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MLURI Hill grazing management model

Windows version 1.0

Ecological and user manual

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No. 83
MLURI Hill Grazing Management Model
Windows Version 1.0
Ecological and User Manual

EN, MLURI, SNH (Contract: F72-18-19)

Nominated Officer: J Manley

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MLURI Hill Grazing Management Model EN User Group

The computer disc holding the MLURI programme, which accompanies this manual, is available from Jayne Manley, Upland and Freshwater SST, Peterborough.

If you would like a copy of the disc please tear off and return the slip below. By doing so you will automatically register as a member of the MLURI Hill Management Model EN User Group. Members of the group will be trained in the use and interpretation of the model and, through its use, assist in its validation.

To: Jayne Manley, Agricultural Ecologist, Upland and Freshwater SST, Peterborough.

From: .... Natural Area & Office: ....

Please send me a copy of the **MLURI Hill Grazing Management Model** programme disc. I understand that on receipt I will be registered as a member of the **EN User Group**.

Date: ....

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INPUTS

1. Site data

1.1 Zone

The zone is the temperature zone in which the site is located and is in the range 1 - 11 (Appendix 1, Fig. 2). Climatic zones are delineated on the basis of mean July temperature at sea level. If a site is on the border between two zones, the model should be run for both climatic zones and the results compared.

1.2 Location (upland/lowland)

The model can predict vegetation production of lowland, as well as upland, heaths. Lowland heaths are generally in the south of England and occur on low nutrient status, sandy soils.

1.3 Latitude (east/west)

The latitude of the country in which the site is located affects the default values for heather cover. If the site is in the east of the country i.e. east of, or including, the Grampians in Scotland or the Pennines in England, the default values are higher than if it is in the west of the country, where conditions tend to be wetter and heather grows less well.

2. Heather information

2.1 Altitude

The average altitude, in metres, of all heather types.

2.2 Area.

The area, in ha, of each of seven heather types at the site.

2.3 Cover

Cover is the average ground cover of heather within the total area of each of these heather types. If possible, the default values should be replaced by site-specific information.

2.4 Heather types.

The seven heather types are defined as follows:

Heather Type	Definition
Newly burnt	Less than 2 years since a burn
Pioneer	Less than 15 cm tall
Building	15 - 30 cm tall
Mature	30 - 40 cm tall
Degenerate	Greater than 40 cm tall
Suppressed	Heather in exposed sites kept short by climatic conditions. Usually less than 10 cm tall.
Blanket bog	Normally waterlogged

3. Indigenous grassland

3.1 Altitude

The average altitude, in metres, of all indigenous grassland types.

3.2 Grassland type

The grassland types which can be simulated by the model are defined as follows:

Grassland type	Definition
Agrostis/Festuca	Species rich grassland dominated by *Agrostis* spp. and *Festuca* spp. but with a higher proportion of *Agrostis* spp. than *Festu*ca spp. This will tend to occur on base rich soils.
Festuca/Agrostis	Species poor grassland dominated by *Festuca* spp. and *Agrostis* spp. but with a higher proportion of *Festuca* spp. than *Agrostis* spp. This will tend to occur on acid soils.
Nardus	Grassland with a higher proportion of *Nardus stricta* than of any other grass types in the model.
burnt *Molinia*	Grassland with a higher proportion of *Molinia caerulea* than any of the other grass types in the model and which has been burnt within the last year.
unburnt *Molinia*	As above but which has not been burnt within the last year.

It is assumed that *Nardus* is not eaten by sheep. The area of Nardus grassland in included, however, because *Festuca/Agrostis* growing between *Nardu*s tussocks can be a very important resource to sheep.

3.3 Areas

The area, in ha, of each of the indigenous grassland types.

3.4 Cover

Cover is the average ground cover within the appropriate grassland type of the grass types for which this is required (*Nardus* and *Molinia*). Cover is also required for species poor *Festuca/Agrostis* growing amongst each of the heather types and amongst *Nardus* and burnt and unburnt *Molinia*. Total cover of any two vegetation types growing in mosaic must not exceed 100%. If it does, you will be given an error message when you try to save the file.

4. Reseeded Grassland

If sheep are taken off the hill and put onto reseeded pasture then do not enter anything into this entry screen. You only need to put information in here if the sheep have free access from the hill to reseeded grassland. Reseeded grassland can be of any age since reseeding and may not necessarily be fertilised currently.

4.2 Altitude

The average altitude of the reseeded grassland.

4.1 Area

The area, in ha, of reseeded grassland open to the hill all year.

