FIG. 1. A typical landscape in northeast Scotland with agricultural land in the valley and heather on the rolling upland. In the middle distance is a small forest plantation.

FIG. 2. Excellent management. The farmer or gamekeeper has successfully burnt the heather in strips—most recently on the left. The dark strips are unburnt—providing nesting sites for red grouse. The pale tone is produced by the young pale green regeneration.

Moor Burning in Scotland

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COMMON HEATHER (*Calluna vulgaris* (L.) Hull) has been deliberately burnt on the moors of northeast Scotland for some 300 years. Burning aims at maintaining the heather in its most productive form as forage for hill sheep, and for the red grouse (*Lagopus lagopus scoticus* Lath.), a valuable game bird.

This paper describes the moorland vegetation, methods of burning, and some characteristics and consequences of the fires. A representative, although not comprehensive, bibliography is attached.

VEGETATION

Definitions.—In Scotland, the term "moor" refers commonly to any tract of unenclosed, usually high-lying land, with an acid peaty soil, supporting dwarf ericaceous shrubs (Tansley 1949). The type of moorland discussed herein is dominated by *Calluna*, where the soil is a shallow peat overlying mineral matter, or else a deeper peat with a relatively dry surface during some part of the year, and known variously as a "heather" or "grouse" moor, or an "upland heath".

Heath Development.—A heath is a seral development, which has originated over most of its range only after forest clearance. Maintenance of the heath requires continued exclusion of the trees, and has been accomplished chiefly by fire.

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Historically, a rather open pine-birch forest, interspersed with patches of peat bog, was the principal vegetation type occurring below the tree line in the highland region. Destruction of this forest by man began in a remote era. Pollen analysis and archeological evidence indicate that a marked decline of the lowland and coastal forests was associated with the activities of late Neolithic and Bronze Age man (*c.* 2000-500 BC). In the more inaccessible highland regions, forest cover was first seriously affected by incursions of vikings in the 8th and 9th Centuries AD. Much more extensive clearances took place in the 16th Century and thereafter. Cattle grazing had long been an integral part of the highland way of life, but the new factor of greatest importance was the use of charcoal for iron smelting, a use (dependent on the cutting of trees) which continued until the end of the 18th Century. The new expanses of treeless country attracted the sheep farmers who, encouraging the opening up of even more territory, enjoyed a period of initial high productivity and prospered into the 19th Century. With the rise of shooting as a remunerative sport, the landowner was still further encouraged to preserve the heath as a grouse habitat.

As Durno (1957) remarks, "by destroying the forests to make way for grazing and cultivation the early inhabitants also cleared the way for the expansion of heath." Where heather became the dominant plant cover, the interests of both sheep and grouse could be served by introducing regular burning, and thus maintaining a continuous supply of nutritious young heather.

Characteristics of *Calluna*.—*Calluna* is an evergreen shrub, whose size and habit depend on age and manner of regeneration, but which normally grows in patches or extensive dense stands to a height of about 3 feet. Regeneration takes place both by seed and by sprouting, although *Calluna* older than 15 years tends to lose its ability to regenerate vegetatively (Kayll and Gimingham 1965). Younger plants which survive a fire normally sprout abundantly from the stem bases, especially if the latter are well branched and embedded in moist litter or a stratum of bryophytes. This type of growth has a dense bushy form in contrast to the taller, more tree-like habit of plants grown from seed (Elliott 1953).

FIG. 3. In steep country, straight edges are not easily achieved. Here a "patchwork quilt" becomes evident with some boundaries overlapping, depending on the age and flammability of the heather. Light areas have been recently burnt, but the heather on the dark areas may be up to 20 years old.

Calluna is native and widespread not only in Britain, but is characteristic as a dominant of west European heath communities. The species is adapted to a typically cool, temperate, oceanic or suboceanic climate, and has a wide ecological amplitude which includes heaths, moors, bogs, fixed sand dunes, and partially stabilized scree (Gimingham 1960). Bell heather (*Erica cinerea*) and cross-leaved heather (*E. tetralix*) are common associates (Bannister 1965).

