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Aspects of the Ecology of The Northern Pennines

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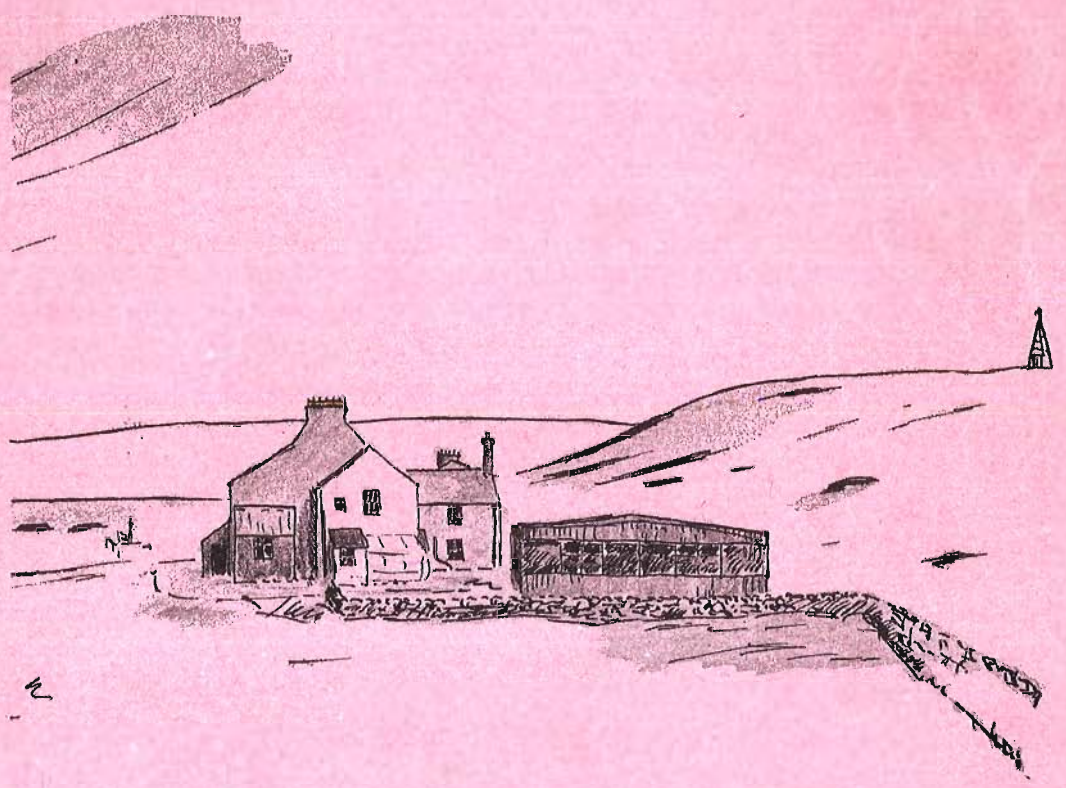

MOOR HOUSE

Aspects of the Ecology of northern Pennine Moorland

1. The Influence of Agriculture

by

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The history of the northern Pennines, as of most upland Britain, is one of exploitation with little input. Harsh climatic conditions and poor soils have often led to extraction without regard to future productivity. Mining has been widespread, and few parts have been unaffected, especially by lead mining, mainly in the 18th and 19th centuries. Many of the present villages, farm houses, field walls and roads owe their origin to the prosperity of mining but little lasting benefit is now to be seen in the fell land. Grouse shooting, however, is still an important source of income and the present heather-dominated scene that we associate with much of our hill land is largely due to grouse moor management. Keepers have been employed to improve conditions to give maximum grouse production and burning and draining have, and are, their means of management. However, sheep have probably exerted the most obvious effect on the vegetation. They were introduced to the northern fells nearly 1000 years ago, although they have not been the only grazers: deer were not uncommon up to 200 years ago.

There are now over 3½ million sheep, in the four northern counties and the majority are hill sheep. Welch (in press) estimated that the present number of hill sheep in south-east Cumberland is three times that of 200 years ago, when the average flock size was much smaller. Indeed since the Norse introduced sheep to our fells there has been general increase in numbers in spite of occasional recessions. The monastic houses, in medieval times, had large flocks and extensive grazing rights. Welch quotes an old charter given in Black Book of Hexham 1479, to say that Hexham Abbey had rights for grazing 40 cows, 10 horses and 100 sheep on Priorsdale, on the Pennines, over 20 miles from Hexham, but the number and size of monastic foundations in the northern Counties, with land, was small compared to the many great establishments in Yorkshire.

