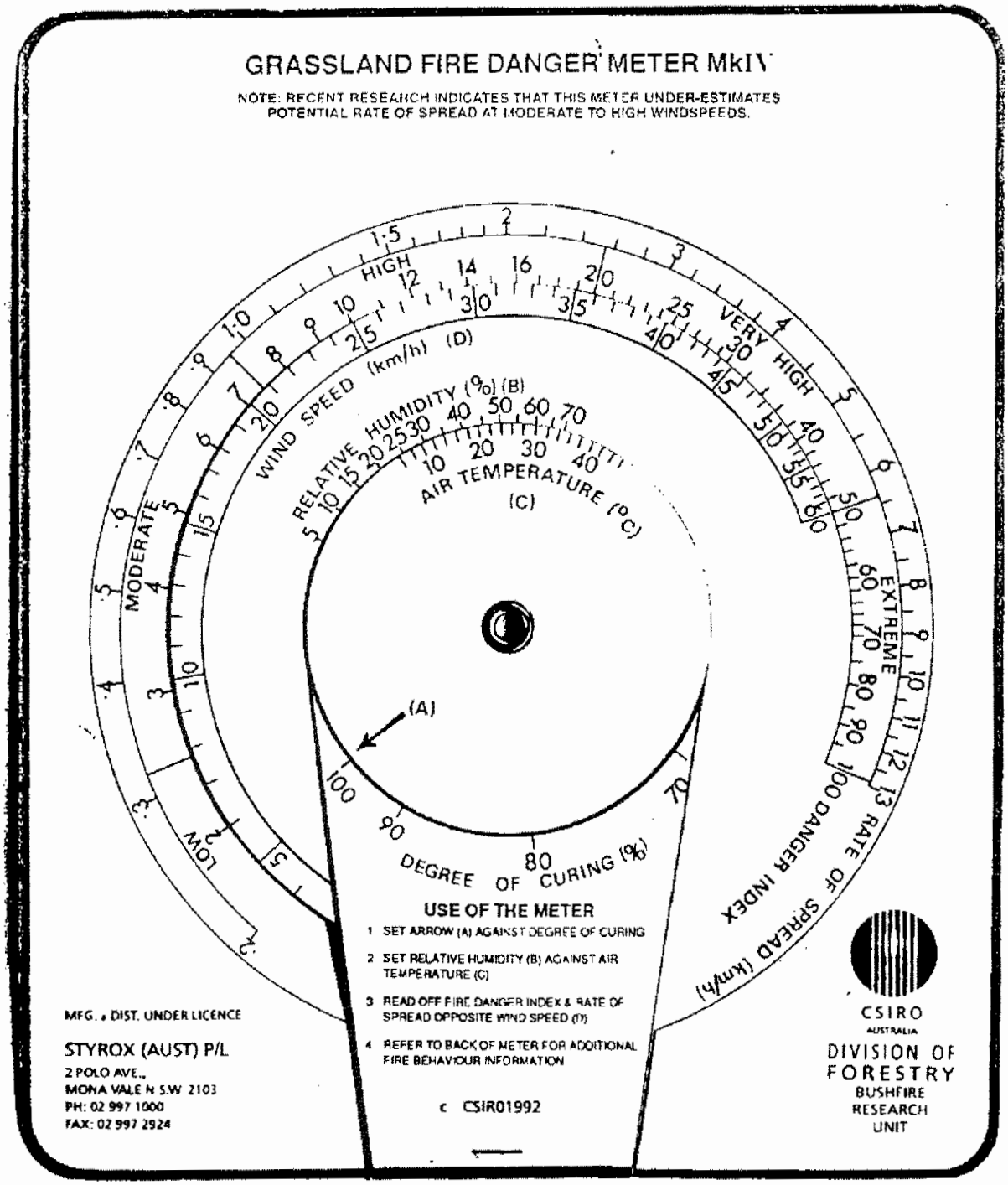

GRASSLAND FIRE DANGER METER MkIV
NOTE: RECENT RESEARCH INDICATES THAT THIS METER UNDER-ESTIMATES POTENTIAL RATE OF SPREAD AT MODERATE TO HIGH WINDSPEEDS.
WIND SPEED (km/h) (D)
RELATIVE HUMIDITY (%) (B)
AIR TEMPERATURE (°C) (C)
(A)
DEGREE OF CURING (%)
LOW
MODERATE
HIGH
VERY HIGH
EXTREME
FIRE DANGER INDEX
RATE OF SPREAD (km/h)
USE OF THE METER
1 SET ARROW (A) AGAINST DEGREE OF CURING
2 SET RELATIVE HUMIDITY (B) AGAINST AIR TEMPERATURE (C)
3 READ OFF FIRE DANGER INDEX & RATE OF SPREAD OPPOSITE WIND SPEED (D)
4 REFER TO BACK OF METER FOR ADDITIONAL FIRE BEHAVIOUR INFORMATION
© CSIR01992
MFG. & DIST. UNDER LICENCE
STYROX (AUST) P/L
2 POLO AVE.,
MONA VALE N.S.W. 2103
PH: 02 997 1000
FAX: 02 997 2924
CSIRO
AUSTRALIA
DIVISION OF FORESTRY
BUSHFIRE RESEARCH UNIT

Box 2. Grassland Fire Danger Meter Mk IV — A.G. McArthur (1973)

Fire behaviour characteristics

The Grassland Fire Danger Index calculated from the measurement of air temperature, relative humidity and wind speed and varied according to the amount of greenness in the pasture, provides a figure directly related to the chance of fire starting, its rate of spread, difficulty of control and the amount of damage it will do.

At an index of 1 or 2 fires will not burn, or burn so slowly that control presents little difficulty. At an index of 100 they will burn so hot and fast that control is virtually impossible.

The intensity of a fire and its difficulty of control is also affected by the quantity of grass in the pasture. Heavy pastures burn with a greater intensity than light pastures and with higher flames.

The rates of spread shown on the outside edge of the meter are average values for fires in annual and perennial pastures carrying a continuous body of fuel and occurring on level to undulating ground. Spread rates will be less than indicated in sparse, discontinuous pastures and will also vary accordingly to topography.