During its life span, which seldom exceeds 30 years, *Calluna* passes through four stages of development, according to Watt (1955):

(1) *Pioneer phase;* one of establishment and growth, in which the leading shoot loses its dominance after about 2 years, and thereafter seeds set every year in fluctuating quantities. This stage lasts from 3 to 6 years.

(2) *Building phase;* lasts up to age 15 or 20 years, while the maximum cover and density of *Calluna* is established and the ground

stratum of bryophytes and lichens is reduced to a minimum.

(3) *Mature phase;* normally lasts to an age of 25 years. The central branches spread apart, permitting enough light to reach ground level for the re-establishment of bryophytes. The branch tips become clustered and the flowering zones shorten.

(4) *Degenerate phase;* sees the development of gaps in the plants as the central branches die. The peripheral branches, if more or less horizontal, may root adventitiously.

***Calluna* as Forage.**—Hill sheep, which thrive on moorland, have special value for crossing with lowland breeds to increase hardiness. This role is a continuing one and makes the hill sheep much more important than the actual numbers carried on moorland pasture might indicate.

Calluna forms a substantial part of the diet of hill sheep throughout the year, and is particularly important in winter since it remains green and is nutritionally superior to dead grass, as well as being richer in trace elements. In summer, preference is shown for the tips of growing shoots, and young plants are grazed extensively. Older but vigorous plants are eaten the year around, and in winter large portions, including woody shoots up to 2 inches long, are taken (Hunter 1954). Plants in late mature and degenerate phases are seldom eaten, except perhaps during the month of flowering.

Calluna provides 70 to 80 per cent of the staple food of red grouse, which feed on the flowers, seeds, and succulent tips, and in addition nest in the mature heather. The grouse-shooting "industry" in Scotland is a valuable one, yet scientific information on the grouse itself is inadequate. To help remedy this situation, the Unit of Grouse and Moorland Ecology in the Department of Natural History, University of Aberdeen, was established in 1960. Animal and plant ecologists are working in close association and results of their studies will be soon forthcoming.

MOOR BURNING

Objectives

1. *To keep the feeding quality of heather as high as possible.* The proportions by weight of protein and ash constituents of the

green shoots of *Calluna* are greatest in pioneer heather. The subsequent decline in value is offset to an age of about 7 years by increasing plant size and therefore yield of edible material per acre. Thereafter a net deterioration in the feeding quality of heather-dominated areas sets in.

2. *To keep a high annual flower and seed production.* Maximum production is reached only in the building phase, and is reduced by heavy grazing.

3. *To maintain a dense, even cover.* This objective also requires a population of plants in the building phase, and is achieved by burning before the mature and degenerate stages. Regenerative cover may thus be restored in 2 or 3 years, but if burning is too frequent the area remains in the pioneer phase for an unduly long time. While *Calluna* can recolonize an open area from seed, full cover is not achieved for at least 5 years and is preceded by temporary dominance of undesirable species such as bell heather, blaeberry (*Vaccinium myrtillus*), or bearberry (*Arctostaphylos uva-ursi*).

4. *To promote conditions for rapid and uniform regeneration.* Most rapid regeneration is achieved when the majority of plants are not killed by the fire, but sprout from the stem bases.

Improper burning, far from attaining these objectives, can have serious results. Too frequent or too severe a burning regime may diminish the vigour and regenerative capacity of *Calluna* to a point where less desirable species such as bracken fern (*Pteridium aquilinum*) or deer grass (*Scirpus caespitosus*) become dominant. Excessive and ill-directed moor burning can even destroy all vegetation and allow erosion to remove the peat. Burning is not the only, or even the most effective treatment for regenerating heather. Clipping appears to stimulate sprouting from a greater number of stem bases (Kayll and Gimingham 1965), but is wholly impractical on a large scale under the prevailing economic conditions.