The Pennines of the 16th century were described as largely pastoral with extensive sheep, cattle and horse rearing and there is evidence that sheep were an important factor in the economy of the northern Counties as far back as the 13th century (Elliott, 1967). The break-down of the wool market in the 16th century caused much hardship. Wool had been sold through Hexham Abbey and exported to the continent from Newcastle.

In the 18th and 19th centuries many small holdings were created in the dales by lead miners and these part-time farmers occupied a few hectares of intake land, frequently grazing a few sheep on the common fell. With the decline in mining much land that had been reclaimed by them reverted to rough grazing.

Most of the hill and common land in Teesdale and Weardale is privately owned. Common land is land over which certain people, normally parishioners, have legal rights, and they exercise these together. In this area rights of grazing are those principally exercised, although peat was at one time cut for fuel. Commoners, occupiers or tenants of holdings within the parish of the common, may have committees to "manage" their affairs, or, as is more usual, they may only form committees when their rights are threatened. Most commons are limited, that is, there are restrictions on number, possibly type of stock and period of grazing and on where the rights may be exercised. This type of common is known as a stinted common each stint being a specific animal unit, often of four sheep or one cow. On some fells stints may be sold and on most stinted commons a Management Committee exists, employing a resident shepherd. On other commons there is no restriction other than that imposed by good neighbourliness and custom. In practice numbers are limited to those that can be wintered on the home farm. In Teesdale and Weardale there are about 32 stinted commons covering 20,000 ha (8,094 acres) and 10 unrestricted but larger commons covering 14,500 ha (5,868 acres).

The main emphasis of hill sheep production remained wool until comparatively recently, when synthetic fibres became more widely used. Indeed, much of the management of hill sheep has remained unchanged for centuries. Flocks have increased in size; sheep, now mainly of the Swaledale breed, have become more prolific, and disease control has reduced losses despite less shepherding on the fell. Improvements came with the change in agricultural practice brought about by the introduction of the turnip to lower-lying farms during the mid-18th century. Lambs produced on the hills were sold to be fattened on turnips. Additionally, a stratified system of sheep farming was developed, involving production from the poorest hill-land to good quality low-lying arable land. Thus draft ewes, that as fell-going sheep may have had three or four lambs, were sold to more productive farms down the dale where they were mated with rams of a better meat producing type, such as the Teeswater, Wensleydale, or Border Leicester. The cross-bred lambs were either sold fat or for further breeding, being tupped by a Down ram to produce a high quality lamb fattened on arable crops.

For economic reasons, however, fat lamb production on good quality land is no longer attractive. Lack of demand has resulted in lower prices to the hill farmer, therefore management policy and future use of the fell must in time change. A recent change has been the return to favour of housing for wintering hoggs and also for fattening lambs. In this way the high cost of agistment of hoggs on lowland pastures is avoided, while, if lambs can be fattened for the January market, better returns can be obtained.

In most cases the ewe flocks have continued to graze the fells throughout the year, other than at lambing and times of heavy snow. On the more remote fells, however, it is customary to remove all sheep during the winter. After lambing, the sheep return to the fell, usually preceded by the previous year's ewe lambs (gimmer hoggs), and there they remain relatively undisturbed until the lambs are weaned and taken off the fell in August or September.

Cattle have been kept on the fells for many centuries but it is only very recently that their numbers have increased. Whilst sheep are ubiquitous, cattle, usually the black Galloway breed, remain localised, sometimes depending as much on the interests of the farmer as on the suitability of the land. Much fell land, however, is too wet, too inaccessible and too low in productivity to support cattle. Rarely are cattle found to be grazing above 700 m (2300 ft) and usually the land is enclosed. The grazing season is normally short, many of the cattle being housed from November to May. But the increase in their number has resulted in large importations of hay and other feeding stuffs and this is undoubtedly of benefit to the fertility of many fell areas.

The fell is utilised in conjunction with the home farm, which generally adjoins it. Enclosed land is limited on most hill farms; it is managed to provide stock, sheep and cattle, with pasturage and hay, and only rarely is it ploughed. The management of meadowland, the better quality dale fields often near the homestead, is the same each year. During the winter these fields are grazed, but it is not until lambing, in March, April and May, that the stocking rate is very heavy. After this, fields are cleared of sheep, often not more than two months before hay harvest, which to obtain a heavy crop is delayed until July, after many of the plants have flowered and set their seed. It is this management that ensures the survival of species and their continuance as components of the meadow flora. In the autumn cattle and lambs may graze the re-growth, commonly known as foggage or fog. Manure from the byres is led to the fields and modest applications of fertilisers and of ground limestone may be given from time to time, but because of cost and inadvisability of producing large hay crops that may be difficult to harvest, heavy dressings are seldom given. Some meadows, mainly in Teesdale, have a distinctive flora, which is perpetuated by this long-continued management.

