PRESCRIBED BURNING ON MOORLAND

Supplement to the Muirburn Code: A Guide to Best Practice

SCOTTISH EXECUTIVE

Making it work together

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Introduction

This booklet is intended to encourage greater understanding of fire and its prescribed use, to complement the regulatory information that appears in *The Muirburn Code*, also published by the Scottish Executive Environment and Rural Affairs Department (SEERAD). The information is based on research and experience, not only from Scotland, but from around the world. However, it does not provide all the answers. Training in understanding fire behaviour, modern safety requirements, and new techniques for the control of fire is strongly recommended even for those with some experience.

A powerful tool which should be used with respect and understanding

Fire has been part of upland environments for many thousands of years. It occurs naturally as a result of lightning strikes and it is probably also one of the oldest land management tools. However, it is a powerful tool which needs to be used skilfully if it is not to do more harm than good. The term "prescribed burning" is used in many other parts of the world to describe the deliberate use of fire as a management tool. It can be defined as the knowledgeable and controlled application of fire to a predetermined area, at a specified time of day and season, and under specified weather and fuel conditions, so as to ensure that the intensity, rate of spread, and limits of spread of the fire meet planned resource management objectives. Prescribed burning of moorland in Scotland is usually referred to as muirburn, and there are four main land management objectives which apply:

- To produce a continuous supply of vigorous and nutritious new growth, by removing accumulated dead and woody plant material which makes the vegetation unpalatable and indigestible for grazing animals;
- To maintain moorland vegetation which is varied in composition and height, allowing greater access by livestock, and which provides increased foraging and nesting opportunities for moorland game and wildlife;
- To maintain the cover of heather, blaeberry and other characteristic moorland plants, in the long-term, so as to provide year round forage and cover for livestock, moorland game and wildlife, and to maintain internationally renowned moorland landscapes;
- To reduce the accumulation of potential fuel and so reduce the risk of damaging, high intensity wildfires.

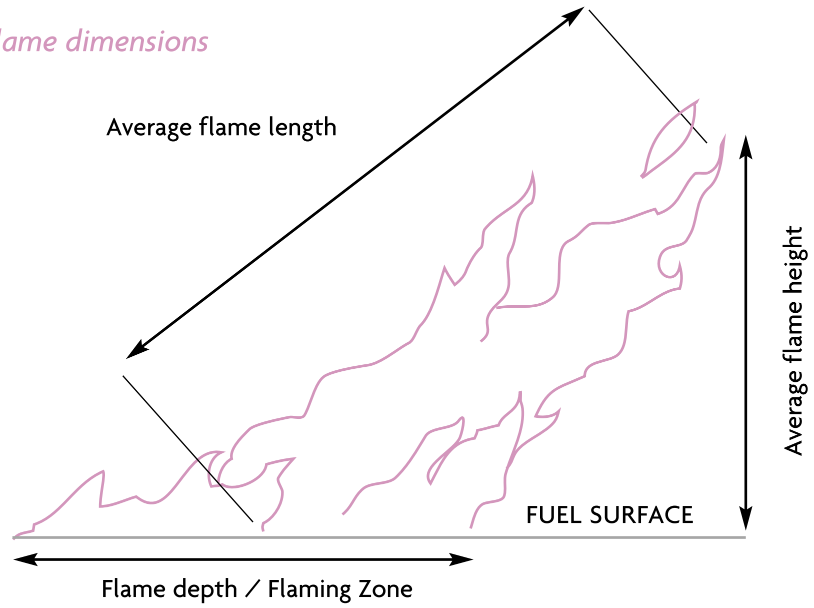
In some parts of Scotland, extensive areas of moorland are burnt too frequently, or when weather conditions are unsuitable, without adequate control, or over inappropriate types of ground, resulting in fires which are damaging. Equally, much moorland that is suitable for burning is burnt too infrequently. Regular, well-controlled burning is essential if the open and varied character of our drier kinds of moorlands is to persist. Where the ground is appropriate for burning, a well-planned programme of muirburn will create a varied patchwork of vegetation of different heights which is more evenly grazed and more productive than uniform vegetation. In combination with fire-free refuge areas, this kind of management will provide a wide variety of habitats for wildlife, and the short heather produced by regular controlled muirburn will leave archaeological features more visible. Also, it will help break-up and reduce fuel loads, reducing wildfire hazard.

How does fire behave ?

The process of burning

When the temperature of a potential fuel is raised by heating, its chemical constituents are broken down into more volatile and flammable substances. In the presence of oxygen these undergo further vigorous chemical reactions, accompanied by the production of heat and, usually, the presence of visible flames. Once a critical temperature is passed more heat is generated than is absorbed and self-sustaining combustion begins. This is the point of ignition. For most plant fuels the critical temperature for ignition is just above 300 °C. The hot gases produced during combustion cool rapidly outside the flames, the cooling effect increasing with increasing speed of the wind. Flame size and fire intensity are closely related, with fire intensity increasing in proportion to the square of the flame length - a doubling in flame length indicates a fourfold increase in the rate of heat production by the fire

Flame dimensions



As well as volatile compounds, charcoal (or char) is also produced. This is largely composed of carbon. The decomposition of the fuel to char or to volatile gases can be competing processes. Char is produced at lower temperatures than volatiles and its production is enhanced if the fuel has a high mineral, or ash, content. This is the basis of action of many chemical fire retardants. It is possible for char to burn by 'glowing' combustion or smouldering. This occurs at the surface of the solid fuel and is less intense than flaming combustion. It requires less oxygen (only about a third as much) and so can occur in more densely packed fuels. In moorland management fires, the fuel that is not completely burnt by the flames generally cools so rapidly that glowing combustion is sustained for no more than a few minutes. However, a smouldering peat surface is less exposed to heat loss and glowing combustion may continue for extended periods, gradually drying and burning down into the peat, where it becomes difficult to extinguish.

A principal fuel in nearly all moorland fires is heather. Once a heather fire is burning freely, the temperature in the heather canopy is usually within the range 400 °C to 800 °C. Over any particular spot, these temperatures usually last for less than 60 seconds and often very much less than this. Temperatures are usually much cooler and more variable at the ground surface, sometimes as low as 200 °C, though they can be as high as 800 °C if the fuel is distributed close to the ground. Raised temperatures persist for much longer at the ground surface than in the canopy and the total heat released is greatest at this level. This is greatly influenced by whether, and how much, smouldering combustion occurs on the ground. Temperatures hardly rise at all more than a couple of centimetres below the surface, since carpets of damp moss (and to a lesser extent plant litter, loose moss and lichens) provide very good insulation. However, if the insulation is consumed, and the duff or peat ignites, temperatures of 600 °C can be attained and temperatures greater than 300 °C may persist for hours or even days where smouldering continues.

The rate of release of heat by moorland fires is variable both between fires and within individual fires. It is usually within the range of 500 - 1000 kW per metre of fire front, but in can be less than 300 kW per m where available fuel is sparse and fragmented to more than 2000 kW per m under the opposite conditions. These correspond to flame lengths of 0.5 to 1 m, or less, at the low end of the scale, 1.5 to 2 m in the mid-range, up to 3 m or more at the high extreme.

The effects of temperature and moisture content of the fuel

Two of the most important factors affecting ease of ignition are moisture content of the fuel and its starting temperature. Burning in the winter half of the year, when conditions are cool and not too dry, greatly reduces the risk of very intense and uncontrollable fires. If the potential fuel is cold it will take more heat to raise it to the critical temperature.

Even more important than temperature is the moisture content of the potential fuel. This is because water requires unusually large amounts of heat to raise its temperature, and to change from liquid to vapour. If there is a lot of water present it will be difficult to reach the critical temperature for sustained combustion. Until the water is entirely evaporated, at least from the surface layers of fuel, the temperature will not rise above 100 °C and a fire will not ignite.

Fresh green foliage of deciduous plants often has such a high moisture content (up to 300% or more of dry weight) that it is very difficult to ignite. Evergreens, like heather or conifers, often have somewhat lower moisture contents, and a higher content of volatile resins, waxes, oils and similar compounds, and will burn more readily. The amount of heather present in moorland vegetation is often a principal determinant of the temperature and intensity of a fire. Normally, there is considerable variation in moisture content within the vegetation. The layer of plant litter, mosses and lichens under the heather may have a moisture content of 200 - 300 % while loose plant litter supported among the shoots of the heather canopy may have a moisture content of only 25%. The moisture content of the heather canopy is likely to be in the range 50% - 100% during the muirburn season. On dry, well-drained ground, moisture contents of the vegetation and litter may become less than 50%.

Dead plant material dries out more quickly and fully than living material, burns even more readily, and often initially carries the fire. The moisture content of dead grass leaves can change from 90% to 20% in less than half an hour under drying conditions. The dead leaf litter from purple moor-grass is one of the first fuels on moorlands to dry out, other than when it forms a compact, damp mat in close contact with the ground. Decomposition of plant litter is often slow on moorlands, significant amounts of dead plant material can accumulate, and this can greatly affect the intensity and rate of spread of fires.

The amount of heat required to dry the fuel is generally a small proportion of the heat released once a fire is self-sustaining. Therefore, much more water is needed to put out a fire, once started, than is required to prevent a fire starting in the first place.

The effects of fuel structure

The structure of the potential fuel also contributes to how readily a fire will start, how fiercely it will burn and how rapidly it will spread. The fineness of the material, the ease with which air can mix with it, and how uniformly it is distributed are the most important factors. Fine twigs and leaves dry more quickly and completely, ignite more easily, and burn for shorter periods, than large twigs or stems. Fine fuels are usually defined as material less than 6 mm in diameter. The leaves, shoots and young stems of heather all fall within the definition of fine fuels. A tall, unbroken and even canopy of heather has all the structural features that encourage fire ignition and rapid spread. A tall dense canopy of heather, and even more gorse (whin), will produce an intense fire.