Other Ecological Effects.—Whittaker and Gimingham (1962) concluded that good burning improves the seedbed for germination of *Calluna* seeds, particularly by permitting maximum light intensity at the soil surface and creating a habitat where fluctuations in temperature are common. The micro-climate near the surface of a burnt area is perhaps slightly warmer and drier than under the

FIG. 4. Near Cairn O'Mounth, Kincardineshire. Excessive and ill directed burning has permitted severe erosion to occur. Up to 3 feet of peat may have been eroded. Note the "patchwork quilt" on the distant hills. Photo by C. H. Gimingham.

canopy of an unburnt stand and thus may be beneficial to the plants (Kayll 1964), although less favourable to insects (Delany 1953).

The effects of fire on nutrients within the soil-plant complex have been studied by Allen (1964). Over half the carbon, nitrogen, and sulphur in the heather are driven off with the smoke, but where mineral nutrients are lost as the result of burning, they can be replaced by the small amounts contained in normal precipitation within a short period, except on porous soils. Replacement of nitrogen by rainfall takes longer, but microbial action may be helpful.

Burning Methods.—The use of burning for management purposes in Scotland dates from perhaps the middle of the 17th Century: an act which prohibited burning after the end of March was passed in 1685 (Miller 1963). The low height and uniform nature of the fuel are the main factors contributing to the simple techniques employed. An estate gamekeeper uses a kerosene oil burner to start

a fire, and controls its edge with a broom—usually a birch stem about 9 feet long, weighing up to 40 pounds, and with a loop of chicken wire on the end. By these means he will expect to burn annually from 5 to 10 per cent of the *Calluna* area of a moor between October 1st and April 15th. (The Act is only slightly modified now to allow burning at higher elevations up to 2 weeks later in the season.)

Most Scottish moor burning is accomplished with head-fires, but back-fires are used in the north of England. There is disagreement among gamekeepers as to the comparative efficacy of spring and autumn burning, although the former seems to be generally favoured in northeast Scotland.

Fire Characteristics.—Table 1 summarizes results obtained from a number of experimental heath fires carried out in autumn and spring by the author, and described in detail elsewhere (Kayll 1964, 1966).

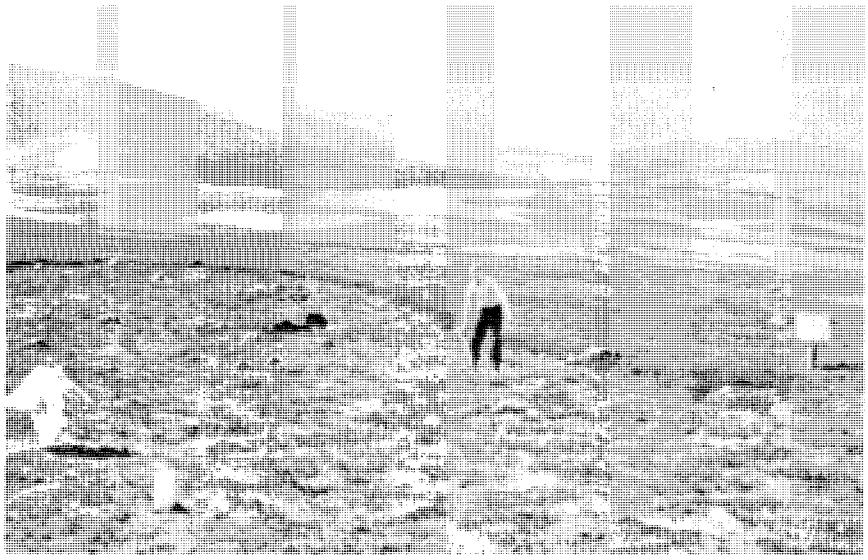

FIG. 5. Experimental area shortly after burning with weather instruments being installed. The unburnt heather adjacent to the burn is about 12 inches high. The background is a typical landscape.