Various fire behaviour characteristics are shown on the following Table:

Fire Danger Index	Rate of spread (km/h)	Difficulty of suppression	Maximum area at various times from start (hectares)*				Average final size of fire (hectares)	Flame height (m) in		
			½	1	2	4		Sparse pasture	Average pasture	Heavy pasture
2	0.3	Low. Head fire stopped by roads and tracks	3	20	80	320	3	0.3	1.0	3.0
5	0.6	Moderate. Head attack easy with water	6	40	160	640	16	0.6	2.0	3.5
10	1.3	High. Head attack generally successful with water	15	90	360	1440	65	1.0	3.0	5.5
20	2.6	Very High. Head attack will generally succeed at this index.	35	210	840	3360	450	2.0	3.5	7.0
40	5.2	Very High. Head attack may fail except in favourable circumstances and close back burning to the head may be necessary	80	480	2000	8000	2400	2.5	5.0	9.0
50	6.4	Extreme. Direct attack will generally fail. Back burn from a good secure line with adequate manpower and equipment, Flanks must be held at all costs.	105	630	2500	10000	4000		5.5	10.0
70	9.0		170	1000	4000	16000	10000		6.0	11.0
100	12.8		300	1800	7000	28000	32000		7.0	13.0
Note: *This assumes that the head fire burns unchecked. Suppression action which is only partially successful will reduce these areas.										

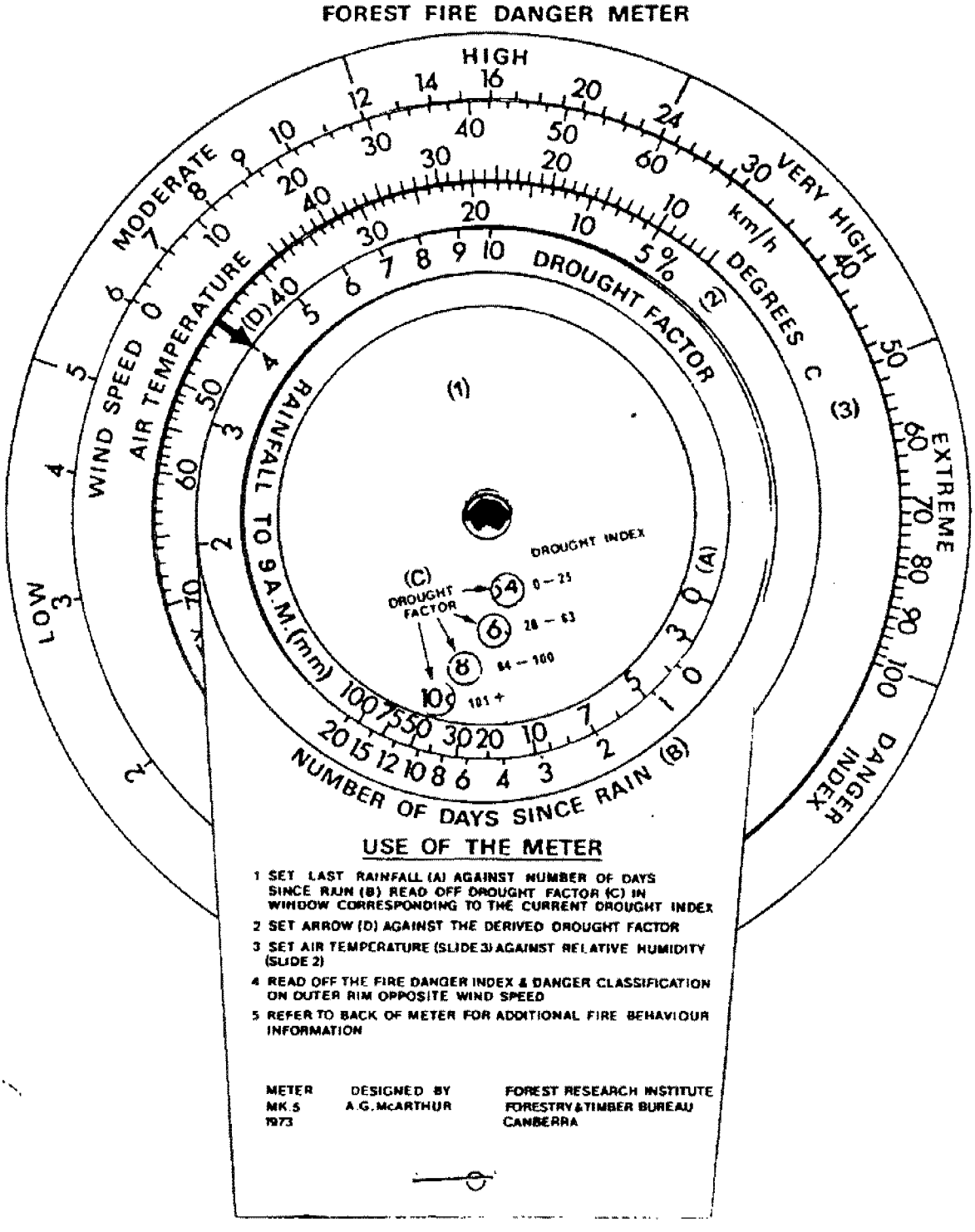
The effect of slope: The rates of spread given by the meter apply to level or gently undulating ground. Over short distances the effect of slope is very pronounced. The rate of forward spread will double up a 10 degree slope and will be four times greater up a 20 degree slope. The rate of spread will be correspondingly reduced on a downslope, except that massive fire whirlwinds are likely to develop under severe burning conditions.

The effect of wind: The wind speed used by the meter is the average wind speed in the open measured at a height of 10 m. The meter can be used to predict fire behaviour in open forests or woodlands with a grassy fuel type but rates of spread will be less than indicated because the trees reduce the wind speed above the fuels.

Perimeter increase: For all practical purposes, the perimeter of a grass fire can be taken as 2.5 times the forward spread, ie if the forward spread is 10 km/h, the perimeter spread will be 25 km/h.

Area increase: The area of a fire increases as the square of the burning time ie the area of 4 hours from start will be 16 times the area of 1 hours. This indicates the need for very fast initial attack and quick control.

Warning signs: Abundant, fully cured grasslands occurring after a rainfall deficient period of 4-6 weeks; increasing temperatures, falling humidities and rising winds immediately preceding a cool change. Always remember wind changes associated with a cool change. On an extreme day, it pays to have all forces available for instant action.