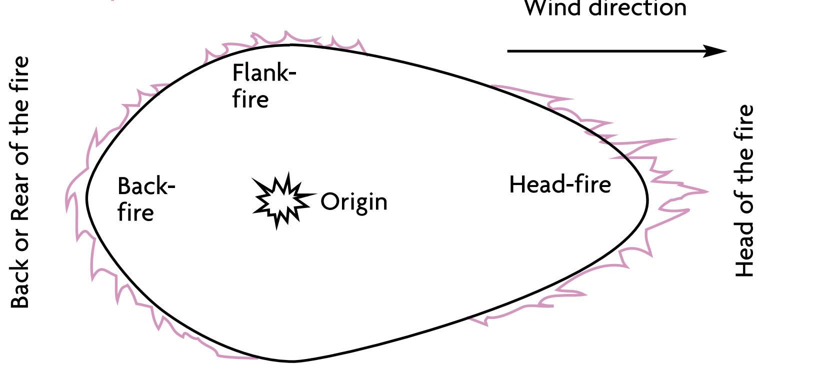
However, even fine dead twigs and leaves will not burn readily when in a compact layer on the ground surface. Also, only very intense fires will completely consume woody heather stems more than about 5 mm - 6 mm in diameter. Burning old stands of heather often leaves many unburnt 'sticks' and this is to be expected in fires of normal, acceptable intensities.

The effects of wind and slope

Most moorland management fires are set to burn with the wind. The wind bends the flames forward over the unburnt vegetation, pre-heating and drying it, leading to more rapid ignition and fire spread. These are 'head-fires' or 'heading fires'. Compared with a fire burning against the wind (a 'back-fire' or 'backing fire') a head-fire spreads much more quickly, produces longer flames from a wider flaming zone, has a greater fireline intensity, and produces more smoke, but consumes the fuel less completely. A back-fire has the opposite characteristics, and additionally its rate of spread is slow and little affected by wind speed. The residence time, the time it takes the entire flaming fire front to pass across a particular spot on the fuel or ground, is about the same for a head-fire and a back-fire. However, heat production is concentrated closer to the ground in a back-fire and this is the main reason why back-fires consume more of the fuel and produce "cleaner" burns. Although a back-fire generally produces less smoke than a head-fire, the smoke tends to stay closer to the ground and is less quickly dispersed. Back-burning can be used to create clean firebreaks but it is too slow, and potentially too damaging to the vegetation and soil, for very extensive use unless used very carefully. The properties of a flank-fire are intermediate between those of a head-fire and a back-fire.

Because the head, flanks and back of a fire have different rates of spread an uncontrolled fire burning in an area of uniform, continuous fuel on flat ground with a steady breeze will spread out to form an egg-shaped outline. The more pointed end points towards the direction of spread of the head-fire. In Force 3 wind, about 7 miles per hour at eye level, the resulting burnt patch will be about twice as long as wide. At twice the wind speed, it will be about four times as long as wide. About a sixth of the area will be burnt by the back-fire, about a half by flank-fire, and a third by the head-fire.

Pattern of fire spread



Slopes have a similar effect to wind. Vegetation above a fire moving upslope is closer to the flames and is pre-heated and dried, as with a heading fire. As a fire moves onto a slope, it will tend to swing upslope and its rate of spread, and flame length, will increase. The rate of spread of a fire is likely to double for every 10° increase in slope. On a 20° slope (about 1 in 3) a fire burning uphill is likely to move 4 times as fast as on level ground. Fires can easily run out of control in this type of situation. On steeper slopes, fires are safer and easier to control if they are burnt *down* and *across* the slope - but personnel should ensure that they are never in a position to be caught by part of the fire moving upslope towards them. A fire burning downslope has similarities to a back-fire. The wind may reinforce or oppose the effects of slope. Where factors like slope and wind reinforce each other the risk of the fire exceeding its prescribed limits is increased. Care should be taken on lee slopes where turbulence can make wind direction and strength unpredictably.

Interactions between individual fires

Fires that are close together tend to draw towards each other. This is because of the rising convection column of hot air, which each produces, causes an indraft at ground level. When two fires merge the intensity of the fire dramatically increases. A solid fire front is rather like a merged line of individual small fires and it increases in intensity, and spreads, faster than a series of spot fires along the same line. This means that lighting patterns (e.g. as a series of spot fires or as a continuous line of fire) can considerably influence the behaviour of a fire. The distribution of fuel can produce similar effects. A fire in fuel that is very uneven or discontinuous will have some of the characteristics of a series of small individual fires rather than a single, continuous fire front.

Rates of spread

A well-controlled head-fire in relatively uniform heather 20 - 30 cm tall, in recommended weather conditions, will move forward at about 0.5 - 5 m per minute (1.7 - 16.5 feet). In relatively moist conditions and low wind speeds the rate of spread will be at the lower end of this range while in dry conditions and relatively strong winds rates of spread towards the upper end of the range will be encountered. Rates of spread of 1 - 3 m per minute are about average. Rates if spread of up to 8 m (26 feet) per minute may be encountered with head-fires in heavier, drier fuels or relatively high wind speeds. Rates of spread can be much greater when the weather and fuel conditions are outside the recommended limits, and wildfires can move at speeds of 50 m per minute or more. Back-fires spread much more slowly, normally at between 0.3 - 1 m per minute. Smouldering fires in duff or peat move very much more slowly, but much more inexorably, at rates of about 3 cm per hour.

What effects does muirburn have ?

Where muirburn is likely to have negative effects

Certain kinds of ground (see the text box) are least likely to have been burnt in the past and, as such, they are the areas most likely to provide important refuges for fire-sensitive species. Such areas also are often difficult and dangerous to burn and for this reason are best left alone. They may cover large tracts in the north and west.

Fire-free situations: areas that should be protected from burning

- **Sites traditionally used for nesting by legally protected birds of prey** such as the golden eagle, hen harrier, merlin, and peregrine falcon.
- **Any areas within half a mile of nesting golden eagles, after the end of February**. The golden eagle is specially protected under the Wildlife and Countryside Act 1981 (Schedule 1) and it is an offence to intentionally cause disturbance to it while it is nest building or while there are eggs or young present.
- **Woodland, woodland edges and scrub**, unless fire is used by appropriately trained and experienced staff as part of *woodland* management, for commercial timber production, to encourage native woodland expansion, or to benefit *woodland* game and wildlife (e.g. as part of habitat management for capercaillie). If fire is used it will follow a prescription specifically designed for woodland, which will differ from prescriptions used on open moorland. Moorland fires should not be allowed to spread into established stands of mature trees, even when sparsely stocked, or into recently replanted or naturally regenerating areas of native trees and shrubs. Many types of native woodland and scrub are scarce and only occur in small, vulnerable stands. The 1992 EC Habitats Directive and the UK Biodiversity Action Plan place obligations on government departments and agencies to promote the conservation of most types of native woodland and scrub. You should seek advice from Scottish Natural Heritage before carrying out muirburn near to any area of native oak, tree birches, aspen, Scots pine, willow or juniper.

  Although juniper is quite widespread on moorlands, as well as in woodlands, it is a declining species and most stands show little or no regeneration. Extensive burning of juniper is undesirable even on open moorland as juniper bushes take a long time to grow and mature bushes do not resprout from the base after fire. Fire may have a role in encouraging regeneration of juniper but berry-bearing mature bushes must be present nearby. If juniper bushes are abundant on moorland where muirburn is carried out, no more than 2% of the bushes should be burnt in any year. This will help ensure that seed bearing bushes are not eliminated.
- **Blanket bogs and raised bogs on deep peat (more than 0.5 m deep),** unless heather constitutes more than 75% of the vegetation cover. In the latter situation the peat is likely to be relatively dry and bog moss (*Sphagnum*) cover is likely to be sparse. Conditions that permit good control of fires are exacting and infrequent on peat ground: either much material is left unburnt, and heather regeneration is poor, or the effects are too intense and the underlying peat is exposed. In very dry conditions the fire may burn uncontrollably and lead to ignition of the peat. Once the peat ignites it may burn for months and is virtually impossible to put out. A fire that burns into the peat will cause considerable damage, which will be long lasting and could lead to serious peat erosion.

- **Peat haggs and other areas with exposed peat**. Burning is likely to exacerbate erosion and there is a much higher risk of ignition of the peat itself.
- **Where the soil is eroding, or if there is less than 5 cm (2 inches) of soil over the underlying rock**. Shallow soils are likely to be very dry and burning them may directly consume them, or damage them by removing the protective vegetation cover. Soil erosion may result.
- **Summits and ridges and other areas that are very exposed to the wind**. These are most likely to occur above 300 m (1000 feet) in the north-west to above 600 m (2000 feet) in the south-east, and in areas at lower altitudes near the coast or where wind is funnelled through a pass. The vegetation often grows as a prostrate mat in which the heather perpetuates itself by rooting from creeping stems. The mat can be up to 15 cm thick (6 inches) but is more usually less than 10 cm (4 inches). Sometimes the heather is quite upright and up to 20 cm tall (8 inches) but with conspicuously wind-blasted shoot tips. There is nothing to be gained by burning this kind of vegetation, and long-term damage is highly probable, as recovery is extremely slow and there is a high risk of starting soil erosion. These areas are also an important part of the habitat of golden plover, one of the birds listed in Annex 1 of the 1979 EC Wild Birds Directive requiring special measures to protect its habitat. Burning this kind of prostrate heath will make it less suitable as habitat for this species.
- **Steep hillsides and gullies**, where fire will be difficult to control and where soil may erode if it is exposed by burning. As a general guide, hillsides with a slope greater than 1 in 3 (18°) are best tackled only by experienced and skilled operators, while slopes steeper than 1 in 2 (26°) are best avoided. Gullies should be avoided. A gully acts rather like a chimney and both fire intensity and rate of spread are likely to dramatically increase in a potentially dangerous way. Steep slopes with old, very woody heather or very dry south facing slopes are also best avoided. In both these situations, vegetation recovery is likely to be slow and the soil will be at increased risk of erosion. Steep north-facing slopes should be avoided. Not only will fire be difficult to control, because of the slope, but such areas will often remain too damp to burn in most years. It is a waste of time trying to burn these slopes. Since these slopes will often have escaped fire in the past, they are the parts of the landscape that are most likely to provide refuges for species that are sensitive to fire.
- **Areas where bracken is present, unless there is a commitment to control any bracken spread** into the burnt area should it occur. Heather is most likely to be invaded by adjacent bracken where it does not regenerate quickly and vigorously after fire. Young, dense, vigorous heather can probably resist bracken invasion in many situations. Bracken control may be eligible for grant through agri-environment schemes (Scottish Executive Environment and Rural Affairs Department).
- **Uneven-aged heather where there is already a self-perpetuating, intimate mixture of short and tall heather bushes**. This can develop in some stands of heather that have not been burnt for a long time. Heather can persist in such situations by layering of stems and occasional seedling regeneration. Creating a mixture of tall and short heather is one of the principal reasons for burning so there is little to be gained by burning in this situation.
- **Tall vegetation at the edge of watercourses**, other than where a watercourse is the only practical type of firebreak. Tall vegetation edging watercourses helps to protect banks from erosion. It also provides shade, and leaves and insects that fall into the water provide food, which benefits fish and other aquatic life.
- **Any other areas identified as fire-free in management agreements**, for example, with Scottish Natural Heritage or as part of an agri-environment scheme agreement.

