries – indeed burning has been suggested as a contributory factor in the initiation of blanket bog formation in some places although the precise roles of human intervention and of climate remain equivocal (see *e.g.* Moore 1993; Charman 1992). Heather-dominated moorlands are particularly susceptible to accidental fires, but in the uplands, fire is currently used as a management tool, particularly on grouse moors, in order to maintain diversity of age structure of *Calluna*, and also to improve grazing for domestic livestock, mainly sheep, by promoting the growth of young plants which are more palatable.

It is now thought that widespread muirburn in Scotland was a consistent feature of landscapes long before the coming of sheep, and a programme of work has been set up to examine in detail the charcoal and vegetation records of study sites to try to identify trends in the effects of changing muirburn frequencies on vegetation (Stevenson & Birks 1995). There is some evidence for the use of fire limiting high altitude scrub regeneration both in England (mesolithic) and Scotland (mediaeval) (see Hester & Miller 1995).

Much of the work relating to burning as a management tool has been carried out with respect to the management of grouse moors or lowland heaths, and hence relates more to the drier types of heath and moorland than those considered in the present review. The use of burning is regulated by legislation (4.4.5), although may still take place illegally outside of the proscribed winter period. Reviews of the use of burning and its effects can be found in particular in Lindsay *et al.* (1988), Mowforth & Sydes (1989), Coulson *et al.* (1992) and RSPB (1995). Much of this information is general in nature, and the detail is not repeated here. The main points are summarised, as these are broadly applicable, and are supplemented with any specific information relating to blanket bog or wet heath. Details which are specific to plant communities or selected species can be found in Section 7.

4.2 Physical effects

Ignition of peat waxes during particularly intense fires can lead to the formation of a skin of tarry bitumen, creating a hard crust on the surface of the peat. This may help to reduce erosion to some extent, but conversely, may retard recolonisation by 'desirable' species, instead being colonised by species of crustose lichens and algae (e.g. Legg, Maltby & Proctor 1992) which themselves can reduce germination of *Calluna* seeds. Formation of a hard crust can also affect the infiltration of water into the peat (Mallik, Gimingham & Rahman 1984), and may in fact lead to increased erosion through increasing the amount of run-off from the bog. On heather moorland, Mallik, Hobbs & Rahman (1988) showed that the presence of organic matter increases the water retention property of the soil which helps seedling regeneration: more seedlings survived in sites with thicker organic matter on the surface, while charred organic matter, 'mat moss' (*Hypnum jutlandicum, Hylocomium splendens, Pleurozium schreberi*) and lichen patches inhibited seedling establishment. Removal of a vegetation cover over large areas reduces interception of rainwater and increases the exposure to wind, both increasing the likelihood of desiccation and erosion, and presenting difficult problems for restoration (as seen in e.g. the Peak District and North York Moors following extensive, severe fires).

Dark surfaces absorb heat more readily than light ones, and hence bare peat surfaces can become particularly hot, thereby exacerbating moisture loss. Removal of the vegetation cover will affect the local microclimate, with consequences for both flora and fauna, and increases the likelihood of freeze/thaw processes and therefore the risk of erosion (Fullen, in NYMNP 1986). The surface may be physically unstable and show considerable temperature fluctuations (e.g. Tallis & Yalden 1983; Salonen 1992), and thus provide an inhospitable environment for establishment of plant propagules and animal colonists. Exposure of the underlying mineral substratum can also exacerbate problems of revegetation, both physically and chemically.

Burning releases nutrients from the plant material in the smoke and ash. Some of this may become washed into the litter/substratum, but there is also potential for loss in run-off/leaching or in the smoke (Allen 1964), although there is some compensation through inputs of nutrients in precipitation. A reduction in nutrient supply will clearly affect recolonisation rates. Gimingham (1972) and Coulson *et al.* (1992) provide a review of the effects of burning on nutrient budgets and cycling in heathlands.

Burning of blanket bog can lead to a reduction in soil moisture storage capacity and lower dry weather flows in drainage ditches (Robinson 1985).

4.3 General effects on flora and fauna

4.3.1 Flora

The effects of fire depend, *inter alia*, on the vegetation composition, intensity and frequency of the fire, time of burning and wetness of the substratum. Removal of vegetation through fire can be considered 'beneficial' in some circumstances (e.g. control of scrub, rejuvenation of heather) but detrimental in others (e.g. destruction of *Sphagnum* hummocks), particularly where the fire is uncontrolled, although of course, perception of the effects will differ depending on the management objectives – this is a considerable problem when assessing reports in the literature. Current thinking on the use of fire in the conservation management of blanket bog is given in Section 10.2.