Undoubtedly the necessity for grazing the meadows in the spring impoverishes the hay crop in both its quality and quantity for domestic animals. If silage conservation was more widespread the danger of producing a heavy unharvestable hay crop would not arise, but changed management of the meadow would alter the botanical composition.

The remaining enclosed land tends to be too wet or the ground too steep to crop for hay; it is best used as pasturage, often throughout the year. The swards grade from Agrostis (bent-grass) to poor quality Juncus (rush) and Nardus (mat-grass) swards, frequently infested with rushes and invaded by bracken. Neglect of fencing and walling is common-place and in many cases these areas are down grading; they are usually botanically uninteresting and of low agricultural productivity.

From time immemorial the hills and dales have been subjected to seasonal movement of stock. Hoggs are removed from the fells to lower ground for winter; draft ewes are taken down to dale country; lambs and cattle are moved to higher ground in summer. Such trans-humance makes good use of land, it utilises sward production of poor land at times of maximum growth, ensures that both fell and inbye land receive periods of rest from grazing and minimises the effect of any nutritional deficiency, especially in mineral balance, that may occur.

A STUDY AREA INVESTIGATED

The ecology of Moor House National Nature Reserve, 3850 ha (9513 acres) of fell land in the northern Pennines, near Cross Fell, at the head of the River Tees, has been investigated by a number of research workers since 1952. Few hill areas have received as much scientific attention and it seems relevant to quote some of these findings here. The relation between sheep, which are the dominant herbivores, the vegetation, and the productivity of the ecosystem, has been the research topic of the author. Previous publications have included those on the vegetation by Eddy, Welch and Rawes (1969), whilst herbage production, its utilisation by sheep and the productivity of the sheep, has been described, mainly by Rawes & Welch (1969).

1. Description

The area which ranges in altitude from 303-847 m (1000-2780 ft) is typical of the more remote and higher parts of the region. Prior to being a Nature Reserve it was managed as a grouse moor but common grazing by sheep has continued.

The extent of the plant communities present is shown in Table 1. Over 50% of the area is blanket bog, a wet vegetation dominated by Calluna (heather), Eriophorum (Cotton Grass) and Sphagnum (Bog moss). The peat is commonly 1.5m (5 ft) deep, although a depth of over 8 m (26 ft) has been found. The species composition of the bog vegetation varies according to the degree of soil moisture, altitude, grazing pressure and time since it was last burnt. At the higher altitudes, above 670 m (2200 ft), Calluna tends to be replaced by Empetrum nigrum (Crowberry) and Eriophorum vaginatum is dominant. Likewise after burning, Eriophorum is the dominant species for at least six years.

There are a variety of grass-type swards, the most abundant being dominated by Juncus squarrosus (Moor-rush) and Nardus and the least widespread by Festuca (Sheep's fescue) with or without Agrostis. There are numerous swards in which these dominants intermingle. The Juncus and Nardus swards together occupy, in equal parts, a fifth of the whole study area and both are common throughout the Pennines: Juncus dominance is largely a result of the long history of sheep grazing (Welch & Rawes, 1964).

Table 1 The extent of vegetation types, in hectares, on three parts of the Moor House National Nature Reserve. The parts are : the western escarpment (W) below 671 m, the central ridge (C) above 671 m and the eastern plateau (E) below 671 m. (After Eddy, Welch & Rawes, 1969)

Vegetation Types	W	C	E	Total
Blanket bog				
Calluna-Eriophorum-Sphagnum	0	63	1137	1200
Trichophorum-Eriophorum & recolonised peat	80	264	340	684
Eroding bog	2	104	217	323
Total	82	431	1694	2207
Grasslands				
Juncus squarrosus	121	239	17	377
Nardus stricta	255	266	94	615
Festuca	35	147	1	183
Agrostis-Festuca	85	28	37	150
Scree, made ground etc.	100	33	21	154
Pteridium (Bracken)	34	0	0	34
Total	630	713	170	1513
Poor fens and flushes				
Total	18	49	55	122
Totals	730	1193	1919	3842

The Festuca swards are mainly restricted to the summits of hills. They may be heavily grazed in the summer, but because of exposure their utilisation is governed by wind speed and direction as well as by the availability of food. The Agrostis-Festuca grasslands are generally thought to be the most important and productive of swards. They are comparatively rich in species and are much favoured by sheep, but on the area investigated they are infrequent and small in extent; they account for only 4% of the vegetation cover, but this varies considerably from fell to fell.