Fire is sometimes used to manage areas of gorse. Even large gorse bushes readily resprout from the stem base and germination of gorse seedlings, from dormant seed in the soil, is greatly encouraged by burning (Fig. 1). New seedlings and sprouting shoots will be browsed quite heavily by many herbivores and this may help to suppress regrowth. Generally, though, burning is not an effective way of reducing the extent of gorse.

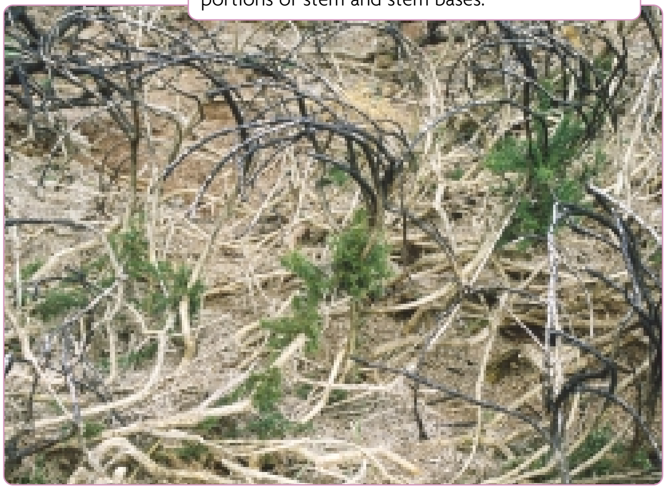


Fig. 1. Gorse resprouting after a fire from unburnt portions of stem and stem bases.

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Dwarf birch (*Betula nana*) is a nationally scarce small shrub, a separate species from the common tree birches, which is sometimes said to be fire sensitive. However, it survives fire in much the same way as heather. It readily resprouts from the base of the stems provided these are not too old (Fig. 2). As with heather, severe fires that destroy the stem base and root crown will kill plants, but unlike heather it does not have the insurance of a large and persistent bank of dormant seeds in the soil. Low to moderate intensity fires will have little direct impact in this species although frequent fires will prevent bushes from growing to maturity and may prevent seed production. The real danger to this species comes from livestock and deer as it is heavily browsed wherever it is apparent and accessible to them. Poorly planned burning that results in concentration of grazing and burning within limited areas may exacerbate these impacts on dwarf birch.

Fig. 2. Dwarf birch (*Betula nana*) resprouting from stem bases after a low intensity fire.

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Where muirburn is likely to have positive effects

Muirburn is most beneficial where heather, or bell heather is an important or dominant component of the vegetation (other than in 'fire-free' areas). Infrequent burning over large areas is likely to produce moorland of low value for livestock, game and wild fauna and flora, with increased risk of uncontrollable wildfires of damagingly high intensity and large size.

On most kinds of moorland, over time, plant nutrients become locked away and relatively unavailable in the woody stems of heather, and other dwarf-shrubs, and in the very slowly decaying plant litter. This also results in reduced food quality for herbivorous animals. Fire helps to release the unavailable nutrients for further use and, biologically, it is like much accelerated decomposition. Soluble mineral plant nutrients like potassium, calcium and magnesium become more available, the soil becomes less acid, and charcoal particles are deposited and become incorporated into the soil. After a fire, regenerating heather shoots may contain up to twice the amount of nitrogen and phosphorus as shoots from pre-fire heather bushes, although this effect disappears quite rapidly over the first four to five years after burning. Charcoal particles can have an important cleansing effect. They absorb, and facilitate the break-down by soil microbes, of compounds produced by some moorland plants that inhibit the growth of other plants. Nitrogen is an important constituent of organisms and may be lost in large amounts in a fire. However, this is compensated by improved conditions for nitrogen-fixing plants and microbes. Phosphorous is another very important nutrient for plants and animals which is sometimes thought to be at risk of loss during muirburn, but research shows that long-term loss is unlikely where fires are at moderate intensities and intervals.

Outside 'fire-free' areas it is best to burn heather when it is still finely branched and vigorous, that is, when its stems are no thicker than pencils (about 5 mm, or 0.2 inch, thick) and 20 cm to 30 cm tall (8 to 12 inches). It will then regenerate freely from buds at the base of the stems and recovery will be rapid and complete (Fig. 3). Resprouting should be easily observed within a year of burning. If it is not obvious by then, it is unlikely to occur. Burning at this stage also stops heather from completely suppressing other moorland flowering plants, which expands the range and quality of food available for livestock, grouse and wildlife, and contributes to the biological diversity of moorlands. Suppression of other dwarf-shrubs and flowering plants is most pronounced in stands of heather that are allowed to become older than about 15 years. New shoots, flowers and fruit of moorland plants are often produced earlier and more vigorously, in recently burnt patches.

Fig. 3. Heather will often resprout vigorously from the bases of relatively thin stems. Thick stems usually fail to resprout.

If heather plants have become old and very woody, regrowth from stem bases is poor. As heather stems become thicker, the buds become progressively buried within the wood of the stem. When this happens they will not produce new shoots and regeneration can result only from seedling germination. Heather seedlings may germinate from the large numbers of seeds that lie dormant in the soil below most heather swards (Fig. 4). But, it is often difficult to get a good seedbed when burning old heather as so much unburnt plant litter is left on the ground. It is hard to get this dry enough to burn, and yet not so dry that the fire cannot be controlled. When conditions are sufficiently dry for the moss and litter to burn the amount of available fuel present may produce damagingly intense fires. The safety of those undertaking the burning also may be seriously compromised in these types of situations. If regeneration of heather is very poor as a result of an ineffective fire it can be improved by re-burning the material left in the following year. This will create a good bed for seedling regeneration, but it is time-consuming to do. Note, however, that even when there is much heather litter remaining it will become redistributed and consolidated by wind, rain, and animal trampling over one to two years after a fire and this will provide a scatter of small patches suitable for seedling establishment. It may be two or three years before seedling heather plants become very obvious, as new heather seedlings are extremely small and take some time to become well-established. Seedling establishment and growth also can be very slow on very dry ground with shallow or very freely draining soils.

Fig. 4. Heather seedlings.

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Burning old stands of heather often leaves many unburnt woody stems and this is often thought to be undesirable. This may not always be true. The unburnt 'sticks' provide some protection against excessive browsing of young plants and provide valuable cover for grouse and other birds (e.g. curlew favour areas with unburnt 'stick' for nesting). Also, a fire of sufficient intensity to remove the sticks is likely to require very dry conditions, which increases the risk of the fire being dangerously intense and difficult to control.

On the whole, it is better to avoid the problems of burning old stands of heather by burning at shorter intervals or by not burning such areas at all.

Poor regeneration of heather following fires encourages the undesirable spread of plants such as bracken, or grasses like mat grass ("white bent") and purple moor-grass ("blow grass" or "flying bent") which are of poor forage quality. These grasses are likely to become dominant if subsequent grazing pressure is heavy, especially where there is heavy winter grazing. They are most likely to present serious competition where the soil is damp and peaty. Where purple moor-grass is dominant, and there is not even suppressed heather present to compete with it, then the accumulation of dead leaf litter will be very rapid. Burning may then need to be undertaken every 3 to 4 years to reduce this suppressive blanket of litter, to improve forage quality and accessibility, and to increase plant diversity. The accumulation of dead leaf litter, and the need to burn, will be much less if grazing is by cattle rather than sheep.

The effects of fire frequency

If burning has been very infrequent, and grazing pressure and wind exposure are both low, the vegetation will tend to become dominated by tall heather. The ground beneath the heather bushes becomes densely carpeted with feather mosses, or bog moss in damper situations, and heather litter. Heather potentially can maintain itself indefinitely in these situations by layering (the production of roots from along stems which have become buried by plant litter or overgrown by mosses and other plants - see Fig. 5) provided that the heather stems are not heavy trampled by livestock or deer. It is possible that the shoots of layering heather might be somewhat less nutritious for herbivores, but this has not been scientifically demonstrated. Also, unwanted plant species may invade any gaps which do eventually appear in the heather. Despite this, these types of situation can have biodiversity, landscape and recreational value, especially in the types of fire-free situation described previously.

On the other hand, if areas are burnt too frequently the carrying capacity for farm stock and most forms of game and wildlife will decline. "Too frequently" means burning before the heather reaches at least 20 cm tall. This may take 8 to 10 years in the most productive situations and up to

Fig. 5. Naturally layered heather. Note the long creeping portion of stem and the production of roots where the stem bends sharply upward.

20 to 25 years in the least productive areas. Heather will grow more slowly in high or exposed situations, or where soils are very poor in nutrients or waterlogged, or where the soil is very dry through being shallow or very freely draining. One or more of these conditions usually is present over extensive areas in the west and north of Scotland, and in parts of the Cairngorms area. If heather is burnt too frequently, it is gradually replaced by coarse grasses like mat grass and purple moor-grass. Similarly, burning of even the more appropriate parts of blanket bogs and wet heaths more frequently than every 15 to 20 years is likely to lead to the spread of deergrass ("deer-sedge") and cottongrass ("cotton-sedge"). This will lead to a reduction in heather and other characteristic bog plants, and a reduction in the supply of winter forage. Where cottongrass is sparse some increase may be beneficial since the leaves (for livestock in winter), and the developing flower heads (in early spring), can be an important source of food for moorland livestock, game and some rarer species of wildlife like the black grouse and the large heath butterfly. Even on rough grasslands, frequent fires can lead to the spread of tussocky grasses and sedges, which will reduce forage value in the long-term, even if a 'spring bite' for livestock is produced in the short-term. Over-frequent burning also increases the risks of depleting the soil of mineral nutrients essential for plant and animal productivity.