The changes in vegetation composition and structure occurring in response to burning are the main reasons for this type of management. Burning is thought to increase the nutritional value of heather to grazers by stimulating new growth which has the highest concentrations of nutrients (see Coulson *et al.* 1992). Changes in species composition following fire are common: for example, tussocks of species more tolerant of burning, such as *Molinia* and *E. vaginatum*, are likely to become more prominent (and may provide an 'early bite'), resulting in changes in microtopography. However, such changes may represent a temporary phase, depending on the frequency of burning (4.4.3). Hobbs (1984), in a study on blanket bog at Moor House, found that variations in post-fire species abundances were related to pre-fire stand composition coupled with the effect of patchy distribution of regeneration centres of rhizomatous species: regeneration following burning is usually mainly by vegetative regrowth of species *in situ* before the fire, although seedlings of *Calluna* and *E. tetralix* may occur (Elliot 1953; Hobbs, Mallik & Gimingham 1984) and *Betula pendula* may invade. However, frequent or severe burning can kill both established plants and any buried seeds, leaving gaps for competitors (Miller, Miles & Heal 1984). A delay until the degenerate phase of heather, and excessively hot fire, or burning followed by heavy grazing, can similarly weaken or completely kill heather, especially on wetter western moors (Watson & Miller 1976).

Forrest & Smith (1975) found that burning increased the productivity of vegetation on blanket bog plots at Moor House, but that this was largely attributable to the subsequent colonisation by *E. angustifolium* and *Scirpus cespitosus* rather than an increase in *Calluna* production (see also Smith & Forrest 1978).

There is some evidence that burning may stimulate the microbial activity in peat, thereby leading to increased rates of decomposition (NYMNP 1986).

4.3.2 Fauna

Many animals are able to avoid the direct effects of burning by moving away, but fire may destroy less mobile animals and those at a vulnerable stage in their life history, such as overwintering insects or breeding birds. There are also indirect effects through changes in physical habitat characteristics (see 4.2) and plant species composition (Section 7), the latter affecting both food sources and vegetation structure (and hence microclimate). The main effects of burning on invertebrates and birds are discussed in Sections 8 and 9 respectively.

As discussed below (4.4), controlled burning of moorland vegetation is carried out a) to provide young, relatively palatable shoots of heather for grouse and or sheep to feed on; b) to prevent succession of the vegetation to scrub and woodland and c) on grouse moors to provide the mosaic of heather stands of different ages and structure which is needed for nesting and as cover from predators. Use of fire is restricted to a specified period between October and April by legislation, although may still be carried out illegally at other times of the year. Illegal burning during the bird breeding season is of concern, particularly in Scotland, where lack of suitable days for burning in the winter (and lack of available personnel) can increase the temptation to burn later (SNH, *pers. comm.*).

Deer and mountain hares may benefit from burning to some extent by the increase in availability of young heather (see 4.4). Anderson (1986) commented that four of the five shrews that were caught in pitfall traps during a survey following a severe moorland fire in the Peak District, were caught in unburnt, rather than burnt, areas. She speculates that small mammals are more likely to be affected by loss in vegetation cover caused by burning than through reduction in invertebrate food supply, although direct evidence is lacking.

Although predominantly found in the lowlands, adders can be found on grasslands, heaths and blanket bogs up to 600 m altitude. Their absence from some apparently suitable localities may be due to severe heath and moor fires (Coulson *et al.* 1992).

4.4 Controlled burning

4.4.1 Introduction

Controlled burning is frequently used as a management tool, in particular to improve productivity of domestic livestock (mainly sheep) and grouse (see 10.2), particularly on the drier types of heather moorland. Regeneration following burning can be affected by the intensity of grazing (see Section 6). Burning is sometimes used as a conservation tool, for example, to control scrub, but this is mainly on sites which have already suffered some damage, or where conservation and economic objectives both need to be addressed. Rowell (1988) and RSPB (1995) provide details of suitable methods in this context.