The fen and flush communities are small in extent and variable. The calcareous flushes are rich in species, while the rush and sedge areas add to the diversity of the vegetation and provide alternative habitats. The clumps of Juncus effusus (Soft rush), give the sheep a certain amount of shelter from wind and rain in an otherwise exposed moorland.

Organic soils predominate and cover over 70% of the area. Blanket peat is the most extensive, it is highly acidic and infertile. Peaty-gleys and peaty podsols are likewise common, and it is on these soils that the poor grasslands, Juncus squarrosus and Nardus are widespread.

Brown calcareous soils, often overlying limestone, are the most fertile. The rocks of the area belong to the Yoredale Series of the Carboniferous, comprising limestone, shales and sandstone in repetitive sequence, but the occurrence of limestone close enough to the surface to influence soil development is not frequent. Alluvial soils are also present, the best are free-draining brown earths, and, like the brown calcareous soils, they support Agrostis-Festuca grassland.

Erosion has been widespread, peat having at one time covered the whole area except for stream sides, scree slopes and possibly some of the larger limestone outcrops. Much of the erosion has been colonised, or is in the process of being colonised, by mosses and flowering plants.

The climate on the hills is more "maritime" than on neighbouring lowlands. Manley (1943) described it as resembling southern Iceland at sea level. The weather of a high level upper Teesdale farm is comparable to that of an Icelandic farm. There are strong winds, low summer temperatures, frosts in any month and relatively long periods of snow cover. Green & Millar (in press) give the following averages for the Moor House Climatological Station (560 m O.D.), based on fifteen years recording: annual mean temperature 5.1°C; mean minimum temperature of the warmest month, July, 7.2°C; mean annual rainfall 1923 mm; average number of days with rain 251; mean annual snow cover 64 days. Manley (1942) estimated that in northern Britain the rate of fall in temperature with increase in altitude was 1°C for every 148 m. This in practice is found by Green & Millar to be correct where the altitudinal differences are great e.g. between Great Dun Fell (847 m) and Newton Rigg (166 m), but at the higher altitudes within this range the temperature difference is greater. For instance, above 566 m it is found to be 1°C for every 90 m.

To the east of the study area the climate becomes drier and, in general, the altitude is lower. Thus at Chopwellwood (136 m), 5 km west of Durham, the annual mean temperature is 8.3°C and the rainfall 730 mm, only 40% of that at the study area's climatological station.

On the higher fells the growing season for plants is short. At 566 m it is 70 days less than at sites nearby but 400 m lower down. Weather conditions limit the duration of animal activity, and, together with poor edaphic conditions, species diversity of both plant and animal life tends to be limited.

On Moor House the grazing season is usually from April to October, and it is limited to sheep and a few fell ponies. At maximum stocking, in July, there are about 8500 sheep of all ages, in 22 different flocks. The fell consists of three unstinted commons.

2. Methods used

The growth of herbage at 16 sites, representing the six most important sward types, was measured at intervals throughout the grazing season. Rawes & Welch (1969) give details of how growth of plants and intake by sheep was measured by differences in sward yield.

The utilisation by sheep of these sites, and more than a dozen others, was observed by counting sheep on census plots and measuring the amount of dung deposited. The amount of dung is closely related to sheep number and this enabled a regression to be calculated which now permits sheep number to be predicted by regular sampling of dung.

Details of sheep distribution and behaviour were obtained by survey both of the whole and of sample areas, and by regularly mapping the locations of marked individuals. Live weight was recorded at intervals during the grazing season.

3. Results

(a) Herbage production and grazing pressure

Herbage production is low, varying from 61 to 343 g dry weight/m^2. Table 2 gives values for sites at which intake was also measured.

Table 2 Summary of herbage production under grazing, intake and grazing pressure. Relative values are bracketted.

Sward	Altitude m	Production g/m^2	Intake g/m^2	% utilised	Sheep -av. No./hectare
Agrostis-Festuca	555	174(51)	110(85)	63	3.7
Agrostis-Festuca	510	196(57)	93(72)	47	8.7
Agrostis-Festuca	747	85(25)	61(47)	73	2.5
Agrostis-Festuca	480	179(52)	83(64)	46	6.3
Festuca	678	90(26)	50(39)	55	2.0
Festuca	840	67(18)	61(47)	100	3.0
Juncus squarrosus	549	343(100)	130(100)	35	1.1
Nardus stricta	549	193(56)	+	+	1.4
Blanket bog	560	154(45)	+	0	0.02
Blanket bog (burnt)	560	69(20)	+	0	0.04

+ small values

There is a considerable difference in herbage production at different altitudes. Growth from the Agrostis and Festuca grasslands is well utilised, being generally relatively digestible. In the Juncus squarrosus sward the dominant is often ungrazed but a large intake is obtained from the grass component and sward production is

relatively high. Changes in the relative growth rates of grasses in the Nardus sward were affected by the methods used (temporary exclosure) and it was only possible to show a very small intake.