The effects of fire temperature and intensity

The lethal temperature for plant tissues varies with the duration of the temperature. So, a temperature above 60 °C is usually lethal regardless of its duration, but plant tissues may survive for up to 10 minutes at 50 °C. Dormant plant parts, especially those with low moisture content, such as seeds, can be somewhat more resistant. The germination of the seeds of some moorland plants actually seems to be stimulated by a brief heat pulse.

Technically, fire intensity is usually defined as the *rate* of release of heat per unit length of fire front. It has an important influence on how difficult the fire will be to control and contain. However, the amount of fuel consumed, the duration of potentially lethal temperatures, and the consequent effect on the vegetation and soil, are more strongly influenced by the total heat produced per unit area and by whether the heat is concentrated in the vegetation canopy or close to the ground. So, although head-fires are often of higher intensity than back-fires, it is back-fires which remove more fuel because in a back-fire the heat is released closer to the ground. A smouldering fire on the ground surface has the greatest and most damaging effect of all on the vegetation and soil because of the long duration of lethal temperatures. It may kill a large proportion of the rootstocks and seeds in the soil with the result that vegetation recovery will be greatly delayed.

A low intensity fire may leave much material unburnt (Fig. 6). This will tend to discourage seedling regeneration of heather, and other moorland plants, though resprouting is likely to be much less affected. Fires that release sufficient heat per unit area to remove a significant part of the plant litter and moss layer, so as to just bare the surface of the duff and no more, will produce the best seed beds. Intense fires that remove all the plant litter, moss and lichen, or that burn into the soil, consuming the duff layer, should be avoided (Fig. 7 - 8).

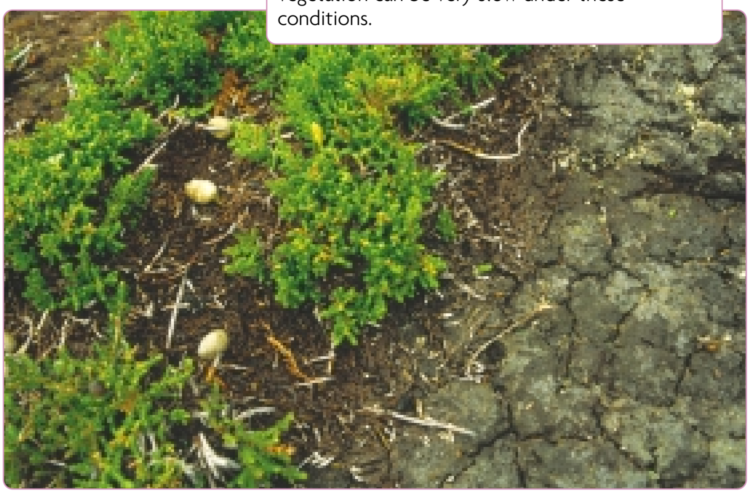
Since most of the seeds and rootstocks from which plants will regenerate are in the top 2.5 – 5 cm (1 – 2 inches) of the soil, vegetation recovery may be very slow after a very intense fire. Intense fires also increase the risk loss of nutrients in smoke and ash, and by erosion, and this may lead to a net, long-term loss of nutrients. Repeated intense fires, or a single very intense fire, will lead to a loss of productivity of the land. It may also damage archaeological features. The objective of always trying to achieve a "clean" burn can be misguided.

On wet heaths and blanket bogs the removal of the protective cover of mosses is not desirable and a cool, quick fire is preferable. Bare peat can be a hostile

Fig. 6. A low intensity fire may leave much material unburnt.

Fig. 7. A high intensity fire may remove too much material, destroying plants and dormant seed and exposing soil to erosion.

Fig. 8. Where the soils are peaty, a high intensity fire will partially consume the surface layers, "cooking" what it does not consume. Re-vegetation can be very slow under these conditions.



substrate for seed germination, for a number of reasons. The chemical and physical properties of the peat become unfavourable if it has been "cooked" as a result of consumption of the insulating moss and plant litter. Its physical structure is modified so that it is less able to absorb moisture, and water-repellent compounds are deposited by distillation during the fire to create layers in the soil that may interfere with water and root penetration and may create structural weakness. Water repellent layers are most likely to be formed at relatively low temperatures, during prolonged smouldering fires in the peat and duff layers. Also, after the fire, the very dark exposed surface can attain damagingly high temperatures on sunny days, and the surface can remain physically unstable for considerable periods once exposed to rain, frost and wind.

Fires can also cause lethal scorching even where they do not directly consume the vegetation. Although increasing wind speed tends to increase the intensity of a fire and its flame length, there is also a cooling effect on both the hot gases produced by burning and on vegetation exposed to radiant heat from the flames. Lethal scorching usually occurs within about one flame length from the tip of the flames (or twice the flame length from the base of the fire front). Scorching beyond the boundaries of the fire is more likely to occur with a head-fire than with a back-fire.

The effects of size of fires

Many small fires, less than about 30 m (100 feet) wide are desirable. These are less likely to disrupt sheep and deer hefts, they produce an intimate mixture of short and tall vegetation that encourages the spread of grazing over the range, and they provide small-scale variation in habitat composition and structure which is important for grouse and moorland biodiversity in general. Note that it is the *width* of the fire that is critical here, and not its total area. A long *narrow* strip can achieve much the same effect as several small patches, although its visual impact in the landscape will be rather greater. Large (wide) fires are often more intense and difficult to control, and there is a greater risk of causing damage to the vegetation and soil. More severe impacts on the soil may occur for two reasons. First, since large fires are often more intense they are more likely to damage the soil directly and to expose it to wind and water. Second, the larger the area from which the protective vegetation cover is removed, the more likely it is that slope wash during heavy rain will build up sufficient momentum to detach and carry away soil material. For similar reasons, where long strips are burnt they should run along the contour rather than directly up and down slopes.

A complication arises where grazing animals are present. Grazing animals concentrate on recently burnt ground, attracted by the short and nutritious new growth. So, where livestock or deer are present, it is important to ensure that a sufficient total area is burnt to reduce such concentrations (Figs. 9 -10). Where there are large areas of uniformly dense, old heather, or where the ground is wet, damagingly high intensities of grazing and trampling can occur in burnt patches if these occupy only a very small proportion of the area. If this practice is continued it can lead to a cumulative loss of heather, forage productivity, and the diversity of moorland plants and animals. In extreme cases, the trampling could initiate soil erosion. If the aim is to reinstate a burning programme over a large area of uniform heather, to which livestock or red deer also have access, it is important to burn more than normal at the start of the programme. As a guide, in the first two years aim to burn about 4 times more than would be carried out normally (up to 40% the total area), reducing the amount burnt in the remaining years of the first rotation to compensate. This could be undertaken in relatively wide strips, if necessary, while keeping within safety margins for control of the fire. Remember that fires with a wide fire front are more intense and difficult to control. Other than in this situation large, wide fires are bad practice.

Fig. 9. Livestock, and deer, concentrate on recently burnt patches.

Fig. 10. To avoid damagingly heavy concentrations of livestock, or deer, on recently burnt patches it is important to burn sufficient total area and to disperse the burnt patches widely.

Effect of muirburn on heather pests

Muirburn is sometimes seen as a possible treatment for several insect pests. The heather beetle (*Lochmaea suturalis*) is probably the most frequently encountered. Heather plants are not often completely killed, unless the outbreak has been very intense or, especially, if there has been a dry spell in the latter part of the summer and autumn. Outbreaks usually dissipate naturally in the second or third year. However, the supply of green heather shoots for sheep, deer and grouse will be reduced for some years within affected areas. Burning will encourage more rapid recovery of a crop of heather shoots where heather has been severely affected, but heather often can recover quickly without burning if only a small proportion of the green foliage and shoots have been browned.

Burning is unlikely to be an effective tool for controlling beetle outbreaks in most situations. Most damage is done by the beetle grubs and these are not present during the legal burning period. When burning is permitted, the adults and eggs are well protected in the soil and, although they will mostly be in and around the patches of heather that are affected, they may disperse elsewhere making their precise location hard to predict. In Scotland, there is no statutory provision for extending the burning season beyond its normal limits into the period when the beetle grubs are likely to be present. Burning affected heather patches might possibly have some indirect effects on the heather beetle population, reducing the survival of some of the hibernating adult beetles, and reducing the availability of food the following the year but this has not been demonstrated scientifically. Similar considerations apply to the small outbreaks of magpie moth on heather, which occur quite regularly in north-west Scotland. On the other hand, burning may help to control outbreaks of winter moth and vapourer moth since the flightless females are active during the first half of the burning season, and the eggs are present on the heather, in and around affected patches, during the second half of the burning season.

Cutting or swiping as an alternative to burning

The great advantage of cutting is that it is much less hampered by the weather and there is no fire risk to neighbours' property. Regeneration can be very good, although less nutritious for livestock or grouse than regrowth in the first few years after a fire. Usually, the most practical technique is to use a chain swipe mounted on a four-wheel drive 80 HP (60 kW) or 100 HP (75 kW) tractor, which can be fitted with double wheels for softer ground. This produces finely mashed-up material which appears to decay quite rapidly, especially in the wetter, western parts of the country where an alternative to muirburn is most needed. It is particularly valuable where there is much purple moor-grass among the heather. On ground suitable for the use of a double-chop forage harvester, the cuttings can be blown outside the cut patch. Alternatively, cut material can be baled and sold for a variety of mulch and filtration uses.

There are some serious drawbacks to cutting. There are many areas where the ground is too steep, rocky, or wet for machinery to be used safely or without causing damage to the vegetation and soil. In drier parts of the country, the cut material may not decay quickly, suppressing regeneration of the heather if a thick mat of cut material is produced. This may even happen in some western areas. Test areas can be cut to see if this is likely to happen. Cutting machinery also can cause damage to archaeological features unless used with great care. In addition, the capital cost of the machinery is high.

In terms of *operational* costs per unit area, cutting using a contractor is likely to be about 20% more costly than muirburn with cut firebreaks and foam traces, which in turn is likely to be about 70% more costly than traditional controlled muirburn. However, if farm or estate labour and suitable machinery is already available then cutting or swiping can be done for about half the cost of traditional controlled muirburn.