4.4.2 Size and pattern of burn

Controlled patch or strip burning leads to mosaics of vegetation with different characteristics and age structure, and tends to be used more on moorland managed for grouse, than those managed for sheep, where larger patches are burnt (see *e.g.* Hester & Sydes 1992), often with less control (and less planning). Fires of 0.5–1 ha, in 25–30 m wide strips, are commonly used on heaths managed for grouse, giving the characteristic patchwork appearance (Hobbs & Gimingham 1987). A complete burning rotation could be expected in 7–20 years, depending on local conditions. However, these authors stress that such a system may not be beneficial in wetter heath, where frequent burning may shift the dominance from *Calluna* to graminaceous species (4.4.3). Indeed, this may be the main aim where burning is carried out to improve grazing for sheep.

Patch burning is apparently not very common on blanket bogs in the North East of Scotland (SNH, *note in file*), and 88 % of an area studied (covering 4700 ha) showed no signs of burning at all between the 1940s and 1989.

Use of patch burning may help to reduce losses of nutrients from the system in run-off and smoke (see Coulson *et al.* 1992).

4.4.3 Frequency of burn

The age of the heather when burnt affects the prospects for recovery: a fire in younger heather causes reduced nutrient losses because of the smaller amount of fuel, and the more rapid recovery of the vegetation because there are more stems from which buds may grow. Fires in older heather cause more damage, and recovery is slower (Watson & Miller 1976; Hobbs & Legg 1983; Hobbs & Gimingham 1984; Berdowski & Siepel 1988: *cit.* Legg 1995). A single fire can create favourable ground conditions for post-fire germination of scrub/tree seedlings while rotational burning destroys established seedlings and saplings (see Hester & Miller 1995).

Watson & Miller (1976) recommend that the optimal interval between burning should be determined by the response of the heather, rather than by specifying a set time interval. Thus, for example, guidelines provided by MAFF (1992b) suggest that pure stands of heather should be burnt when they reach 20 – 30 cm in height, on a rotation which reflects the length of time taken to achieve this height.

On grouse moors, an 'under-burned' moor is one on which there are few patches of young heather, which creates increased grazing pressure on these patches, and hence increases competition between grouse and sheep. This is becoming an increasing problem in some areas, for example on the North Yorkshire Moors, where changing economic conditions have lead to a reduction in the traditional 10–15 year heather burning regime, with large areas carrying 'over-aged' stands of heather, which are more prone to accidental summer fires (NYMNP 1986). An increase in forestry plantations on or adjoining moorlands has also probably contributed to the decline in burning as the fires need to be more tightly controlled to prevent spreading.

Studies on a long-term experiment on *Calluna–Eriophorum* bog at Moor House (e.g. Hobbs 1984), indicated that the length of time between management fires affects the post-fire vegetation development. A short rotation burn (every 10 years) resulted in increased dominance by *Eriophorum* spp. (*E. vaginatum, E. angustifolium*) while a long rotation (every 20 years) resulted in greater abundance of *C. vulgaris*. A similar effect was found by Currall

(1981: *cit.* Hobbs & Gimingham 1987) in *Molinia*-dominated communities, where very frequent burning all but eliminated *Calluna*. Lance (1983) comments that replacement of *Calluna* by deciduous species such as *Molinia* leads to an increase in litter and lowers the winter stocking capacity, and can result in an intensifying spiral, with the need to burn at ever-shorter intervals to remove the litter and encourage new growth as soon as possible in the spring.

4.4.4 Intensity of burn

The intensity of a fire is determined by the temperature reached and speed of travel, and will have an effect on subsequent vegetation regeneration (see Gimingham 1972; Hobbs & Gimingham 1987; see also summary by Coulson *et al.* 1992). A slow-moving, hot fire will kill most, or all of the plants (including bryophytes), so that there is no regeneration from stools and exposure of bare ground is prolonged. Conversely, most plants will survive a quicker-moving, cooler fire, particularly where the ground is wet, and, provided that there is no thick layer of litter, new shoots will rapidly appear. However, on heathlands, low-intensity fires may be considered as detrimental as high-intensity ones because they do not burn the entire vegetation cover and leave a large amount of debris on the surface which may retard regeneration (see Coulson *et al.* 1992). Regrowth and germination is better on 'soft', damp, peaty soil than on 'hard' ground as the damp peat insulates the buds and seeds from the heat of the fire, and protects the young shoots from drought (Watson & Miller 1976; Gimingham 1995).