FOREST FIRE DANGER METER
HIGH
VERY HIGH
EXTREME
MODERATE
LOW
WIND SPEED
AIR TEMPERATURE
DROUGHT FACTOR
RAINFALL TO 9 A.M.(mm)
km/h
DEGREES C
5%
(1)
(2)
(3)
(A)
(B)
(C)
(D)
DROUGHT INDEX
DROUGHT FACTOR
0 – 25
26 – 63
64 – 100
101 +
NUMBER OF DAYS SINCE RAIN
DANGER INDEX
USE OF THE METER
1 SET LAST RAINFALL (A) AGAINST NUMBER OF DAYS SINCE RAIN (B) READ OFF DROUGHT FACTOR (C) IN WINDOW CORRESPONDING TO THE CURRENT DROUGHT INDEX
2 SET ARROW (D) AGAINST THE DERIVED DROUGHT FACTOR
3 SET AIR TEMPERATURE (SLIDE 3) AGAINST RELATIVE HUMIDITY (SLIDE 2)
4 READ OFF THE FIRE DANGER INDEX & DANGER CLASSIFICATION ON OUTER RIM OPPOSITE WIND SPEED
5 REFER TO BACK OF METER FOR ADDITIONAL FIRE BEHAVIOUR INFORMATION
METER MK.5 1973
DESIGNED BY A.G.McARTHUR
FOREST RESEARCH INSTITUTE FORESTRY & TIMBER BUREAU CANBERRA

Box 3. Forest Fire Danger Meter

Fire behaviour relationships

The fire danger index given by this meter is directly related to the chances of a fire starting, its rate of spread, intensity and difficulty of suppression according to various combinations of temperature, relative humidity, wind speed and both long and short term drought effects. Damage potential, expressed in terms of area burnt, is a power function of the index.

An index of one (1) means that fires will not burn, or burn so slowly that control presents little difficulty. An index of one hundred (100) means that fires will burn so fast and hot that control is virtually impossible.

The meter is designed for general fire danger forecasting purposes and is based on the expected behaviour of fires burning for an extended period in high eucalypt forest carrying a fuel quantity of 12.5 tonnes per hectare and travelling over level to undulating topography.

The behaviour of individual fires can be predicted with reasonable accuracy providing the effect of fuel quantity and slope is taken into account. The variation of some fire behaviour characteristics with fuel quantity is shown below.

The rate of perimeter spread is generally three times the rate of forward progress but may increase to a factor of four on a large irregular fire.

Fires travel upslope with the prevailing wind faster than on level ground. A five degree slope increases spread by 33 per cent; a ten degree slope by a factor of two and a twenty degree slope by a factor of four. Corresponding reductions occur on downslopes.

Fires in low quality eucalypt forest tend to spread at faster rates than those shown, due to greater wind movement near the ground. However, the spotting potential is generally lower.

The meter can be used to determine broad control burning conditions, although a high degree of precision should not be expected. Burning at an index greater than twelve (12) would be very risky expect in very light fuel types.

The rate of forward spread refers to a moving flame front which is only affected by relatively short distance spotting. When long distance spotting occurs, the rate of spread may be greater than indicated. The spotting distances given in the table below are for fuel types containing a high proportion of fibrous- barked eucalypts, Gum-type eucalypts will only throw long distance spot fires after a crown fire develops.

Atmospheric instability is not included as a factor affecting fire behaviour. However the rates of spread indicated are for generally unstable conditions and may be less under conditions of stability.

Fuel quantity(t/ha)	Fire behaviour	Fire danger index												
		5	10	15	20	25	30	40	50	60	70	80	90	100
5	R(km/h)	0.03	0.06	0.09	0.12	0.14	0.17	0.23	0.28	0.34	0.39	0.45	0.50	0.56
	H (m)	0.3	0.6	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	S (km)	-	-	-	0.1	0.2	0.3	0.6	0.8	1.0	1.2	1.4	1.7	1.9
10	R(km/h)	0.06	0.12	0.18	0.23	0.29	0.34	0.45	0.56	0.67	0.78	0.89	1.00	1.11
	H (m)	1.0	2.0	3.0	4.0	5.0	5.5	7.0	8.5	10.0	11.0	12.0	13.0	14.0
	S (km)	-	-	0.2	0.4	0.6	0.8	12	1.7	2.1	2.5	3.0	3.4	3.8
15	R(km/h)	0.09	0.18	0.26	0.35	0.43	0.51	0.68	0.85	1.02	1.18	1.35	1.42	1.68
	H (m)	2.0	3.5	5.0	7.0	8.0	9.5	12.0	14.0	----------Crown fire----------				
	S (km	-	0.2	0.6	0.9	1.2	1.5	2.2	2.8	3.4	4.1	4.8	5.4	6.0
20	R(km/h)	0.12	0.24	0.36	0.48	0.60	0.72	0.96	1.20	1.44	1.68	1.82	2.16	2.39
	H (m)	2.5	5.0	7.0	9.0	11.0	13.0	----------Crown fire----------						
	S (km	0.1	0.5	0.9	1.3	1.7	2.2	3.0	3.8	4.7	5.6	6.4	7.2	8.1
25	R(km/h)	0.14	0.30	0.45	0.60	0.75	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00
	H (m)	3.0	7.0	10.0	12.0	14.0	----------Crown fire----------							
	S (km	0.1	0.6	1.1	1.6	2.1	2.6	3.6	4.6	5.6	6.6	7.6	8.6	9.6

R = rate of forward spread in kilometres per hour. H = flame height in metres. S = average spotting distance in kilometres. Fuel Quantity is expressed in tonnes per hectare of combustible material less than 6 millimetres in diameter.

The measurement of meteorological elements

1. **Temperature**: The screen temperature at the time the fire danger is determined
2. **Relative humidity and dew point**: The calculated values corresponding to the screen temperature
3. **Wind speed**: The average wind speed estimated or recorded over a period of at least five minutes in an open flat locality The measurement should be made at a height of 10 m above ground level or above tree top level in restricted forest openings.
4. **Rainfall**: The amount of rain measured at 9 am from a standard rain gauge. The afternoon of a day on which rain is recorded at 9 am is taken as being one day after rain. If rain falls after 9 am use the zero setting.
5. **Drought index**: This is used as a measure of seasonal severity and fuel availability. It is derived from daily records of maximum temperature and rainfall.
6. **Drought factor**: This is a broad measure of fuel availability as determined by seasonal severity and recent rain effects. Where the effect of one rain period is superimposed on another, use the lowest drought factor.

English Nature's policy on fire in the uplands: A discussion paper

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1. The principles of moorland burning

1.1 Introduction

Burning has long been used as a tool for the management of vegetation in Britain, principally for stimulating new growth of grasses or heather. The purpose of this report is to present an appraisal of burning in the uplands. It is written from the perspective of uplands in England but draws on experiences from Scotland and elsewhere. As such the conclusions should be relevant to the UK as a whole.