Cutting or swiping is not subject to the same statutory seasonal limits as muirburn. However, an offence would be committed under Part 1 of the Wildlife & Countryside Act 1981 if cutting or swiping intentionally resulted in the death or injury of wild birds. It should not be used after the 15th April and throughout the summer months, as ground-nesting birds will be present. The use of cutting machinery on a Site of Special Scientific Interest may also be an offence if the use of vehicles has been identified as a 'potentially damaging operation' and a consent for their use has not been given. Other legal obligations relating to the safe use of machinery will apply.

Preparing a burning plan

When to start

Start preparing a burning plan at least a year before you intend to undertake any burning.

Identify fire-free areas

The first step in planning should be to identify areas where muirburn would be harmful or a waste of time and resources. These areas should be marked on a map as 'fire-free' areas. These are listed in the box on pages 8 and 9 "Situations which should be kept fire-free".

Identify areas where burning might be beneficial

Once fire-free areas have been identified, the remaining areas of open moorland can be considered potentially suitable for muirburn. Agricultural businesses may be able to claim grant aid for muirburn costs under agri-environment schemes, administered by the Scottish Executive Environment and Rural Affairs Department. You can obtain further details from your local SEERAD office.

Determine the total amount of ground to be burnt each year

The next step is to decide how much of this potential area should be included in a burning programme. This will be determined by how rapidly the heather grows and by the availability of labour, time and equipment to carry out burning to a good standard. The amount of annual burning which will be needed will vary from place to place.

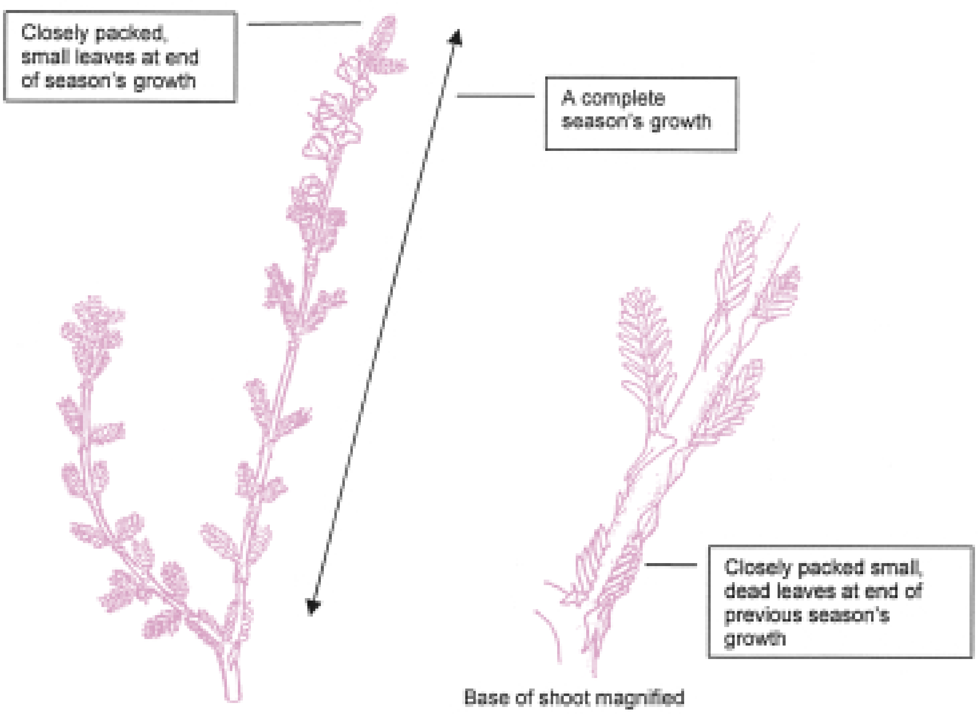
Start by looking at the height and average rate of growth of the heather over the potential area within the burning plan. Annual growth increments of heather shoots are not difficult to determine (see diagram). Look back down a heather shoot from its tip and you will see small, closely packed leaves at the tip followed by larger, more widely spaced leaves. These larger leave may have side shoots or flowers arising at the point where they join the shoot. After some distance you will again encounter some small, closely packed leaves. These will probably be dead but still attached to the stem. These mark the end of the previous year's growth. The stem often branches at this point. This process can be repeated to identify several years' growth.

Next, divide the height of the heather by the average yearly growth to get an approximate estimate of its age. As the growth rate changes with the age and size of the heather plant this technique will tend to underestimate the age of young plants, when growth rate is often accelerating, and overestimate the age of old plants which usually have decelerating growth rates. Be careful in situations where there is more than light browsing of heather. Heavier browsing will reduce the rate of height growth of the plants so that the age of the plants is likely to be underestimated. The time it takes for heather to reach 30 cm may vary from about 8 years to 25 or more according to the amount of browsing and local soil and climatic conditions.

Divide the area suitable for muirburn by the age estimate. Average this over the whole area identified as suitable for burning within the muirburn plan, taking account of any significant differences in heather growth rates. This will provide an average figure for the area to be burnt each year. It may not be possible to burn every year, particularly in the wetter west, but over several years every effort should be made to keep to the burning programme. In years when more days are suitable for burning a little more should be burnt to compensate for years when weather conditions make burning difficult.

Consider leaving a few tall patches of heather to provide concealed nesting sites for moorland birds, holding areas to concentrate grouse during long drives, and accessible forage during snow for farm stock and deer.

Identifying the most recent annual shoot growth of heather



Determine the size of fires

In an average winter there are between 5 and 15 days suitable for muirburn in the west and between 10 and 25 days in the drier east of the country. The first priority is to ensure that a sufficient total area is burnt each year to maintain the burning programme. The second priority is to decide if this total area will be burnt as a few moderately large fires or many small ones. On this decision will depend how many people will need to be employed, and budgeted for, if the burning is to be to a good standard. An active squad of two or three will burn an average of eight well controlled fires per day, where each fire is about 0.8 ha (2 acres) in size.

Fires should be as small (narrow) as is practicable, subject to maintaining the appropriate muirburn rotation. Small fires are safer and easier to control, other things being equal, since ease of control is related to fire intensity and this is usually greater in large fires. However, small fires do require more labour and time than if the same total area is burnt in larger patches. In practice some compromise is likely to be required between ideal size and ensuring that sufficient total area is burnt, but individual fires should not be allowed to exceed 50 m (165 feet) wide if adequate control of the fire is to be maintained.

Determine where and when individual areas will be burnt

Individual patches to be burnt, or sets of similar patches, should be marked out on a map. The patches should be prioritised. This will help to ensure that effort and resources are used most efficiently and effectively. In particular, it is important to identify patches where there is the potential to cause danger, loss of control or damage.

Ensure that there are effective firebreaks

Identifying firebreaks is an essential part of muirburn planning. No fire should be lit if you are uncertain where it will stop. Firebreaks for moorland fires need to be at least 10 m (33 feet) wide to reliably stop a fire under all, or nearly all, circumstances. The width necessary will depend on the length of flame expected. A rule-of-thumb is that the width of a firebreak should be at least 2.5 times the maximum expected flame length, and preferably *more* where relatively high intensity fires are expected. Flame lengths of 0.5 – 1.5 m (about 1.7 – 5 feet) are common where there has not been a large accumulation of dry heather fuel, and where wind speed is within the recommended range when burning. However, flame lengths can be 3 m or even 4 m (about 10 – 13 feet) where the heather is both dense and more than about 0.5 m tall, when a long dry spell of weather has produced much dry fuel, and the wind is at or beyond the recommended maximum.

Firebreaks may be natural or man-made, such as banks of snow, grassy "greens", rivers, lochs and tracks. Note that it is an offence to burn within 15 m (50 feet) of a public highway if this causes interruption or danger to road users. Several types of firebreak may be used in combination to make a more effective break. Artificial breaks can be created in a variety of ways.

Patches burnt in the same, or previous, season can be used, provided that they have been burnt cleanly and carry little unburnt material or heather regeneration. Back-fires can be used to create clean breaks across the line of proposed fires. This technique can be used to reinforce existing firebreaks. In other parts of the world where prescribed burning is part of land management, the creation of firebreaks by back-firing is routine. On rough terrain, this may be the only practical technique for creating firebreaks. Back-fires should be avoided, or only used with extreme caution, where there is peat underlying the heather. Since they are more likely to remove the protective litter and moss layer, and to heat the soil surface, there is increased risk that the peat will either be exposed to erosion or, worse, that it will ignite. These risks can be reduced by only burning when the surface of the peat is thoroughly wet or frozen.

Where the terrain allows safe access for a tractor-mounted chain swipe, or quad bike mower, without causing damage to the vegetation and ground, firebreaks can be swiped or cut. These breaks must be swiped *immediately before* lighting the fire. The chain swipe makes a swathe of compacted, mashed-up heather and litter which, provided it does not dry out, will not ignite readily although it probably will not stop a high intensity fire. Swiped breaks are not reliable if the cut trash dries out. If firebreaks are cut, rather than swiped, the cut material should be removed from the firebreak. If used in conjunction with other fire control methods a narrower swathe of 2 – 3 m (6.5 - 10 feet) is likely to be sufficient and can double the efficiency of a burning squad. Try to avoid square, very straight-sided patches. These do not produce the indented edges and close mixture of short and tall heather that is most beneficial for sheep, game and wildlife and they can detract from landscape value.

High-pressure water pumps, producing an atomised jet of water, or modified for foam production, and mounted on a cross-country vehicle can be very useful for making firebreaks more effective in critical situations, such as near woodland or forestry plantations. A continuous trace of thick and creamy, low expansion foam, at least 1m (about 3 feet) wide but preferably more, laid not less than 5 minutes and not more than 60 minutes before the fire reaches the break, will provide a barrier that will greatly enhance fire control. A much wider trace will be needed to ensure security when burning tall, dense heather or when the flames are being fanned by a relatively strong wind. Your local fire service will be able to supply technical information on using foam to control fires.