No intake was measured on the blanket bog sites. Eriophorum is certainly grazed and provides feed at times of scarcity in winter and early spring. It is also a valuable source of phosphorus and is said to have vermifugal properties. Calluna is little grazed by sheep during the summer. The effect of burning blanket bog is to kill the old Calluna stems and to encourage new growth from seedlings and old rootstock. Eriophorum, which is dominant for the following six years, is stimulated by the burning of dead leafage.

The utilisation of the swards over the six month period was variable both within similar sward types and between them. In the grasslands utilisation was dependent on amount of food available, which may be associated with altitude and the number of sheep around. The most preferred swards were the Agrostis-Festuca, which averaged more than 5.5 sheep/ha (2.3 sheep/acre) but with a range of 3-13 sheep/ha (0.1 - 5.4 sheep/acre), whilst the least used vegetation was that of the blanket bog, which in some instances was almost completely neglected. Densities as low as 1 sheep/40 ha (100 acres) have been recorded for this habitat, but even so observations showed that at least one of the eight sites was utilised on 76 days out of a possible 167.

The utilisation of most consus areas was consistent, probably because grazing was confined only to that part of the year when herbage was generally readily available. But the use of some sites was more dependent on local climate. For example, wind speed and direction may be of significance in altering what may be a diurnal pattern of grazing different habitats and this is certainly true when the speed exceeds 14 m.p.h. Similarly the grazing of the coarser vegetation types in preference to the Agrostis-Festuca when the vegetation was wet was shown to be statistically significant. However, utilisation must to a great extent depend on food availability, and thus upon the time of growth of palatable species. The lower (3 sheep/ha) (1.2 sheep/acre) density of sheep on the highest Agrostis-Festuca was as much related to low sward production as to climate.

Much of the vegetation of the area is poor grassland, Nardus, Juncus squarrosus and Festuca dominant. These swards are commonly found throughout the region and on most upland areas of Britain. Their existence is closely related to grazing; under the system examined they had densities of sheep ranging from 0.25 to 4 sheep/ha (0.1-1.6 sheep/acre). The utilisation of Nardus tended to be most variable, but unlike the Juncus swards they are well used late in the season.

(b) Sheep behaviour

The gimmer hoggs are the first sheep to return to the fell in spring. They remain in groups, often of about ten animals, until the ewes and lambs appear in May when the sheep spread out over the fell. The common group is now that of the ewe, her lamb and often a hogg, the previous year's lamb. In July, family groups aggregate, and, from then until October small flocks of up to 20 sheep are commonly seen.

As they are little disturbed, hill sheep behave in many respects like the feral Soay sheep of St. Kilda described by Grubb & Jewell (1966). Rams, however, only run with the flock at tupping time and generally are not on the fell. The ewe therefore, is the main animal of the study. She maintains a territory, normally of up to 100 ha (40 acres) to which she returns each year and to which the lamb, as a gimmer, will return in future years. The territory will usually consist of a number of different sward types, the diversity of most fells being considerable. The individual territory is within that of a number of other sheep, usually related individuals, and both the individual and group territory, or home range, are subject to the stresses of social behaviour. A ewe may therefore be seen to defend her territory and on occasion aggression may occur. This defence is more obvious on the most preferred swards and an interesting hypothesis is that the Agrostis-Festuca grasslands are grazed each year by a similar number of sheep irrespective of the sheep population on the whole area. Thus, if the size of the sheep flock is increased these swards will not be grazed by more sheep, although because of a shortage of feed elsewhere they may be grazed more intensely, but the extra sheep will be found on the Nardus and Juncus swards.

Sheep graze mainly during daylight hours, in the winter most of the day, but in mid-summer the greatest activity is early in the morning and in the later afternoon. Grazing shows both seasonal and diurnal patterns though the latter may be dependent on the habitats available. In general, the greater the diversity the more suitable the fell for year-round sheep grazing.

(c) Sheep production

Whereas there is variation between different flocks and within a flock the sheep on the study area were found, over a four year period, to have much the same live weight when 18 months old, irrespective of the wide differences, due to management change and genetics, that they had in their earlier months. The hill sheep, in general, is bred to survive rather than to produce products of quality of quantity.