Careful, periodic burning of upland vegetation can have advantages for agriculture, game rearing, wildlife conservation and intrinsic landscape appeal. However, inappropriate and careless fires in the uplands can be more damaging than a complete lack of burning management. Nature conservation in the uplands of England is best served by achieving a range of burning management regimes, from more intensive, to less intensive and no burning at all. This desirable range of regimes applies across an individual site as well as across the country. It will create a mosaic of habitat types with vegetation of different ages, composition and structure. These in turn will support a diversity of animal and plant species.

The most commonly burnt upland vegetation type is dwarf-shrub heath, although some burning of blanket bog, enclosed and unenclosed grassland, bracken and shrubs is also undertaken. Burning can alter the vegetation composition, pattern, physical and age structure, nutrient status and carrying capacity for herbivores, as well as the associated fauna. A summary of the advantages and disadvantages of burning for different land uses is given in Table 1.

1. 2 Burning versus layering of heather

Heather moorland is the most commonly burnt habitat in the uplands and is particularly associated with grouse moors, where it provides the conditions required to support a significant population of red grouse. Heather regenerates after burning by re-sprouting from the bases of the stems (if these survive and are not too old and woody), or by the exposure and germination of seeds which have lain dormant in the upper few centimetres of the soil. In both cases the new shoots produced grow more vigorously than on the bushes prior to burning, ie. the plants are rejuvenated. Re-sprouting heather plants can grow much more quickly than heather seedlings. But re-sprouting from dormant buds on the stem bases declines as bushes become larger and more woody. So when older stands are burnt germination of seed becomes the principle means of regeneration.

Table 1 Advantages and disadvantages of burning moorland habitats for various land uses

This is a generalised summary of potential impacts, and actual affects will vary according to the characteristics of the area being considered. Further details, particularly of species-specific reactions, should be sought in the appropriate references (Gimingham 1972; Miles 1987; Rowell 1988; Mowforth & Sydes 1989; RSPB 1995; Thompson *et al* 1995; Shaw *et al* 1996).

Land use	Habitat	Potential advantages of well-conducted burning management (Note: These will be influenced by other management practices, such as grazing)	Potential disadvantages of well-conducted burning management (Note: Further disadvantages will result if burning management is not well-conducted)
Nature conservation	Dwarf-shrub heath & blanket bog	Direct benefits: • Stimulates young heather growth and seedling regeneration, which is beneficial where the heath is in danger of being lost. • Encourages certain important animal and plant species, eg. red grouse, golden plover, bog rosemary and cloudberry. • Creates a mosaic of stands of different ages, so enhancing the structural variation of the vegetation and the diversity of invertebrates. • Creates bare ground which is required by some invertebrates. • Prevents the establishment of trees and shrubs, which is desirable is some situations, eg. where birch is encroaching into south-western heaths. • May rejuvenate heather so that it out competes bracken, although this is likely to be dependent on various factors, eg. grazing pressure and soil depth.	• Progressively reduces floristic diversity. • Encourages the predominance of dwarf-shrub vegetation in dry heaths, particularly heather, to the exclusion of other species. • Encourages the predominance of hare's-tail cotton grass on some blanket bogs. • Encourages purple moor-grass on blanket bog and wet heath where it occurs, to the exclusion of other species. • Changes vegetation communities, potentially from ones of wildlife interest to those of less interest (particularly in combination with other management practices such as heavy grazing or drainage), eg. blanket mire to wet heath, wet or dry heath to grassland. • Impoverishes the bryophyte, lichen and fern flora. • Reduces the likelihood of layering by dwarf-shrubs. • Destroys and can discourage certain animal and plant species, such as less mobile animals (eg. molluscs), some insects (eg. springtails and mites) and plants which cannot tolerate fire (eg. lesser twayblade, some mosses).
		Indirect benefits: • Increases the tolerance of dwarf-shrubs to grazing. • Patch burning helps to spread the grazing pressure across an area. • Reduces the risk of uncontrolled fires, which can destroy large areas of wildlife habitat.	• Prevents the establishment of native trees and shrubs, which are often desirable because they diversify the habitat and enhance the biodiversity. • Leads to erosion and loss of habitat when burns do not regenerate well, especially if the peat itself catches fire. • Removes habitats, damages populations and creates even-aged stands when large areas are burnt instead of a mosaic of small patch burns. • Encourages the spread of bracken in some circumstances.
	Purple moor-grass dominated areas	• Reduces the dominance of purple moor-grass, when conducted in combination with the appropriate grazing regime. • Reduces the risk of uncontrolled fires, which can destroy large areas of wildlife habitat. (See also paper in this report by Rob Wolton.)	• Encourages purple moor-grass to the exclusion of other species, if not conducted in combination with the appropriate grazing regime. • Removes habitats, damages populations and creates even-aged stands when large areas are burnt instead of a mosaic of small patch burns. • Leads to erosion and loss of habitat when burns do not regenerate well, especially if the peat itself catches fire.
Grouse moors	Dwarf-shrub heath & blanket bog	• Encourages the growth of young heather, which increases the carrying capacity for red grouse. • Improves the nutritional quality of heather and other moorland plants, which become increasing indigestible with age. • Leads to the predominance of dwarf-shrub vegetation (where grazing levels are appropriate). • Creates a mosaic of stands of different ages, which is required by nesting and feeding grouse. • Prevents the establishment of trees and shrubs.	• Leads to erosion and reduced carrying capacity for grouse when burns do not regenerate well, especially if the peat itself catches fire. • Prevents the establishment of trees and shrubs, which are important for black grouse.
Agriculture	Dwarf-shrub heath & blanket bog	• Encourages the growth of young heather, which increases the carrying capacity of the area for stock. • Improves the nutritional quality of heather and other moorland plants, which become increasing indigestible with age. • Enables and encourages stock to move around the land, thereby spreading the grazing pressure.	• Leads to erosion and reduced carrying capacity for stock when burns do not regenerate well, especially if the peat itself catches fire. • Encourages the predominance of purple moor-grass and hare's-tail cotton grass, where these occur, which can reduce the stocking capacity when they replace heather.
	Purple moor-grass dominated areas	• Promotes the growth of young grass in spring and summer for stock grazing. • Prevents the accumulation of dead leaves and surface litter. See also paper in this document by Rob Wolton.	• Encourages the spread of purple moor-grass to the exclusion of all other species.
	Gorse	• Helps stock to move around the land and encourages an initial flush of grass growth.	• Regenerates and encourages the spread of gorse.
Other	Any habitat	• Reduces the likelihood of undesirable, uncontrolled fires by: a) reducing the amount of material available to burn; b) creating fire breaks.	• Destroys large areas of valuable wildlife habitat, threaten public safety and property, ties up the emergencies services, cause erosion and scars the landscape when not adequately controlled. • Burns into the peat itself when not undertaken responsibly, leading to drying, oxidation, bare areas and erosion, which adversely affect all land uses, as well as water quality, flow rates and water courses.