Make sure fire control equipment is ready

Equipment for extinguishing fire must be on hand and in good order before burning begins. Members of the burning control squad must have suitable types of beaters, which can be used to 'scrub' as well as 'beat' out the fire. Beaters with aluminium handles and with an end made from an aluminium grain shovel, perforated steel plate, or a rectangle of aluminium with weld mesh between, are robust and long-lasting. Wire-mesh heads only work well on flat, even ground. Although they can be very effective, they can also cause problems in some situations. Burning grass litter can become entangled in the wire-mesh and serve to spread the fire rather than control it. Also, the wire-mesh can sometimes become entangled among heather stems. The commonly seen beaters made with a rectangle of reinforced rubber conveyor belting are good where there is much purple moor-grass but do not last as long as metal beaters and may not work well in heather or rough ground. Brushes based on birch twigs bound with wire netting can be effective on rough, rocky ground but the wood and twigs from which they are made needs to be green. If they are allowed to become old and dry they may break or catch fire. They should be renewed every year. Beaters with handles 3 to 4 m (9 to 12 feet) long reduce heat exposure for those using them, but shorter 2 m handles are lighter and easier to transport and may be perfectly adequate for low intensity fires. A variety of beater and scrubber types should be available on the day of burning to cope with variations in the ground and the nature of the fire. Spares should also be taken as breakages can be quite frequent. Small knapsack sprayers, adjusted to deliver a 2 mm water jet, can be useful for extinguishing smouldering hot spots which are difficult to reach with a beater or scraper. These should be reserved for fire control and should not be used for spraying pesticides or herbicides.

Fire-retardant clothing is advisable. Face visors (BS2092 and BSEN166) are highly desirable. Some operators prefer fire safe goggles as these give greater protection to the eyes, although less protection to the rest of the face. If prolonged exposure to smoke is likely it may be advisable to wear a mask: BS4275 (published in December 1997) provides a comprehensive guide to best practice in the use of respirators. Leather gloves are recommended, but it is important for safety to intermittently take them off to check how hot clothes are becoming, particularly if fire-retardant overalls are not being worn. Where foam is being used waterproof gloves and footwear should be used to avoid adverse skin reactions caused by the foaming agent. A first-aid kit should also be provided and at least one member of each burning squad should have first aid training.

A high-pressure water pump mounted on a four-wheel drive tractor (with double wheels), all terrain vehicle, or quad bike can be a useful addition for laying foam, wetting down vegetation, or extinguishing hot spots. Fogging systems suppress fire, and use water, more efficiently than coarse sprays or water jets. A fogging spray rapidly absorbs heat because of the small droplet size and quickly reduces the intensity of a fire. Suitable pumps can be obtained with hoses, connectors, and "Expandol" synthetic foam compound. Control equipment must be checked to ensure that it is in full working order before any fires are lit. Do not rely completely on a machine as technical problems can arise during the course of muirburning - back-up methods of control should be available. Before any burning is started, water tanks need to be put in place and filled, and pools or streams used to recharge tanks should be checked to ensure that they contain sufficient water.

Consult and prepare thoroughly well in advance of the burning season

A burning plan should be drawn up which should include maps of where muirburn will be undertaken, descriptions of the conditions under which burning will be carried out and the objectives of burning (the "prescription"), details about available labour and equipment, communications, and safety and emergency procedures. There may be more than one prescription within the burning plan. The Health & Safety Executive encourage the writing of emergency plans for all work activities. Ensure that you have copied your fire plan to your local fire brigade.

Consider joining your local Rural Fire Protection Group. These groups exist in many areas, and provide a formal arrangement for land owners, managers and the fire brigade to co-ordinate their resources and provide mutual assistance in the event of an emergency.

On Sites of Special Scientific Interest you should inform and seek the advice of Scottish Natural Heritage, and if muirburn is listed as a 'potentially damaging operation' you will need to obtain a consent. Scottish Natural Heritage will also be able to provide more general advice on nature conservation, landscape or amenity considerations. Advice, and where necessary consent, should be obtained from Historic Scotland where archaeological features are present.

There should be consultations to establish, or confirm, a muirburn programme for the year between the farmer, shepherd, keeper, owner and others who have an interest in the moorland. This is an opportunity to reduce costs and risks through co-operative use of labour and equipment, as well as giving due notice of intentions. Neighbours will also have an interest especially those with adjacent woodland or forest, and may provide assistance.

Seek further information and training for personnel as required, and arrange appropriate insurance cover.

Make sure you have a backup plan in case things go wrong

Back-up staff should be available and contactable by radio or mobile phone. Everyone taking part in burning should be able to make radio or mobile phone contact with their base or directly with the fire brigade. If you are a member of your local Rural Fire Protection Group, this may provide extra assistance should a fire escape control. If the fire brigade needs to be called, their job will be made easier if you can provide them with appropriate information. They will need information about ownership boundaries, watercourses, fire dams, tracks and whether they are passable by fire tender or four-wheel drive vehicle, assembly points, location of any fire fighting equipment and what it is, and the location of potential helicopter landing sites. Fire tenders have the road capabilities of a standard articulated lorry. Helicopters need a level area clear of obstructions which is greater than 60 m in diameter. This information should be marked on an Ordnance Survey map, preferably of 1:25,000 or 1:10,000 scale.

Fire control and suppression map symbols

Feature	**Description of map symbol**
Forest or woodland areas	Yellow wash
Road or track accessible to all vehicles	Solid red line
Road or track passable to 4 x 4 vehicles	Broken red line
Open water	Blue wash
Water tanks (surface or underground)	Open blue rectangle with tank number inside
Hydrants	5 mm solid blue square with HD at the side
Perennial stream	Solid blue line
Telephone	Red T in 5 mm green circle
Fire Support Office	10 mm solid red square
Rendezvous points	Blue triangular flag with number
Electric power lines or gas lines	Red zig-zag line
Helicopter landing site	Red H in red circle
Helicopter equipment store	Red H in open red square
Equipment store	Red E in open red square
Possible hill top repeater site for radio communications	Black transmitter tower symbol
Flexi-dam site	Red FD in open red circle
Fire pond	Open blue circle
Beater stand	Red B in open green circle

Summary of what to consider when planning burning

1 Objectives	Clearly state what the fires are to achieve e.g. habitat for grouse, better forage for deer, the wider dispersion of grazing pressure, improved wildlife habitat, fire hazard reduction etc. Different individual fires may have different objectives.
2 General location map	Prepare a map showing the location of the area where burning will be carried out in relation to the whole holding or estate, in relation to neighbouring properties (noting names, addresses and contact numbers), and access points.
3 Map of past fires	Record any existing burning pattern.
4 Identification of areas to be protected from fire	Describe and map the identity and location of all public roads, buildings and any areas which fall within the definition of fire-free areas.
5 Description of areas where burning will be carried out	Record the features of the vegetation, topography and fuel which will be relevant to undertaking burning and achieving the land management objectives.
6 Fire prescription	Define what the fires should be like in terms of flame length, intensity, rate of spread. State the acceptable limits of wind speed, wind direction, slope, fuel characteristics, and fire behaviour.
7 Smoke management	Identify where precautions need to be taken to avoid danger to users of public roads or to avoid public nuisance or health risks.
8 Fire control and suppression procedures	Describe how each fire will be lit, how its spread will be controlled, and how the fire will be extinguished.
9 Test fire	Describe procedure for carrying out test fires and ensure there is a procedure for recording the results.
10 Obtaining weather information	Describe what weather information will be needed, and from where and how it will be obtained. Record when, and how often, weather information will be checked.

11	Equipment and personnel	List available equipment. Check that equipment is in working order and identify if any spare, or new, equipment is needed. List the names, addresses, contact numbers and duties of all personnel who will be involved in undertaking burning.
12	Detailed map of planned fires	Map the desired boundaries of new fires. Indicate their priority within the plan, when they will be burnt, and the existence of hazards. Highlight any topographic features which will have an important effect on fire behaviour and influence potential hazard. Indicate actual control lines and ignition patterns.
13	Identification and preparation of potential control lines	Describe any special work which needs to be carried out to establish firebreaks e.g. the location and width of permanent firebreaks, or the installation of temporary or permanent fire dams.
14	Safety of personnel and public	Describe safety procedures for normal burning activities.
15	Contingency and emergency procedures	Describe procedures to be undertaken in the event of a fire escaping control or threatening to escape control. Describe procedures to be undertaken in the event of accident or injury.
16	Record required approvals and/or signatures of agreement	List all those who should be consulted and discuss plans with them. Identify and seek approvals from owners/ occupiers/ tenants as appropriate and from any relevant statutory organisations which must be consulted or must give consent.
17	Costs and funding	Estimate the potential costs, and identify who will fund the work. Record any conditions, relevant to carrying out the burning, which apply to the funding.
18	Communications	List the contact numbers or radio frequencies of key personnel and emergency services.
19	Briefing of personnel	Ensure that all personnel have copies of, and understand, the objectives, safety and emergency procedures, and the map of planned fires for each day of burning.

20	Notification immediately prior to burning	List who must be given 24 hours written notice and should be notified on the day of burning.
21	Monitoring and evaluation	Describe procedures for recording when fires were burnt and under what conditions, whether the fires behaved as expected, what the results were in terms of impacts on the vegetation and ground, whether the land management objectives were achieved.
22	Remedial actions	Describe action to be taken if fires are ineffective, do not achieve the desired objectives, or cause damage in any way.

Carrying out the burning

Inform neighbours and the fire brigade

You must, by law, give adjoining proprietors at least 24 hours written notice of the date, place and extent of intended muirburn. A follow-up telephone call in the morning before muirburn is planned, or the previous evening, will usually be appreciated.

Make sure you have a detailed written fire plan and copy this to your local fire brigade. On the morning of the day of burning, telephone your local fire brigade and provide details of the location (including Ordnance Survey map grid reference) and extent of intended burning. At the end of the day let them know when all fires have been extinguished.

Burn only when the weather is suitable

Starting two weeks before the beginning of the burning season, follow the weather forecasts each evening, noting the wind direction and speed, to ensure that no days are missed and that the burning will always be done when the fire can be controlled easily. Every effort should be made to make use of suitable periods in autumn. If you wait until spring before starting you will be more rushed and there will be a temptation to burn under conditions of greater risk. Try to obtain a weather forecast as close as possible to the time when you intend to start burning. Various telephone and internet services are available from the Meteorological Office and other weather service providers.

Burning should not be attempted after prolonged dry weather. High risk periods can occur even during the muirburn season. Dangerous and damaging fires can be avoided if burning is carried out only when the moss and litter is not completely dried out and the semi-decomposed material underneath is still moist (or frozen). Where peat underlies the heather, burning should only be carried our when the water table is very close to the surface.