Sheep production is commonly measured in economic returns or as weight of saleable products, such as a fat lamb and wool, or as number of lambs reared. The Ministry of Agriculture (1966) define the standard net output of sheep as the value of lambs and wool produced per ewe per annum. This is adjusted for weather conditions and takes into account the concentrates and forage crops fed, in addition to pasturage, to ewes and lambs. Employing these criteria upland ewes are estimated to have a national standard net output half that of lowland sheep. The study area, however, was not grazed throughout the year, neither indeed are any high fells by the whole flock, so it was necessary to consider production, live weight and wool increment, for the time spent on the fell alone.

The level of plant above-ground production by flowering plants alone is less than 1400 Kg dry weight/ha/annum (1250 lbs/acre) and the net sheep production, body and fleece weight increment, is 22.8 Kg fresh weight/ha, (20.3 lbs/acre). Allowing for body weight to contain on average 50-60% water the dry weight production comparable to the weight of herbage might be 10 Kg/ha (8.9 lb/acre). Herbage is ingested for the maintenance of life and for production of flesh, wool and energy. An average intake might be 1.5 Kg (3.3 lb) a day. Thus during the grazing season the sheep (on average there are 5600 on the fell)

will require 1784000 Kg (1752 tons) of dry vegetation to give an animal production of 385000 Kg (378 tons). The efficiency of this conversion is seen to be 2.2% and on this basis the farming system is inefficient, due mainly to the keeping of a high proportion of animals that produce little. Macfadyen (1964) estimated that 6% of the organic matter produced under a pastoral system in England was assimilated by herbivores. Beef cattle raised on grassland have an assimilation efficiency of 10.9% (Phillipson 1966), but their intake is in the order of one-seventh of total primary production (Macfadyen 1964). Rawes and Welch (1969) considered that on the best grasslands of the study area half the sward herbage produced was eaten, Eadie & Cunningham (1969) however, shows this to be an over-estimate on other vegetation types the intake diminished until it was unmeasurable. As most of the area comprises poor quality vegetation it is reasonable to assume that intake is certainly not more than the one-seventh quoted by Macfadyen, particularly as an average sward production of 2500 Kg/ha (2230 lbs/acre), much of this being bryophytes and other unpalatable species, is a likely value according to measurements made.

Thus there is a considerable amount of plant growth that is apparently unutilised. Under good conditions this is either consumed by invertebrate herbivores, or, on the death of the leaf, reduced by decomposing organisms and incorporated into the soil. Under upland conditions, however, where soils are wet and cold and plants are often naturally resistant to decay, the rate of decomposition is slow. Measurements have shown (Heal, pers comm) that the loss in dry weight of fallen plant parts was, after two years, only 29% in the case of Calluna shoots, 37% for Eriophorum leaves and 30% for Juncus squarrosus, whereas under lowland conditions grass leaves can be expected in the summer to disappear within weeks or at the most months of senescence.

(d) Effects of grazing

An increase in grazing reduces the amount of plant material available for decomposition, and, provided the animal production is low, may not deplete the nutrient stock; rather by defaecation, urination and treading the grazing animal may stimulate biological activity and improve the availability of soil nutrients.

Sheep, however, may be responsible (1) for the loss of nutrient elements both from specific swards by their transfer in dung and urine both from the sward and from the fell as a whole; and (2) for changes in botanical composition, both in the long-term, and, more quickly, after changes in management, such as an alteration in grazing intensity, in times of grazing or in the age groups on the fell.

(1) Nutrients

The estimated effect of sheep on the nutrient status of two important swards is shown in Table 3. These amounts are small. Table 4 shows the calculated loss from the fell in sheep output.

Table 3 Approximate amount of calcium, nitrogen, phosphorus and potassium in the herbage eaten by sheep on two swards and the amount returned in the dung and urine (g/m^2) (after Rawes & Welch, 1969).