The initial vegetation composition (and hence the previous management history) can influence the intensity and spread of fire, for example, vegetation with a high proportion of woody or grassy material has a higher combustibility than that dominated by bryophytes (RSPB 1995, *unsourced*), and therefore may result in a fire of higher temperature. Thus fire in old stands of heather may be particularly intense. An intense fire which causes ignition of the peat and subsequent erosion may cause major losses of soil organic matter and nutrients. Recovery of the vegetation is very slow (Maltby, Legg & Proctor 1990; Legg, Maltby & Proctor 1992). It also destroys the seed bank, and/or the fibrous root mat which provides surface stability after a normal fire, leading to poor regeneration and progressive erosion (Legg 1995). Regeneration is then dependent on immigration from neighbouring stands. In some situations, this may provide an ideal opportunity for invasion of tree seedlings; in others the formation of a hard crust may retard recolonisation and reduce water infiltration (see 4.2).

Accidental summer fires are most likely to be of high intensity, and thus particularly detrimental (see 4.5).

4.4.5 Timing of burn

The period of the year during which moorland burning can be carried out is controlled by legislation (see *The Muirburn Code*: Phillips, Watson & MacDonald 1993), being restricted to the late autumn to early spring, unless granted a special licence. Smith (*in* Snowdonia National Park 1984), comments on the effects of burning on the Berwyn Mountains during the 1976 drought, when 700 ha of moorland was burnt: by 1984, less than one quarter of the area had revegetated, and many areas remained as bare peat, clay and rock. Burning outwith the legal period can be particularly detrimental for birds if carried out during the breeding season.

The timing of the burn is thought to affect the temperature of the burn – spring and summer burns are generally more intense than those in autumn or winter, probably primarily because the vegetation and litter have a higher moisture content at the latter times (Hobbs & Gimingham 1987). This is one reason why accidental fires in summer may be much more severe than at other times (see 4.5 and e.g. Anderson, 1986).

It has been suggested that (i) heather regenerates more successfully after autumn fires (e.g. Miller & Miles 1970), (ii) autumn muirburn may discourage *Eriophorum* and *Trichophorum* (Mowforth & Sydes, 1989), and (iii) nutrient losses as a result of burning may be increased following an autumn, as opposed to spring, burn, as fewer nutrients are taken up by the vegetation with increased losses through run-off and leaching (R.J. Aspinall, in NYMNP 1986).

4.5 Accidental fires

Although burning is commonly used as a management tool to improve food supplies for the dependent fauna, accidental, or even deliberate, moorland fires resulting from public access can cause extensive damage, particularly in years of summer drought, and in areas of thin peat. They may result in severe erosion and poor vegetation regeneration (Anderson, 1986; see also 4.4.4), and thereby adversely affect the 'commercial' productivity. The effects of a small light accidental fire will be similar to controlled burning, but severe accidental fires are likely to be particularly detrimental as (a) they are largely uncontrolled and may burn for long periods and over large areas; (b) the peat/humus layer is more likely to be ignited (see Hobbs & Gimingham 1987). As a result, large areas can remain either as bare peat or where the peat is removed, bare mineral soil for many years, giving subsequent problems of revegetation and erosion, which are likely to be exacerbated by grazing (see Section 6).

The speed of revegetation will depend on a number of factors including the altitude and exposure of the site, the rainfall, levels of atmospheric pollution and the presence of grazing animals. Some encouragement can be taken from the gradual recovery of the *Sphagnum*-based vegetation on the lowland raised bog at Glasson Moss (Cumbria) from a severe accidental fire in 1976. Anderson (1986) gives examples of bare peat areas in the Southern Pennines that are known to have originated from wildfire damage in 1947, 1959, 1976 and 1980, and there are similar areas in the North York Moors (NYMNP 1991) (although both of the latter situations were probably exacerbated by continued grazing). Maltby, Legg & Proctor (1990) report on the problems of revegetation of peaty moorland in the North York Moors, following a severe summer fire in 1976.

The Peak District Moorland Management Project has produced an Information Sheet[1] providing guidance on the prevention, or at least limitation, of damaging moorland fires, particularly those resulting from a careless public. In particular, this recommends that the moors should be managed by rotational burning in the winter or cutting, to create irregular fire breaks close to public access paths which will help to limit the spread of fires in the summer.