It is a common misconception that the main purpose of heather burning is to regenerate the heather (SNH 1996). The implication is that the heather will disappear if it is not burnt, but this is only the case in old, even-aged heather stands which are heavily grazed, or where regular burning has reduced the capacity of stands to maintain themselves vegetatively.

Heather is able to regenerate vegetatively under the right conditions. On wet ground heather stems buried by the growth of *Sphagnum* and other mosses produce adventitious roots and these continue the growth of the heather stems. This process, known as layering, promotes regeneration without the necessity to burn. Layering tends to be associated more with deep peat and more sheltered conditions (MacDonald *et al.* 1995). Like burning or cutting, it rejuvenates heather plants and stands in which vigorous layering is maintained will not become degenerate. High levels of productivity can be maintained for many decades and it can lead to a diverse age structure and mixture of species.

Hence heather cover can be maintained by layering for many decades in the uplands, without burning, even in drier eastern areas. However, regular burning (or cutting) is likely to reduce the capacity of stands to maintain themselves by layering should burning (or cutting) cease. In the absence of burning such stands may undergo successive degenerate phases while conditions conducive to layering slowly become established. In the absence of succession to woodland, heather cover is likely to stabilise eventually, with the formation of an uneven-aged and unevenly structured stand.

1.3 To burn or not to burn?

Whether burning is or is not appropriate for a piece of land will depend on the objectives for that particular area. These objectives may be for nature conservation, game, agriculture or landscape. Achieving these objectives may or may not require burning. The advantages and disadvantages of burning various habitats for different land uses are shown in Table 1.

If it is decided that burning is necessary to achieve the desired objectives, the actual effects of burning on any particular area will depend on the following:

- the vegetation composition and condition, including the proportions of different communities, species distributions, age and structure;
- the previous management history, particularly whether the site has been burnt, drained or grazed;
- the current management regime, particularly the grazing intensity and whether shepherding is carried out;
- the method of burning, including frequency, the intensity of the fire, patch sizes and pattern, and the time of year;
- the nature of the substrate, such as mineral soil or peat, its depth, water content and organic content;

- the local physical conditions, such as climate, altitude, aspect, exposure and topography.

The decision to undertake burning should also consider the following points:

- the availability of appropriate labour, equipment and expertise to burn, because without these burning may be uncontrolled and damaging;

- the likelihood of a planned, appropriate burning programme being continued into the future, because sporadic burning may be worse than none at all.

In many instances, burning may not be necessary for any other reason than to prevent uncontrolled fires. These can lead to the loss of valuable wildlife habitats, threaten public safety and property, tie up the emergency services, cause erosion and scar the landscape for long periods of time. Large stands of woody heather or extensive areas of dense grass litter may develop in the absence of burning, and these can pose a significant fire hazard. In these situations, burning may be appropriate to reduce the fuel available to burn, to create fire breaks and generally reduce the likelihood of uncontrolled fires

Recommendations concerning burning of dry heath, wet heath, blanket bog and grassland for nature conservation purposes are given in the following sections.

2. Burning dry heath for nature conservation

2.1 Introduction

The optimum burning regime for heather moorland will depend on the primary aim of management: grouse, agricultural purposes or wildlife. A patchwork of small, regular burns are favoured by grouse moor managers, farmers tend to utilise larger, less regular burns and areas managed purely for wildlife may involve a variety of burning regimes, including no burning at all.

When considering whether to burn dwarf-shrub heath, is should be remembered that burning can lead to a progressive reduction in floristic diversity (Gimingham 1995). Heather dominance as a result of burning may be at the expense of other species of dwarf shrubs, bryophytes and lichens. For example, in the east of Britain moorland which has been burned repeatedly is characteristically dominated by heather, to the almost total exclusion of other species. A reduction in the diversity of invertebrates and other species of interest such as birds and reptiles may then follow. Therefore, good management to maintain heather and red grouse will not inevitably lead to conservation of the full range of moorland species (Mowforth & Sydes 1989). A variety of burning management regimes, from intensive burning management to a total absence of burning, will best serve the needs of nature conservation.

In the absence of burning, heather-dominated areas may be colonised by shrubs and trees. These can regenerate in gaps in heather stands which are formed when plants age and begin to die back, opening up the bushes from the centre. Where the main objective is to maintain the dwarf-shrub heath, control of scrub invasion by burning may be appropriate. However, where the heath is sufficiently large for some loss of habitat to be acceptable, it is desirable to establish scattered mosaics of native scrub and woodland, for

example of hawthorn, rowan and birch. This is because the diversity of the moorland habitat is increased and this benefits many associated animals.

2.2 Timing

Where burning is desirable for the objectives of the area, it will generally allow sufficient time for heather to regain dominance but prevent it from accumulating too much woody material. Heather is best burnt when it has reached the end of its building stage or the early mature phase. The time taken to reach this stage will depend on the climatic and edaphic conditions prevailing locally, but usual rotations are around 10-15 years (Coulson *et al.* 1992). A practical way to adjust the burning regime to take account of local productivity is to burn when the heather is 20-30 cm tall.

The older the heather stand at the time of burning, the longer the time taken for regeneration. This is because there is a change from the *Calluna* regenerating vegetatively to regenerating by seedling growth (Coulson *et al.* 1992). Stands of older heather take at least 5 years to regain 50 % cover, while young heather regains 50 % within about 3 years.

2.3 Temperature

The temperature of the burn is very important if regeneration of heather is to be successful. A good burn clears away all the above-ground parts of the plants but leaves the stem bases from which, beneath the soil surface, new shoots are produced which can draw on the fully developed root system. (A second means of regeneration is from the germination of seed and establishment of seedlings.) Higher temperatures increase the loss of nutrients in smoke and reduce vegetative and seedling regeneration. The risk of burning into the litter and peat layers below is also increased. The actual temperature produced is determined by a number of factors including:

- wind speed
- rate of passage
- the amount of moisture in the vegetation.