TABLE 1: CHARACTERISTICS OF MOOR FIRES

	Autumn		*Spring*
	Fire 1	*Fire 2*	*Fires 3-7*
Condition of Calluna			
Age, yrs.		15	25
Height, inches		14	18
Cover, %		90	80
Moisture content, %	nd*	79	85
Wind			
Nature	Gusty	Steady	Steady
Velocity, mph	21	14	10
Air			
Temperature, °F,	61	57	44
Relative humidity, %	64	79	70
Fuel			
Available, tons/acre		7.1	10.4
Consumed, tons/acre		6.6	2.9
Consumed, %		93	28
Rate of Spread, ft/min	23	10	6.5-20
Fire Temperatures, °F			
Maximum recorded			
a) Crown	nd	1020	680
b) Surface litter	nd	140	680
Most common in stems and canopy	nd	nd	390-570
***Intensity*, BTU/sec/ft	900	400	225

*nd—not determined
**Based on Byram (1959):
Intensity = heat of combustion (BTU/lb.)
× rate of spread (ft/sec)
× fuel consumed (lbs/ft²)

The first autumn fire at its maximum intensity (estimated by Byram's (1959) formula) produced approximately 900 BTU/sec/ft. In the second autumn fire the maximum temperatures in the crown were high (*c.* 930° F), but those at the surface were low (*c.* 140° F) and all temperatures were maintained for short periods only (*c.* 30 seconds). The intensity of this fire (400 BTU/sec/ft) was much less because of the lower wind velocity (only 14 mph *vs* 21 mph for the first fire).

Both fires removed the aerial portions of the *Calluna*, including stems. In the following year, the vegetative regeneration from pro-

tected meristems was excellent in a generally good year. A farmer or gamekeeper would regard these as efficacious fires.

The several spring fires were incomplete: only 30 per cent of the fuel was consumed, leaving many "leggy birns" (*Calluna* stems) and much of the moss and surface litter. Although isolated maxima of 680° F were recorded, the general crown and surface temperatures were lower (*c.* 480° F, and ambient to 210° F, respectively), and the intensity was only 225 BTU/sec/ft. The ensuing regeneration was poor: where sprouting occurred, the shoots frequently had to force their way through a heavy moss cover, and were then subject to mechanical abrasion by the charred stems.

A particular problem is achieving a satisfactory burn in old heather. It seems likely that an effective burn in stands of *Calluna* older than 20 or 25 years (late mature-degenerate phases) would require an intense fire (*c.* 500 BTU/sec/ft), produced by back-burning techniques. The burning would have to be done under conditions of high risk: the *Calluna* very dry, the slope moderately steep (so that flames could carry through the clumped *Calluna*), and a moderate wind blowing down the slope. A back-fire might move too slowly to produce an intensity of 500 BTU/sec/ft, but if the *Calluna* were dry it would be satisfactorily burned. To control fires under these extreme conditions, the traditional broom should be supplemented at the fire with some "back-pack" fire fighting water pumps.

COMMENT

To a stranger, particularly if he is a forester, the removal and subsequent exclusion of the forest may seem a detrimental consequence of moorland fires. Yet the point is that many Scottish land owners can afford *not* to grow productive forest on the moorland parts of their estates. Estate owners, who generally have other sources of income, enjoy the shooting themselves and rent it to others—an increasingly profitable undertaking. Maintaining a productive crop of heather therefore continues to be a desirable objective and the use of fire remains the cheapest and simplest technique for accomplishing this end.

Yet uncertainty exists about the long-term influence of repeated moor-burning on soil fertility, and the precise ecological and physiological effects of fire on the vegetation. The experimental fires and other investigations cited herein have shed some light on these matters, but much additional research is necessary to provide factual information on which sound burning practices can be based.

REFERENCES AND SELECTED BIBLIOGRAPHY

Allen, S. E. 1964. Chemical aspects of heather burning. J. Appl. Ecol. 1:347-67.