[1] Peak District Moorland Management Project, Information Sheet No. 3: Preventing Damaging Moorland Fires.

4.6 Interactions with other factors

4.6.1 Drainage

The water level prevailing at the time of the burn (and hence degree of drainage) is likely to influence the effects of the fire, for example the amount of damage caused to the *Sphagnum* carpet or to the peat itself. Moist peat is considered to be an excellent insulator, providing a shield against heat for buried seed and basal buds of *Calluna*, thereby allowing rapid recovery from fire (Watson & Miller 1976). These authors stress that fires should not be started if the peat has dried out to a depth of 50 mm or more, as the peat itself is likely to catch fire. Maltby Legg & Proctor (1990; see also NYMNP 1986) report on an investigation of a severe moorland fire in the North York Moors, which showed that the effect of the fire was influenced by the depth of peat, its moisture content and the presence of previous desiccation cracks which allowed localised entry of oxygen. In areas where the peat depth was > 800 mm and the moisture content was more than 5x the dry weight of peat, the fire affected only the surface vegetation. Peat which was 200–400 mm deep was most severely affected and those areas which had dried out during the summer were ignited completely to ash. Where the peat was of intermediate depth (400–800 mm) and therefore more moist, or contained some mineral material, the fire resulted in charring, surface contraction and hardening, with complete loss of litter.

Hydrological research at Moor House suggested that severe burning of the peat surface reduced the water storage capacity of the soil and lowered dry weather flows, but increased peak flows in drainage ditches (Robinson 1985).

4.6.2 Erosion

One of the main detrimental effects attributed to burning on upland peatlands by many authors is the exposure of bare peat, with consequent increased risk of erosion, particularly in areas of high rainfall. Farey (1815, *cit.* Anderson 1986) describes moorland in the Peak District burning for weeks and then the peat collapsing in the late 1700s, indicating that the damage caused by bad burning practice (attributed to shepherds) has been going on for a long time.

Tallis (1987) suggested that the onset of widespread erosion at Holme Moss (S. Pennines) appears to have been associated with one or more severe fires in the 18th century which resulted in the loss of the surface horizons of peat. Anderson (1986) investigated the ecological implications of accidental fires in the Peak District, and concluded that although erosion was undoubtedly linked to climatic factors, at least some of the expanding areas of bare peat seemed to be the product of past fires – vegetated areas were not associated with erosion of peat.

4.6.3 Climate

The weather conditions prevailing at the time of a burn, particularly the wind speed and direction, are important contributory factors in determining its effects. *The Muirburn Code* (Phillips, Watson & MacDonald 1993) gives guidelines on appropriate weather conditions and suggests that there are only likely to be between 5 and 15 days in the west and 10–25 days in the east when conditions area likely to be suitable for well-controlled burning. This is one of the contributory factors cited for the increased tendency for poor management practice, as a general reduction in manpower in the uplands means that it is not always possible to gather sufficient personnel together at short notice to carry out the optimal burning regimes.

Gimingham (1972) cites McVean & Lockie (1969) in suggesting that management by burning is inappropriate in the more highly oceanic conditions of western Britain, because it has been responsible for the extensive spread of species such as *Nardus stricta* and *Scirpus cespitosus* which are of low nutrient content and palatability to grazing animals. This is particularly so in the short growing season in the north, where regeneration is particularly slow, increasing the danger of peat erosion and 'hagging'.

Lindsay *et al.* (1988) suggest that the increased mineral content in rainfall towards the west of Scotland appears to encourage algae such as *Zygogonium* to colonise burnt peat before other species, making subsequent colonisation difficult. The development of an algal scum promotes surface run-off, but it may also help to protect the underlying peat from erosion under high rainfall.

It is possible that the course of vegetation development following burning may be influenced to some extent by atmospheric pollution; for example, it has been suggested that the spread of *Molinia* in mid-south Wales following burning may be exacerbated by increased N deposition (M. Yeo, *pers. comm.*).

No specific information has been found on the influence of altitude on the effects of burning, other than, for example, occasional comments that burning is considered to be inappropriate and regeneration is slower at high altitudes. However, it would be possible to make some inferences from variations in communities with altitude and published ecophysiological studies on the main species. For example, Rawes & Welch (1969) showed that there was a marked reduction in standing crop of *Calluna* between 560 m and 688 m altitude.