Old heather consists of a greater proportion of woody stems and may burn hotter and for longer than younger heather (Mowforth & Sydes 1989). However, some of the highest temperatures and longest durations of high temperatures have been found in building and mature heather stands (Hobbs & Gimingham 1984). The structure and especially the height of these stands is an the important factor. Low intensity fires should also be avoided because they leave large amounts of debris on the surface which retards regeneration (Whittaker & Gimingham 1962).

Particularly severe burns can alter the physical structure, the chemical composition and even the hydrology of the soil, which influences the resulting vegetation and the appearance and character of the landscape.

2.4 Frequency

Burning can lead to heather dominance, but this will depend on the frequency of burning. For example, *Erica cinerea*, *Vaccinium myrtillus* and *V. vitis-idaea* may be temporarily abundant or dominant after fire, but they can be gradually suppressed by the regrowth of heather (Gimingham 1972). Where frequent burning suppresses heather regrowth these species can attain lasting dominance. Where burning is relaxed, the heather stands can become degenerate and less suitable for grouse and sheep grazing. They may also be open to invasion by grasses or bracken or, if seed parents are present, shrubs and trees (although this may be desirable for the nature conservation objectives of an area of heath).

Burning *Calluna*-dominated stands on mineral soils at about 3-6 year intervals shifts the dominance to grasses, especially *Deschampsia flexuosa* on well drained soils and *Molinia caerulea* on poorly drained soils (Miles 1988).

If not carried out appropriately, burning dwarf-shrub heaths can be counter productive for grouse moors, agriculture and nature conservation alike, destroying plant communities and their associated invertebrate and bird populations. Financial help to develop burning programmes, utilise existing expertise and acquire the necessary labour may be important in establishing appropriate burning management of moorland areas.

Recommendations concerning burning of dry heath are contained in boxes 1-5.

Box 1 Legal requirements for moorland burning

Legal requirements for burning

Burning of heather, grass, gorse, bracken and bilberry is governed in England and Wales by The Heather and Grass etc. (Burning) Regulations 1986 (SI 1986 No. 428), as amended by The Heather and Grass etc. (Burning) (Amendment) Regulations 1987 (SI 1987 No. 1208).

See the MAFF leaflet *The heather and grass burning code* and the SNH leaflet *A Muirburn Code*.

By law, burning is only allowed:

- 1 October - 15 April in the uplands (ie. Severely Disadvantaged Less Favoured Areas).
- 1 November - 31 March in the lowlands.
- At other times under a licence which can be obtained only in very specific circumstances. Licence applications must be made to the local office of the Ministry of Agriculture, Fisheries and Food (MAFF) 28 days in advance.

Those undertaking burning must:

- Give not less than 1 day nor more than 7 days written notice of intent to burn to neighbours and owners and occupiers of the land, with details of dates, time, place and extent of the burn.
- Ensure that sufficient people and equipment are on hand to control the burn.
- Take all reasonable precautions to prevent injury or damage to people and animals.
- Follow special arrangements and plan well in advance if burning on a Site of Special Scientific Interest (SSSI). Where appropriate burn according to a burning plan agreed and consented by English Nature.

Those undertaking burning must NOT:

- Start burning between sunset and sunrise.
- Cause a nuisance through the creation of smoke.
- Create dark smoke.
- Start a fire which is likely to injure, interrupt or endanger road users.
- Damage scheduled ancient monuments.

Box 2 General recommendations concerning burning of dry heath

- Follow the legal requirements contained in Box 1.
- Plan a programme of burning for the area concerned.
- Identify areas where burning would be harmful (see Box 3), mark them on a map and exclude these from the burning programme. These may cover say 10 % of the moor, or 33 % where the vegetation is in favourable condition (see Jerram & Drewitt 1998).
- Identify areas where burning is not necessary, because natural regeneration is taking place, and exclude them from the burning programme.
- Identify areas where burning is desirable to promote diversity and mark them in a map for inclusion in the burning programme.
- Where burning is appropriate, it should be continued on a regular yearly basis, because this keeps stock moving around the moor and prevents recently burnt areas suffering excessive grazing.
- Use a variety of burning cycles and patch sizes across an area, to improve habitat complexity.
- Burn some heathland areas and margins less intensively to encourage habitat diversity, particularly abutting onto other habitats.
- Consider cutting some areas instead of burning them.
- Ensure herbivore levels are appropriate to retain heather, and preferably stock should be shepherded to spread grazing evenly across the hill.
- Follow the recommendations in the following boxes, including the safe burning guidelines in Box 5.

Box 3 Areas to be avoided when burning dry heath

To benefit wildlife, do not burn in the following situations:

Vegetation types:

- Dwarf-shrub stands which have not been burnt for long periods (more than 40 years), where known, and which have well developed layering.
- Flushes and valley mires, because these important habitats can be damaged.
- Grass-heath mosaics, because the grassland may spread at the expense of the heathland.
- Areas of bracken, and dwarf-shrubs into areas of bracken, unless bracken is invading mature dry heath and bracken control will be undertaken. Leave or cut a strip of 5 m (6 yards) from the bracken edge, or burn narrow strips (30 m, 35 yards wide) at right angles to the bracken edge.
- Areas where the grazing pressure exceeds 1.5 ewes per hectare (or equivalents for other animals), because the regrowth is likely to be eaten out by stock.
- Areas where stock tend to congregate, as again the regrowth is likely to be eaten out.
- Large blocks of vegetation, because burning in smaller patches benefits all land uses.

Physical conditions:

- Wet, shaded or humid situations (eg. steep northerly slopes, bogs) where layering is likely and species sensitive to burning are likely to be found.
- Steep, rocky or scree slopes, rocky outcrops, gills and cloughs, because of the risk of erosion and the wildlife value of these habitats.
- Exposed summits, ridges, areas above the natural tree line (about 600 m or 2000 ft), and where heather is already prostrate through natural causes, because vegetation cover here is often patchy and growth very slow.

For birds:

- Wet flushes and small areas of cotton-grass, because these are important sources of invertebrate food for birds.
- Known merlin and hen harrier nesting sites, but leave some areas of long heather for breeding birds.

For woodland and scrub:

- Some heathland margins, particularly adjacent to native shrubs and trees such as hawthorn, rowan and birch, so that mature dwarf-shrub and scrubby vegetation can develop and diversify the habitat.
- Next to forests, woodlands, scrub and hedges, because of the danger to these features.
- Areas of juniper scrub, because of its wildlife value and slow regeneration.

SSSIs:

- On or near Sites of Special Scientific Interest (SSSI) without the consent of English Nature.