4.2 Management class

Management class is 1 if it is permanent grassland containing large amounts of clover. It is 2 if in is permanent grassland receiving less than 300 kg N/ha.

4.3 Fertiliser

If fertiliser rate is applied then the rate, in kg $ha^{-1}y^{-1}$, must be supplied as well as the soil type (Table 1) and the average summer rainfall (Table 2).

Table 1.

Soil Class	Soil description
1	All soils except shallow soils over chalk/rock or gravelly and coarse sandy soils or organic soils in the east of the country.
2	Shallow soils over chalk/rock or gravelly and coarse sandy soils or organic soils in the east of the country.

Table 2.

April - September rainfall	Rainfall class
Less than 350 mm	4
350 to 425 mm	3
425 - 500 mm	2
Greater than 500 mm	1

5. Sheep

5.1 Average line weight
This is the average live weight of a typical ewe (kg). Some examples of typical live weights for different breeds are given in Table 3.

Table 3.

Sheep breed	Typical live weight (kg)
Black Welsh	27
Shetland	27
Welsh Mountain	32
Herdwick	41
Hill Radnor	41
Cheviot	43
Swaledale	43
Whiteface Dartmoor	43
Exmoor Horn	45
Rough Fell	45
Dales Bred	48
Black face	50
Llanwenog	50
Dartmoor	52
Lonk	52
Southdown	52
Derbyshire Gritstone	54
North Country Cheviot	54
Devon Close Wool	57
Ryeland	59
Beulah Speckled Face	64
Dorset Down	64
Kerry Hill	64
Wiltshire Horn	64
Polled Dorset Horn	66
Shropshire	66
Clun Forest	68
Dorset Horn	68
Hampshire Down	68

5.2. Sheep numbers

The number of sheep on the hill in each month of the year. The model assumes that all sheep are ewes and produce one lamb each.

HOW THE MODEL WORKS

The structure of the model is shown in Appendix 1, Fig. 1. The model first calculates the production of each of the vegetation types in each month of the year taking into account altitude and temperature zone. It then simulates vegetation production and grazing by sheep from each vegetation type on each day of a typical year. The model runs for two years. By the second year it has reached a steady state and will not be influenced by initial values. The model results are for the second year. Further details on how the model works can be found in Appendix 1.

OUTPUTS

The output file contains all the information entered into the input screens as well as a large number of outputs. These data are in the form of single items, a three column array or monthly values.

1. Single items

Listed under single items are: site name, data collector, side of the country, location in uplands or lowlands, temperature zone, heather altitude, reseeded pasture area open to the hill all year, reseeded pasture altitude, reseeded pasture management class, fertiliser rate, rainfall class, soil type, reseeded pasture annual production, indigenous grassland altitude and average ewe line weight.

2. Array data

The array data gives the model's predictions of the annual production (kg Dry Matter ha^{-1} y^{-1}) of each of the vegetation types considered by the model. It also lists the area (ha) and ground cover (%) of each as input to the model by the user. *Festuca/Agrostis* growing in mosaic with each of the other vegetation types is considered separately.

3. Monthly data

The monthly data presented is either the total for each month or the daily value on the last day of the month depending on which is appropriate.

3.1 Heather data

For each heather vegetation type, heather shoot biomass production (kg Dry Matter ha^{-1}), the amount eaten by the whole flock (offtake) from the most recent year's shoot biomass (kg Dry Matter ha^{-1}) and standing biomass of the most recent year's shoot growth (kg Dry Matter ha^{-1})

are given as totals for each month. The proportion of the most recent year's shoot growth t date which has been eaten by the sheep (utilisation rate) is calculated cumulatively from th start of heather growth on the first day of May and is given for the last day of each montl The value for April is, therefore, the annual utilisation rate.

3.2 Grass data

For each grass vegetation type, biomass production, offtake of green biomass and offtake c dead biomass (kg Dry Matter ha^{-1}) are given as totals for each month. Utilisation rate i calculated cumulatively from the start of the grass growing season on the first day of Apri and is given for the last day of each month. The value for March is therefore the annua utilisation rate. Standing green biomass, standing dead biomass (kg Dry Matter ha^{-1}) an sward height (cm) are given for the last day of each month. *Festuca/Agrostis* growing i mosaic with each of the other vegetation types is considered separately.

3.3 Sheep data

Ewe numbers on the hill in each month of the year, as input to the model by the user, ar listed. A range of other information is provided for an individual ewe, on a daily basis, o the last day of each month and in relation to each vegetation type. These are: the amoun eaten by a single ewe in one day (intake) (kg Dry Matter), digestibility of the diet i.e. th proportion of the intake which can be digested, grazing time (minutes), bite weight (mg Dr Matter per dite), potential intake of digestible material (kg Dry Matter per day), rate of intak (g Dry Matter $minute^{-1}$) and bite rate (bites $minute^{-1}$). For the first three of these, totals fo all vegetation types are also given.