Bannister, P. 1965. Biological flora of the British Isles. *Erica cinerea* L. J. Ecol. 53: 527-42.

Burnett, J. H. 1964. (Ed.). The vegetation of Scotland. Edinburgh, Oliver & Boyd. 613 p.

Byram, G. M. 1959. Ch. 3 (combustion of forest fuels) and Ch. 4 (forest fire behaviour). *In* Forest fire, control and use, ed. by K. P. Davis: 61-123. New York, McGraw-Hill Book Co. Inc. 584 p.

Delany, M. J. 1953. Studies on the microclimate of *Calluna* heathland. J. Anim. Ecol. 22:227-39.

Durno, S. E. 1957. Certain aspects of vegetational history in north-east Scotland. Scot. Geogr. Mag. 73:176-84.

Durno, S. E. and McVean, D. N. 1959. Forest history of the Beinn Eighe Nature Reserve. New Phytol. 58:228-36.

Elliott, R. J. 1953. The effects of burning on heather moors of the south Pennines. Unpubl. Ph.D. Thesis, Univ. of Sheffield.

Gimingham, C. H. 1956. Fire on the hills. J. For Comm. 25:148-50.

Gimingham, C. H. 1960. Biological flora of the British Isles (*Calluna* vulgaris (L.) Hull. J. Ecol. 48:455-83.

Gimingham, C. H. 1964. Land use in the Scottish Highlands (Ed: L. D. Stamp, C.B.E.) III. The composition of the vegetation and its balance with environment. Advancement of Science XXI:148-53.

Hansen, K. 1964. Studies on the regeneration of heath vegetation after burning-off. Saertryk af. Bot. Tids. 60:1-41.

Hunter, R. F. 1954. The grazing of hill pasture sward types. J. Brit. Grassland Soc. 9:195-208.

Kayll, A. J. 1964. Effects of heat and fire on components of forest and moor vegetation. Unpubl. Ph.D. Thesis, Univ. of Aberdeen.

Kayll, A. J. 1966. Some characteristics of heath fires in north-east Scotland. J. Appl. Ecol. 3:29-40.

Kayll, A. J., and C. H. Gimingham. 1965. Vegetative regeneration of *Calluna vulgaris* after fire. J. Ecol. 53:729-34.

Kenworthy, J. B. 1963. Temperatures in heather burning. Nature 200 (4912):1226.

Lovat, Lord, (ed. A. S. Leslie). 1911. Heather burning. The grouse in health and disease. Comm. of Enquiry on Grouse Disease. London.

McVean, D. N. 1959. Moor burning and conservation. Scottish Agriculture 39:79.

Miller, G. R. 1963. The management of heather moors. Paper Presented to Brit. Assoc. Aberdeen.

Radley, J. 1965. Significance of major moorland fires. Nature 205 (4978):1254-9.

Robertson, R. A. 1958. Heather management. Scot. Agric. (Winter '57-58): 4 pp. Rp't No. 359. Macaulay Inst. Aberdeen.

Smith, W. G. 1916. Heather burning with special reference to sheep grazing. Edin. and E. Scot. Coll. Agr.
Tansley, A. G. 1949. The British islands and their vegetation. Cambridge. 970 p.
Thomas, P. H. and R. W. Pickard. 1962. Fire spread in forest and heathland materials. Report on forest research for the year ended March, 1961:105-8.
Wallace, R. 1917. Heather and moor burning for grouse and sheep. Edinburgh.
Watt, A. S. 1955. Bracken versus heather, a study in plant sociology. J. Ecol. 43:490-506.
Whittaker, Edith. 1961. Temperatures in heath fires. J. Ecol. 49:709-15.
Whittaker, E. and C. H. Gimingham. 1962. The effects of fire on regeneration of *Calluna vulgaris* (L.) Hull from seed. J. Ecol. 50:815-22.
Wynne-Edwards, V. C., D. R. Jenkins and A. Watson. 1960. A population study of red grouse in Scotland. New Scientist 8:709.