Archaeological interests:

- On or near archaeological features, without the advice of English Heritage or the County Archaeologist, because they are likely to be damaged.

Box 4 Length of burning rotation for dry heath

- Take account of local productivity; grouse moor managers burn when the heather is 20-30 cm (8-12 inches) tall, but for nature conservation objectives heather may be allowed to grow taller before burning.
- Burning rotations can be from 6-10 years on Exmoor in southern England to 10-12 years in north-east Scotland (Mowforth & Sydes 1989), tending to be shortest towards the east and at lower altitudes. But a longer rotation of 12-15 years is preferred for nature conservation interests, because stands of dry heath in favourable condition may be 15-20 years old (see Jerram & Drewitt 1998).
- Once it is determined how many years it takes for the heather to reach 30 cm (12 inches), divide the area of the site by this number to obtain an average figure for the area to be burnt each year.
- Lengthen the burning rotation to say 20 years in the south west of England and 15 years in the Pennines, at least in some areas, and have other areas which are never burnt.
- Long burning rotations are particularly relevant on slopes, above gullies and cloughs, and at the moorland edge. This allows the heather to grow taller to provide nest sites for birds such as merlin, hen harrier, twite and ring ouzel.
- Use a shorter burning rotation on flat or gently sloping (<15°) ground to keep a short sward for nesting waders.
- Where heather is the dominant species but grows in mixtures with grasses, lengthen the burning cycle until the plants are taller than the height recommended above.

Box 5 Guidelines for safe moorland burning

Public safety:

- Plan and be prepared well in advance.
- Inform the fire service when burning commences and when it is finished for the day.
- Have a mobile telephone or radio system available for calling up extra assistance or the fire service.
- Erect warning signs.
- Ensure fires do not put neighbouring areas at risk.

Weather conditions:

- Burn when the weather is dry enough to allow a controlled burn but not so dry that the burn will be too hot.
- Choose a day with a steady but gentle breeze (Force 3, 7-10 knots or 8-12 miles per hour), which would move leaves and small twigs constantly but not blow dust about or move small branches of trees.
- Burning after frost or when the ground is wet is helps to avoid damaging fires.

Equipment and man power:

- Use sufficient people who understand the work and know the ground well.
- Have be one person available for every 5m (6 yards) of fire front, with burns no wider than 30 m (35 yards).
- Wear appropriate protective clothing; use fire resistant clothes and helmets with tinted, heat resistant visors, and avoid gloves because this allows the temperature of the fire to be assessed.
- Have sufficient, appropriate equipment on hand; the following can help::
  - knapsack sprayers with diesel are effective for initiating fire fronts;
  - water-sprayers should be used to control the fire, either knapsack ones for putting out small fires and hot spots, or vehicle mounted sprayers for larger areas, preferably on vehicles with a low ground pressure;
  - plenty of beaters and scrapers should be available;
  - foam additives increase the volume of water and are simple and easy to use;
  - fire-retardant foam is another option.
- Be realistic about the area of heather you intend to burn; estimates vary, but a guide for England is about 2 ha (5 acres) per person per day, which is calculated using a speed of fire advance of about 2 m (2 yards) per minute, a fire width restricted to 30 m (35 yards) and 6 hours of actual burning time in a day.

Fire Breaks:

- Choose natural boundaries for the burn wherever possible, or create fire breaks as soon as possible in the season.
- Fire breaks need to be at least 6m (20 feet) wide and preferably 10 m (33 feet) long.
- Break up large areas of tall heather initially with a lattice pattern of long fire-breaks (Phillips & Watson 1995). These can be created by careful, small scale burning or cutting (see section on cutting below). Then burn 20-30 % of the moor in the first two or three years, thereby giving stock a wide choice of forage and reducing the risk of local severe browsing.

Direction of burns:

- Always burn away from woodland, forests, scrub, mires, steep slopes, ancient monuments, and other areas of conservation value.
- Burn with the wind, preferably downhill and towards a fire break. Burning against the wind, or "back burning", can be used to create fire breaks. It produces a hotter fire than burning with the wind, and is more difficult and will require greater expertise and man power.
- Control the flank of the fire at a desired width leaving the fire front to move in the predetermined direction, with at least one flank defined by a natural or prepared fire break.

Size of burns:

- Burn a patchwork of widely scattered, small areas across the moor, for example, long narrow strips up to 30 m (100 feet) wide and covering about 0.5-1.0 ha (1.25 -2.5 acres). Smaller burns are less likely to produce intense fires and are easier to control. They also provide structural diversity for birds and other animals, and help to spread the grazing pressure of sheep across the moor.
- On slopes, relatively shorter burns should be used up hill and longer burns along the contour of the slope.

Severity of burns:

- Burn so as to leave the stems from which heather will regenerate vegetatively.

3. Burning of blanket mire and wet heath for nature conservation

The question often raised in relation to blanket mire and wet heath is whether or not it should be burnt. Fire cycles on mires are not fully understood (Lindsay 1995), but burning these habitats in the same manner as dry heaths can reduce their conservation value (Usher & Thompson 1993). For this reason, burning on blanket mire and wet heath should be minimised and is not necessarily required to maintain conservation interests (Rawes & Hobbs 1979; Mowforth & Sydes 1989).

Heather is able to regenerate vegetatively by layering, as discussed earlier, without the need for burning. The results of a recent English Nature literature review suggest that burning is not usually recommended for management of blanket bog for nature conservation, although there may be a case for its infrequent use in some circumstance (Shaw *et al.* 1996). For example, where the blanket mire has deteriorated due to past management practices, such as grazing, burning or drainage, and is no longer in favourable condition, burning management may be appropriate. But it has been argued that burning here does not lead to an increase in grouse numbers (Hobbs 1984) or grazing potential (Rawes & Williams 1973).

Burning has a marked effect both on the floristic composition and production of blanket mire and wet heath vegetation (Heal & Perkins 1978). For example:

- unburnt bog may have greater species diversity than burned bog (Hobbs 1984);
- some plants, notably *Sphagnum* mosses, can be eliminated by burning;
- a short burning rotation (every 10 years) can result in increased dominance by *Eriophorum* spp., while a long burning rotation (every 20 years) can lead to greater abundance of *Calluna vulgaris* after fire (Hobbs 1984);
- crowberry, bilberry and grasses can be encouraged if burning rotations are short;
- hare's-tail cotton-grass *Eriophorum vaginatum* recovers quickly after burning and can become dominant;
- *E. vaginatum* above-ground standing crop after five years can be about 65 % of the total higher plant community (Gore & Olson 1967), and can assume permanent dominance if the community is burnt frequently (Rawes & Hobbs 1979);
- heather *Calluna vulgaris* regenerates more slowly, taking about 20 years to regain its full dominance, when it can contribute 70 % to the above-ground standing crop (Forrest 1971);
- *C. vulgaris* on blanket bog may eventually be eliminated by a 10-year burning cycle;
- cloudberry *Rubus chamaemorus* and cross-leaved heath *Erica tetralix* may dominate initially after fire, but are likely to be succeeded by heather during long intervals between fires (Mowforth & Sydes 1989).