	Ca	N	P	K
Agrostis-Festuca grassland				
Intake	o.5	2.05	0.15	1.45
Dung	0.2	0.65	0.10	0.35
Urine	+	1.70	+	1.20
Amounts removed from sward	0.3		0.05	
Amounts added to sward		0.20		0.10
Juncus squarrosus sward				
Intake	0.1	1.8	0.2	0.7
Dung	+	0.1	+	0.1
Urine	+	0.3	+	0.2
Amounts removed from sward	0.1	1.4	0.2	0.4

Urine values estimated from:

Ca - based on data of Herriott & Wells (1963)
N - based on data of Wolton (1963) and Herriott & Wells
P - based on data of Wolton, Herriott & Wells and Barrow & Lambourne (1962)
K - based on data of Wolton, Herriott & Wells and Watkin (1954)

The swards that support most sheep are likely to be those most affected by any depletion of nutrients, but some areas habitually used at night (night camping sites) have high concentrations of dung and on these places there is likely to be an increase in the nutrient stock. Often, of course, these latter sites being relatively dry, are also the most heavily used and grazed during the day time. In addition, it has been shown by Hilder (1966) that dung is not evenly distributed throughout a pasture but that 30% of it is deposited on only 6% of the whole area. Transfers of fertility within 0.1 ha (2.5 acre) plots have also been noted by Collins (1967) whereas we have found certain parts of swards being examined for dung deposition to consistently have similar amounts during a year of measurement. Thus translocation of nutrients must be considered on a micro-scale and this is of importance because so many hill communities are small in extent, and on some of these good swards there is evidence of sward variability which may be due to grazing and dunging habits. Taking the fell as a whole, however, it is unlikely that nutrient transfer is important under the present grazing regime.

Table 4 Annual loss of calcium, nitrogen, phosphorus and potassium ($g/m^2 \times 10^4$) from the fell by way of sheep output (from Rawes & Welch, 1969).

	Ca	N	P	K
Sheep sale	236.8	349.7	71.1	29.6
Wool sale	1.6	95.3	0.5	82.2
Total	238.4	445.0	71.6	111.8

The removal of minerals and nutrients in sheep has been estimated from analyses of carcase and fleece composition applied to the live-weight production on the fell (Rawes & Welch, 1969). The values given in Table 4 appear small when compared with the total loss from the fell in erosion and the input in precipitation. Crisp (1966) estimated that for a 83 ha (205 acre) catchment on the area there was a net annual loss of 50 Kg (110 lbs) of calcium, 9 Kg (20 lb) of nitrogen and 8 Kg (18 lb) potassium; phosphorus loss was very small. The annual input by rain and snow was estimated as 745 Kg (1639 lb) calcium, 681 Kg (1498 lb) nitrogen, 255 Kg (561 lb) potassium and 45 Kg (99 lb) phosphorus, whilst the total output (sheep, stream output, erosion, annual drift) was 4864 Kg (10700 lb) calcium, 1467 (3227 lb) nitrogen, 961 Kg (2114 lb) potassium and 71 Kg (156 lb) phosphorus. The major loss in sheep production was of nitrogen, but even this was less than 0.5% of the total from the area. The highest percentage removal of any mineral was of phosphorus, but even so it was less than 1% of the total lost.

(2) Botanical

In sixteen years, blanket bog swards at 560 m (1837 ft) O.D. protected from grazing have altered little and it seems most unlikely that much change would occur in the long-term on this vegetation. Where the bog has been burnt, however, if the grazing pressure is heavy, there is a continuation of Eriophorum dominance and low Calluna cover much beyond the more usual six years. At higher altitudes grazing, probably together with climate, is responsible for there often being little Calluna, its place being taken by Empetrum nigrum. However, increased grazing of blanket bog may increase its grazing value. Welch & Rawes (1966) showed that a bog close to the study area was grazed over the year, by on average, 1 sheep/2 ha. Within this bog the remaining Calluna had little cover, but Deschampsia flexuosa (Wavy Hair Grass), Festuca ovina and Juncus squarrosus were present and Eriophorum was common and generally closely grazed.

The position of Juncus squarrosus raised interesting hypotheses for clearly it is a plant associated with sheep grazing, in that if grazing is prevented the plant frequently dies out (Welch and Rawes, 1964),, or at least occupies a subordinate position in the sward. These swards, however, are more productive than many moorland swards, and thus, if management practices can be directed to increasing their extent at the expense of those swards more neglected by sheep, this could be considered advantageous. It is suggested that some blanket bog areas now covered by Calluna-Eriophorum-Sphagnum could, by an increase in grazing pressure, be converted to include Juncus squarrosus and fine-leaved grasses and even possibly to a sward dominated by Juncus squarrosus. Trials are at present being undertaken on the study area to test this and preliminary results support this hypothesis. On both Juncus and Nardus swards, there are possibilities of further change, induced by increasing grazing pressure. Nardus swards with a greater proportion of broad-leaved grasses and flowering plants are more productive and better utilised than the under-grazed and species-poor tussocky swards that are frequently found in areas of low sheep density. On these latter swards it is only the minimal grazing they receive that prevents the incursion of ericaceous species and the development of a dwarf shrub community.