You should check the moisture in the vegetation, plant litter, moss and soil on the day prior to burning before deciding if, where, and how, burning will be carried out. On the day of burning the moisture content of the vegetation, and thus the available fuel, should be kept under constant review and burning plans should be changed if there is the potential for fires to become over-intense, uncontrollable, or, at the other extreme, ineffective. You should stop burning if a fire starts to behave erratically, or if it starts lofting firebrands and spotting new fires.

Wind speed also is important. At any particular fuel moisture content, a stronger wind will produce a more intense fire. Head-fire burning is most effective and most easily controlled when there is a steady breeze of about 7.5 miles per hour at eye level (3.4 m/ 11 ft per second). At this wind speed only the tallest parts of the heather canopy will be in just perceptible motion. This is equivalent to a weather forecast wind speed of about 10 miles per hour, or Force 3, since forecast wind speeds are standardised for a height of 10 m above the ground. Burning should not be attempted if the forecast wind speed is likely to exceed 18 miles per hour or Force 4. This is equivalent to an eye level wind of about 15 miles per hour (6.7 m/22 feet per second). The wind is too strong if the taller heather stems start to thrash about continuously and even the shorter, more sheltered heather stems are in continuous motion. Back-fires are much less affected by wind speed and are safer in stronger winds. Care must also be exercised when winds are light. Light winds are often variable in direction and strength, making it more difficult to predict fire behaviour.

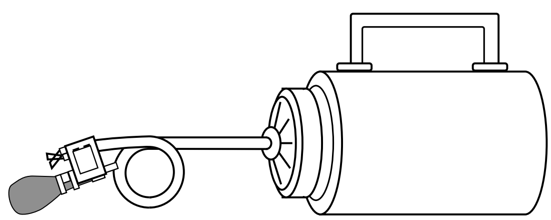
Light and control fires safely

On moorland where there is public access, it may be worth erecting signs at access points to warn the public that it is dangerous to approach fires. Although for most people a smoke plume will be a much more conspicuous and informative indicator of potential danger than a sign, it may still be worthwhile to provide a conspicuous temporary notice. This is also an opportunity to explain to visitors why burning is being undertaken. This will reduce unnecessary call-outs for the fire brigade and adverse publicity.

Fires should not be lit unless you know how and where they will be extinguished, and you can make an informed estimate of how the fire is likely to behave. A test fire should be lit and carefully observed to ensure that conditions are suitable. Safety is paramount. Uniform areas of tall heather are a potential fire hazard. A fire should not be lit if it seems likely that the combination of fuel load and weather conditions will produce a fire with flames longer than 3 m (10 feet). See page 22. Such fires will be difficult and potentially dangerous to control and will require fogging equipment as well as beaters to control safely. This is most likely in dense heather (or gorse) more than 0.5 m (1.7 feet) tall. If flame lengths are likely to be greater than 1.5 m (5 feet), there should be additional staff on stand-by to help with fire control. Also, a fire should not be lit if the wind is likely to blow the smoke across a public highway so that it reduces visibility for vehicle drivers.

Sufficient people should be present to control all fires. If there are few firebreaks there should be sufficient people to have *at least* two per side for each actively burning fire which is more than 20 m (65 feet) wide. Fewer will be needed if fires are narrower, where there are numerous firebreaks spread out over the moor, and if fuel and weather conditions are such that there is a low risk of exceeding the prescription for fire intensity and rate of spread.

Some people use a pressure lamp or a knapsack sprayer filled with kerosene or diesel to light fires. This approach allows a fire to be lit quickly so that it develops a 'face' rapidly. This saves time and helps to produce an even and vigorous fire which will dry the vegetation in front of it and will burn cleanly. However, there are much safer alternatives including proprietary brands of LPG weedburner or the traditional kerosene muirburn lighter. LPG weedburners have a built-in ignition system and use disposable LPG canisters. Both these ignition tools have the disadvantage that they do not add any fuel to vegetation, and so an evenly burning face can take longer to establish.



A "drip torch" is a safe and effective alternative used in North America and many other countries. This is basically a hand-held, unpressurised can of fuel, with a flame-carrying head at the end of a spout, which when tilted deposits a burning stream of fuel wherever the spout is pointed. The fuel mixture used in North America is usually 3 to 4 parts diesel to 1 part petrol. The spout has a circular loop to form a fuel trap and prevent flashback. It is also fitted with an adjustable air vent to adjust the flow of fuel. They are usually constructed from aluminium, weigh about 2.3 kg (5 lbs) empty and 7.3kg (16 lbs) full, and when fully assembled for use are about 64 cm (25 inches) long by about 15 cm (6 inches) diameter.

As soon as the fire is going properly, the members of the burning squad should extinguish the back-fire on the downwind side. They should then immediately attend to the sides of the fire to limit its lateral spread and control the width of fire front. When using "beaters" to extinguish the fire, remember that you are trying to reduce the supply of oxygen to the flames, disrupt the continuity of fuel so fire spreads more slowly and with reduced intensity, and break up smouldering embers so that they cool more quickly. If using a water spray or stream of foam, this should be directed to the burning fuel at the base of the flames.

Unless flames of the fire front are less than 1 m (3.3 feet) long, the head of the fire will generally be too hot to approach or control directly. The width of the fire should not be allowed to exceed 50 m (165 feet). Under good conditions, the fire can be guided for several hundred yards before reaching the pre-planned firebreak that extinguishes the fire head.

Unless fires are to be burnt over a short distance into a reliable firebreak, it is good practice when burning on slopes to burn down and across the slope as it is then easier to maintain good control. As a general rule, do not burn uphill on steep slopes. Particular care must be taken when burning on steeper slopes, since it is more difficult to work safely, and the slopes can affect the direction and rate of spread of fires. It is potentially very dangerous to be on a slope immediately above a fire that could burn uphill.

Caution is needed where purple moor-grass grows abundantly. Burning scraps of straw and dead leaves from the grass can be lifted in the updraught from the fire and can start new fires. Keep careful watch for these while burning on this type of ground. Additional assistance in controlling fires in this type of vegetation will almost certainly be needed and you should ensure that sufficient staff and equipment will be available.

During burning, be continually alert for any changes in the weather. Be alert to possible changes in temperature, humidity and, particularly, wind speed and direction. A sudden lull in the wind can sometimes precede a change in its direction or strength. Constantly watch the movement of smoke above the fire. Remember that rough terrain can dramatically affect local wind direction and speed. Where weather conditions approach the higher risk limits then only burn in areas where control is easiest, and where risk to safety or damage is least if the fire does exceed its prescription limits. Switch to back-fires as conditions approach the higher limits of risk. You should stop burning if the wind shifts direction significantly. A 90° shift in wind direction can transform an easily controlled flank fire into a more intense, much less easily controlled head-fire. Other indicators of dangerous conditions developing are if the smoke becomes dark in colour and flame height changes dramatically, or if spot fires appear ahead of the main fire front.

Finally, ensure that all fires are extinguished before leaving the site.

Further information and training

Formal training.

- Borders College (Thorniedean House, Melrose Road, Galashiels TD1 2AF, Tel 01361 883 738, http://www.scet.org.uk/educ/online/borders.asp) which includes moorland management modules in its Gamekeeping and Rural Development residential course.
- Forestry & Arboriculture Safety Training Council (Room 323, 231 Corstorphine Road, Edinburgh EH12 7AT, Tel 0131 314 6193, http://www.treecare.co.uk/22fores.htm) for information about forestry vocational qualifications relating to the use and control of fire. These are also relevant to moorland fires.
- Lantra, The Rural Centre, West Mains, Ingliston, Midlothian EH28 8NZ (Tel 0131 472 4131, http://www.lantra.co.uk), the national training organisation for land based sectors.
- National Interagency Prescribed Fire Training Center (3250 Capital Circle SW, Tallahassee, Florida 32310, Tel 00 1 877 223 2198 / 00 1 850 521 2080; http://fire.r9.fws.gov/pftc). Intensive 24 day courses in prescribed fire use and control including 5 - 12 days of actual prescribed burning under variety of field conditions plus 3 - 4 days of classroom instruction.
- North Highland College (Ormlie Road, Thurso, Caithness K14 7EE, Tel 01847 896 161, http://www.uhi.ac.uk/thurso) which runs a residential Highland Gamekeeping course.
- Scottish Qualifications Authority (Helpdesk 0141 242 2214, Hanover House, 24 Douglas Street, Glasgow G2 7NQ and Ironmills Road, Dalkeith, Midlothian EH22 1LE, http://www.sqa.org.uk) for information on Scottish Vocational Qualifications.

Advice, and periodic demonstration days and short courses related to the use of fire.

- Farming & Wildlife Advisory Group, FWAG Scotland, Rural Centre, West Mains, Ingliston, Newbridge, Midlothian EH28 8NZ (Tel 0131 472 4080).
- The Game Conservancy Ltd Advisory Services, Couston, Newtyle, Perthshire PH12 8UT (Tel 01828 650 543).
- The Heather Trust, The Cross, Kippen, Stirlingshire FK8 3DS (Tel 01786 870 808).
- Scottish Agricultural College, SAC Central Office, West Mains Road, Edinburgh (Tel 0131 535 4000, http://www.sac.ac.uk).
- RSPB Scotland, Dunedin House, 25 Ravelston Terrace, Edinburgh EH4 3TP (Tel 0131 311 6500).

Rural Fire Protection Groups

Your local fire brigade is the best source for details about your local Rural Fire Protection Group. By late 2000, such groups had been established in North Grampian, South Grampian, Strathspey, Inverness, Lochaber, Skye and Lochalsh, Ross and Cromarty, Caithness and Sutherland, and the Western Isles. As well as being a source of mutual assistance such groups provide for exchange of information and experience and may also provide some training for members.