The actual effects of burning on any particular area will depend on a number of factors, as discussed earlier.

In practice moors are usually burnt in spring, often because this is the only time when the weather conditions are appropriate, although some research suggests that heather regenerates more successfully after autumn fires (Mowforth & Sydes 1989). Autumn burning on blanket mires and wet heath may be better than spring burning, because it discourages *Eriophorum* and *Trichophorum* which increase their dominance at the expense of heather after fires. As their buds are dormant until April they are probably not affected by spring burning (Rawes & Hobbs 1979).

Recommendations concerning burning of blanket mire and wet heaths are contained in Box 6.

Box 6 Recommendations concerning burning of blanket mire and wet heath

- Where blanket bog and wet heath is in favourable condition (see Jerram & Drewitt 1998), the ideal option for nature conservation purposes is not to burn at all.
- Where blanket bog and wet heath vegetation has been degraded by factors such as drainage, burning, over-grazing, or atmospheric pollution, a burning rotation of 20-25 years may be appropriate. A 20-year burning regime is the recommended minimum (Mowforth & Sydes 1989).
- When conducting any burning on blanket mire or wet heath, follow all the legal requirements, areas to be avoided and other recommendations contained in Boxes 1-5.
- Large areas of old, tall heather on wet substrates are ideally left unburnt, because of the risk of very hot fires and little regeneration.
- Large areas dominated by cotton-grass *Eriophorum* spp., are also best avoided, because this will encourage these species, unless accompanied by stock reduction as part of a restoration phase.
- Areas which contain pools or excessive peat hagging, and close to eroding runnels, should also not be burnt.
- As a general rule when managing mires for nature conservation, if in doubt, do not burn (Brooks & Stoneman 1997).
- Where accidental fires are likely and extensive areas of old, woody heather exist, burn fire breaks as a precaution (Mowforth & Sydes 1989) or consider cutting fire breaks (see below).
- Areas where *Molinia* is present at more than 20-30 % cover, are best not burnt, because this will encourage this grass (but see Box 1 on burning of *Molinia* in Rob Wolton's paper in this report).

4 Burning of upland unenclosed grassland for nature conservation

4.1 General considerations

Burning of grassland favours plant species best able to withstand the effects of the burn, notably those with perennating structures protected at or below the surface of the ground (eg. purple moor-grass *Molinia caerulea* and mat-grass *Nardus stricta*). On wetter upland soils purple moor-grass and rushes *Juncus* spp. are sometimes burnt to prevent tussock formation and promote succulent new herbage for livestock (Crofts & Jefferson 1994).

As a rule, burning alone should not be used to manage grasslands. It can encourage purple moor-grass to dominate, and the nutrients released during burning can also encourage other undesirable plant species to invade. The aftermath needs to be grazed, and in conjunction with grazing, burning can be an effective reclamation technique.

Recommendations concerning burning of grassland are contained in Box 7.

4.2 *Molinia* grassland

Burning has traditionally been used in upland areas to burn off dead and unpalatable parts of purple moor-grass *Molinia caerulea* to provide a flush of young, palatable grass for grazing. Summer grazing on *Molinia* grasslands is only readily available if the leaf litter is burnt every year (Miles 1971), or if the tussocks are intensively in the spring (Grant *et al.* 1963).

Yearly burning perpetuates *Molinia* and debilitates heather (Miles 1971). *Molinia* is liable to dominate after a fire on suitable damp substrates because most of its buds are protected from the fire by its dense tussocks (Mowforth & Sydes 1989). If it is not burned or grazed regularly, *Molinia* litter builds up, quickly smothering other vegetation and increasing its dominance. It can form large tussocks which may be very difficult to use or remove.

In certain areas, burning *Molinia* is beneficial for birds. For example, in the South Pennines it provides a rich source of seeds for twite and other finches in spring.

The major aims in management of *Molinia*-dominated areas for wildlife are to reduce the dominance of this species to allow more diverse communities to develop, and to produce habitats which are suitable for invertebrates and birds such as breeding waders.

Box 7 Recommendations for burning upland unenclosed grassland

(See also paper in this report by Rob Wolton)

Do

- Follow the legal requirements and general recommendations contained in Boxes 1-6.
- Remember that it is illegal to burn grassland without a licence from MAFF:
  - Between 31 March and 1 November in the lowlands.
  - Between 15 April and 1 October in the uplands.
- Burn in January, February or March to reduce the adverse effects of fire on flora and fauna.
- Burn small portions of the site on rotation, to decrease the likelihood of eliminating entire populations of plants or animals, and to increase the rate of recolonisation from the surrounding unburnt areas.
- Burn in small patches to provide a variety of conditions for wildlife.
- Burn on dry winter days when the ground is cold or wet, and there is a steady, gentle breeze (about 7-10 knots or 8-12 miles per hour).
- Burn with the wind, because it is less damaging to invertebrates as the fire travels faster and is cooler.
- Leave areas of tall, dense or tussocky vegetation to provide cover for small mammals and invertebrates.
- Identify natural firebreaks, or create them by rotovating or "backburning" strips of land at least 5 m wide. Alternatively spray strips of vegetation with a fire-retarding chemical such as mono-ammonium sulphate or sodium alginate.
- Graze the aftermath.
- Leave some areas out of the burning cycle for a couple of cycles, to mature and develop a tussocky structure with a build up of litter, for invertebrates which require these conditions.
- Ensure there are always some areas in the mature, tussocky state, and that when they are eventually burnt there has been a period of overlap in condition with other areas that are allowed to retain this condition.

Do not:

- Introduce burning on un-burnt sites until the implications for the communities and species present are understood;
- Burn unless some sort of management regime, such as grazing, mowing or increasing the stocking density, is to be introduced after the burn (unless grazing at appropriate levels and times is not possible);
- Burn an entire site;
- Burn the same area every year;
- Burn where *Molinia* is present as part of a mixed plant community because it will increase rapidly at the expense of other species.

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