The majority of the places below an altitude of 600 m (1970 ft) that are now grassland would support trees or shrubs in the absence of grazing. Sorbus aucuparia (Rowan) grows on rock ledges which are inaccessible to sheep, at 540 m (1772 ft), and, when planted and fenced, is, along with other hardwoods, being grown at higher elevations. Rawes & Welch (1969) considered the grasslands botanically relatively stable under the present sheep grazing regime. Little change has been noted during 15 years observation. A few Agrostis-Festuca swards, may, however, be grazed so heavily that thistles and bryophytes are increasing at the expense of plants more acceptable to sheep. But generally these grasslands are rich in species and there is reason to suppose that their overall diversity is in no small measure due to an optimal grazing regime. The removal of grazing from such grasslands has been found, within the first 12 years, to reduce the number and cover of species. Evidence, however, has been found of local dominance by species which were previously minor components of the sward (eg. Deschampsia cespitosa (Tufted Hair Grass).

Jones (1967) found that exclosure resulted in a reduction of species on moorland in Wales. These swards from which grazing had been removed are, however, in a transitional stage of seral development towards a climax vegetation. It is nevertheless interesting to note that reversion to previous sward composition takes a long time. The effect of a period of exclosure was, in Wales, apparent 25 years after the site had been re-opened to grazing.

CONCLUSION

Diversity of plant communities is important for the continued use of fell land by sheep under the present grazing management. Species diversity within swards together with a good range of communities improves the overall quantity and quality of food available over a great part of the year.

The Agrostis-Festuca and Festuca swards provide nutritious feed during the summer and autumn but growth may be late in the spring and plant leafage negligible in winter. Taller swards, Nardus and Juncus squarrosus, however, provide out-of season feed; they not only contain different species but their micro-climate, being less subject to the extremes of the short-turfed grasslands, may beneficially affect plant growth rates and improve productivity. The dominants themselves provide feed at times of scarcity, although Nardus in particular has a high fibre content and is poor in minerals such as calcium. Juncus squarrosus is one of the few plants that, irrespective of climate, remains winter green and its shoots are often closely grazed by sheep in the early spring.

Even the larger rushes, Juncus effusus and J. conglomeratus, are readily grazed by sheep, cattle and horses when the ground is snow-covered, and they provide shelter from the weather. Whilst cattle may more readily graze rushes they poach the ground to a greater extent and the abundant and highly viable seeds of these species quickly find the bared soil a suitable habitat to colonise. Grass swards created on blanket bog in Ireland have been shown to be more quickly invaded by rushes when grazed by cattle than by mixed stocking or sheep alone.

Calluna provides winter feed for sheep but is unable to withstand prolonged grazing especially by cattle. Eriophorum vaginatum has the capacity to grow at lower temperatures than most plants and the flowering shoots may appear at any time during the winter months if conditions are temporarily suitable. The leaves, and particularly the shoots, retain good contents of potassium and phosphorus. Trichophorum cespitosum (Deer Grass), Narthecium ossifragum (Bog Asphodel), Eriophorum angustifolium and Rubus chanaemorus (Cloudberry) all plants of high-level blanket bog, are grazed, often in late summer when the grasslands may offer less.

It is well known that sheep are highly selective grazers, and may seek out the smallest of plants. Frequently inflorescences are eaten. Thus the botanical composition of a sward may often appear less diverse than it is.

It is also accepted that grazing effects differ according to the type and breed of animal. Cattle tend to be less selective than sheep, whilst horses are fastidious. Dunging patterns also differ, horses tend to habitually utilise specific areas whereas sheep and cattle do not. Sheep raised on a Calluna dominated moor, with little alternative vegetation, will thrive on it but sheep accustomed to grass swards will only graze Calluna when food is scarce. In the past older animals grazed the fells and the wether flocks, with sheep 3-5 years old, commonly used the higher ground to a greater extent than now and they were also said to have made more use of the Nardus areas (Roberts, 1959).

Without sheep much of the northern Pennines below 454 m (1500 ft) would be covered by a scrub or woodland vegetation. On the higher and more exposed ground climate would exert such an influence as to make this unlikely. Ideally, to provide most biological interest, a variety of habitats, some grazed and others not, is necessary to achieve the greatest diversity. Under most hill conditions there are usually small areas that are inaccessible to sheep and others that are little grazed. However, it is probable that in order to retain certain interesting and genetically important communities, larger areas, where grazing, burning and draining are either eliminated or closely controlled are required. The future value of hill land both for farming and conservation, depends on careful management of its meagre natural resources.

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