Publications

- *The Muirburn Code.* Scottish Executive Environment and Rural Affairs Department (2001). Available from SEERAD Publications, Pentland House, 47 Robb's Loan, Edinburgh EH14 1TY (Tel 0131 556 8400)
- *A Manual of Red Grouse and Moorland Management*. P.J. Hudson and D. Newborn (1995). Game Conservancy Trust. Available from Game Conservancy Trust, Fordingbridge, Hampshire SP6 1EF (Tel 01425 652 381).
- *Good Practice for Grouse Moor Management*. The Moorland Working Group. Copies available from Scottish Natural Heritage Publications, Battleby, Redgorton, Perth PE1 3EW (Tel 01738 627921)
- *The Lowland Heath Management Handbook*. C.H. Gimingham (1992). English Nature. Copies available from English Nature Publications, Northminster House, Peterborough PE1 1UA (Tel 01733 455 000).
- *Introduction to Wildland Fire*. S.J. Pyne, P.L. Andrews and R.D. Laven (1996). 2nd edition. John Wiley & Sons Inc., New York. Very comprehensively describes fire behaviour, the use of prescribed fire, fire planning, and fire control techniques in North America.
- *A Guide for Prescribed Fire in Southern Forests*. D.D. Wade and J.D. Lunsford (1989). Technical Publication R8-TP11, Forest Service Southern Region, United States Department of Agriculture. USDA Forest Service, Southern Region, 1720 Peachtree Road, NW Atlanta, Georgia 30367-9102. Although dealing with prescribed burning of the understorey vegetation in the pine forests of the south-east USA, this provides a very relevant and concise account of fire behaviour, and the practicalities of prescribed burning, in a short booklet well illustrated with colour photographs.
- *Australasian Fire Authorities Council Learning Manuals*. These excellent manuals cover a wide of range fire-related issues in a concise and clear way, well illustrated with colour diagrams. There are manuals on *Wildfire Behaviour* (manuals 1.12A, 2.28, 3.23), *Wildfire Suppression* (manuals 1.12B, 2.29, 3.18) and *Prescribed Fire* (manuals 3.17, 4.25). Tasmania TAFE, Learning Media Services, P.O. Box 949, Rosny Park, Tasmania 7018 (Tel 0061 3 62 33 7397). Details about these other manuals can be found at http://ausfire.com/index.htm.

- *Prescribed Burning Guidelines in the Northern Great Plains*. K.F. Higgins, A.D. Kruse and J.L. Piehl (1989). U.S. Fish and Wildlife Service, Cooperative Extension Service, South Dakota State University, U.S. Department of Agriculture EC760, Jamestown, North Dakota, USA. This document can be found and downloaded free at http://www.npwrc.usgs.gov/resources/tools/burning
- A six page illustrated guide to the safe use of a drip torch can be found at http://www.bouldermountainfire.org/training/drip.
- Forestry Commission publications on forest and moorland fire suppression. Available from Forestry Commission publications, P.O. Box 100, Fareham, Hampshire PO14 2SX (Tel 01329 331345)

The following *SNH Information and Advisory Notes* are relevant to aspects of muirburn and are available, free of charge, from Scottish Natural Heritage Publications, Battleby, Redgorton, Perth PE1 3EW (Tel 01738 627921)

- *Heather layering and its management implications*. No. 35. A.J. MacDonald.
- *Cutting heather as an alternative to muirburn*. No. 56. A.J. MacDonald.
- *Grazing behaviour of large herbivores in the uplands.* No. 47. H. Armstrong.
- *Heather moorland management for Lepidoptera*. No. 78. A.J. MacDonald and K. Haysom.

- The FireBeaters website (http://www.ed.ac.uk/~ebfr89/firebeat/home.htm) provides information about fire ecology in the UK. It has links to other relevant websites, providing access to a large amount of useful information on prescribed burning, wildfire control, techniques and tools, from other parts of the world.

Equipment

Consult farming, forestry and field sports equipment suppliers and suppliers of fire protection equipment. Check Yellow Pages and trade magazines. Links to fire protection and equipment companies are provided by Firenet at (http://www.fire.org.uk/others.htm). Drip torches may not be easily found in the UK but are quite readily available in North America. Small orders are likely to require prepayment by credit card or direct wire fund orders and will be despatched only by parcel post. Many of the American companies stock specialised spades, rakes, axes, and combination tools specifically designed for prescribed fire and wildfire situations.

A selection of internationally used prescribed fire terms

Aerial fuels	Standing or supported plant material not in contact with the ground.
Alignment	The degree to which influences on fire intensity, such as slope or wind, act to reinforce each other. When the factors are in alignment the fire intensity is maximum, but when they are completely out of alignment it is at a minimum.
Anchor point	A position from which a control line can be safely laid out which minimises the possibility of being outflanked by the fire while the line is being set.
Available fuel	The amount of fuel which will actually be consumed under particular weather conditions and fire behaviour. Usually much less than either potential fuel or total fuel.
Back-fire, or backing fire	Fire spreading against the wind direction.
Blacking out	See Mopping up.
Blackline	Firebreak created by burning to remove all fine fuel.
Blowup	A drastic increase in the rate of spread or intensity of the whole fire, to levels likely to be beyond control.
Breakaway	Where a fire escapes across a control line.
Buildup	Cumulative effects of long-term drying on fire risk.
Burning rotation	The period of time between one fire and the next within a particular burning unit.
Burning unit	A specific patch to be burnt.
Candling	See Torching
Canopy	The foliage and fine twigs of dwarf-shrubs (such as heather), shrubs or trees.
Contained	A wildfire is contained when its spread is under control and halted.
Control line	General term for firebreaks or other types of fire barrier used to control a fire.
Creeping fire	Slowly spreading fire with short flames
Crown fire	Fire burning through tree crowns
Crowning	When a fire spreads from tree canopy to tree canopy.
Direct attack	Fire fighting right at the edge of the fire front.
Drip torch	Hand-held canister with a long spout used to drip burning liquid fuel, at a variable controlled rate, onto the vegetation in order to start a fire.

Duff	The layer of dark brown or black partially decomposed plant material above the mineral soil, or peat, but below the loose plant litter, moss or lichen layer.
Fine fuels, or flash fuels	Fine material no more than a few millimetres in thickness (6 mm or less is frequently used internationally), which dries quickly and is usually sufficiently dry to burn within a day of rain (and possibly within as little as a couple of hours for some types of fine fuel).
Fire behaviour	The way a fire responds to the combined effects of weather, fuel and topography.
Fire front	The line or strip along which there is continuous flames.
Fire run	A rapid advance of a fire front as a result of a marked change in fire intensity and rate of spread.
Firebrand	Any pieces of flaming or smouldering fuel which could start another fire.
Firebreak	A natural or artificial break in the continuity of the fuel, used to stop or control the spread of a fire.
Fireline	See Control line
Fireline intensity	The rate of heat release per unit length of fire front per unit of time.
Flame depth	The distance between the front and back of the fire front.
Flame height	The vertical distance from the tip of the flame to the ground.
Flame length	The distance from the tip of the flame to the base of the flame (at the middle of the flame depth).
Flank attack	Controlling a fire by suppressing its sides.
Flank-fire, or flanking fire	A fire spreading at approximately right angles to the wind direction.
Flareup	A sudden but relatively short duration increase in the rate of fire spread or fire intensity.
Flash fire	A rapidly spreading fire which consumes most of the available fine fuel.
Fuel load	The oven-dry weight of fuel per unit area.
Fuel moisture content	Water content of potential fuel as a percentage of oven dry weight.
Ground fire	Fire burning in the soil, usually in peat or duff
Handline	A control line constructed using hand tools.
Hazard reduction	Treatments to reduce the likelihood of fire ignition and/or to reduce fire intensity to less damaging levels, and to increase controllability.

Head (of the) fire	The front edge of a fire where the intensity and rate of spread are greatest.
Head-fire, or heading fire	A fire which spreads in the same direction as the wind.
Indirect attack	Using prepared firebreaks or other forms of control line, often constructed by back burning, to contain the fire within a designated area rather than directly attacking the fire front.
Knock down	Rapid suppression of a fire by concentrated application of water or foam in order to reduce fire intensity prior to manual attack.
Mopping up, or mopup	The final phase of a prescribed fire to ensure that the fire is completely extinguished or is in a state in which it will definitely self-extinguish within the prescribed boundaries within a set time.
Parallel attack	Containment of a fire by creating a control line parallel to the edge of the fire, far enough from the fire to permit safe and effective work by control squads. Usually includes removal of fuel in front of the head of the fire by back-burning from the control line.
Plant litter	The cast leaves, shoots, and fragments of bark, flowers, seed capsules and other dead or dying plant material which falls to the ground.
Potential fuel	The material which might burn in the most intense fire likely on a site. Usually less than total fuel.
Prescribed fire	A planned and controlled fire set under specified conditions to achieve specified land management objectives.
Residence time	The time during which flaming combustion is occurring above a fixed point at the surface of the fuel (or ground). The time taken for the fire front to pass.
Running fire	Rapidly spreading fire, usually out of control
Smouldering	Burning without flames and spreading very slowly.
Spot fires	Isolated fires started by firebrands dispersed from a parent fire.
Spotting	When a main fire produces sparks and embers (firebrands) which are carried up in the convection plume of hot air, dispersed by the wind, and start spot fires elsewhere.
Surface fire	Fires in grass, heather, shrubs, plant litter.

Torching	When a fire spreads from a surface fire into the crown of an individual tree.
Total fuel	The total live and dead plant material above the mineral soil, including any peat or duff layer above the mineral soil. May include material which will rarely, if ever, burn except under the most extreme circumstances.
Wetline	A temporary control line formed by soaking a line of vegetation with water, foam or solution of chemical retardant, for starting or stopping a low intensity fire.
Wetting agent	A chemical added to water to reduce its surface tension and improve penetration into fuel.
Wildfire	An uncontrolled fire burning outside the limits of prescription, or a fire which has escaped control.

Alternative names of plants mentioned in this booklet

	Other common English names	*Botanical species*
Aspen		*Populus tremula*
Bell heather		*Erica cinerea*
Birch		*Betula pendula* *Betula pubescens*
Bog moss		*Sphagnum* species
Bracken		*Pteridium aquilinum*
Cottongrass	Cotton-sedge	*Eriophorum angustifolium* *Eriophorum vaginatum*
Deergrass	Deer-sedge	*Trichophorum cespitosum*
Dwarf birch		*Betula nana*
Gorse	Whin	*Ulex europaeus*
Heather	Common heather Ling	*Calluna vulgaris*
Juniper		*Juniperus communis*
Mat grass	White bent White-grass	*Nardus stricta*
Oak		*Quercus petraea* *Quercus robur*
Scots pine		*Pinus sylvestris*
Purple moor-grass	Flying bent Blow-grass White-grass	*Molinia caerulea*
Willow		*Salix* species