PREDICTING DAMAGING GRAZING RATES ON HEATHER

A utilisation rate on pioneer heather greater than 40% may cause a gradual decline in cove For other heather types, the utilisation rate above which cover will decline is likely to b considerably lower. The model predicts the average utilisation rate on each vegetation typ In practice, grazing is not spatially uniform even within a vegetation type. On heathe utilisation rates are likely to be higher than the average where there is a large proportion c *Agrostis/Festuca* or *Festuca/Agrostis* growing amongst the heather or in close proximity t it or around feeding sites. A utilisation rate prediction by the model of greater than 40% ca be interpreted as suggesting a high probability that the heather will be damaged by grazin especially in the most heavily grazed areas. If the model also predicts high utilisation rate on the *Agrostis/Festuca* and *Festuca/Agrostis*, especially the latter growing amongst heathe (perhaps greater than 70%), then this would provide a further indication that the heather i likely to be at risk.

SHEEP MANAGEMENT

The model assumes that sheep are not shepherded, are not given supplementary feed othe than storm feeding and that all sheep are ewes producing one lamb each. If sheep ar shepherded then the spatial distribution of utilisation rates within each vegetation type i likely to be more uniform. If sheep are given supplementary feed then the offtake of th indigenous vegetation may increase or decrease depending on the quantities of supplementar feed given. If only small amounts are given, this is likely to increase offtake from the indigenous vegetation since diet digestibility will increase and this will allow intake per ewe to increase. If the sheep can obtain most of their intake from the supplementary feed then offtake from the indigenous vegetation will fall.

FEEDBACK

Since this model is still under development, it is supplied free of charge. Neither the Macaulay Land Use Research Institute, Scottish Natural Heritage nor English Nature can accept any responsibility for decisions made on the basis of information obtained from the model. To help us with further development we request that you keep us informed of the performance of the model; not only its usefulness as an educational tool but also your opinions of the accuracy of its predictions. Please direct your comments to:

Dr John Milne, Macaulay Land Use Research Institute, Craigiebuckler, Aberdeen, AB9 2QJ
Tel: (0224) 318611

or

Dr Helen Armstrong, Scottish Natural Heritage, 2, Anderson Pl., Edinburgh, EH6 5NP
Tel: (031) 446 2476

Any general queries about the model should be addressed to the latter.

November 1993

Appendix 1

Technical description of the model

VEGETATION

OVERVIEW

Thirteen vegetation types, all common in the hill areas of the U.K., are considered; seven dominated by heather, reseeded pasture and five types of indigenous grassland. Mosaics of indigenous grass and heather vegetation types are also considered. A flow diagram of the model is given in Fig. 1.

Gross annual dry matter (DM) production of all herbages is calculated as a function of the temperature zone and altitude of a given site. In the case of reseeded pasture, past and future fertilizer rates, summer rainfall and soil water capacity are also used to calculate gross annual DM production. Annual DM production is then divided into monthly DM production using information on patterns of seasonal production. Rules governing rates of senescence and litterfall determine how much live grass is converted to standing dead grass and how much standing dead grass disappears. Relationships between biomass and sward height are used to predict mean sward height of each grass vegetation type. The outputs from the model for the grass vegetation types are annual and monthly gross DM production, monthly biomass of live and dead DM and sward height. The outputs for the heather vegetation types are annual and monthly gross DM production of the current year's shoots.

ADJUSTMENT OF ALTITUDE FOR TEMPERATURE ZONE

In order to adjust DM production of a vegetation type for varying climatic conditions altitude is adjusted on the basis of mean July temperature to its equivalent in the temperature zone (see Figure 2 for a description of the temperature zones) where the relationship between DM production from a given vegetation type and altitude was derived, using the following relationship (Lance 1987):

$$A_T = L(A + Z) \qquad (1a)$$

where A_T = altitude adjusted for temperature zone (m), L = adjustment factor for differences in the rate of change of temperature with altitude (lapse rate), A = unadjusted altitude (m) and Z = adjustment factor for temperature zone. (Appendix Table 1 contains a list of the symbols used in all the equations). Z and L values for each of the ten temperature zones, shown in Figure 2, and for each vegetation type, are given in Appendix Table 2. These have been modified from Lance (1987) so that the zone where no adjustment is necessary is set at zones 5, 9 and 7 for heather, reseeded pasture and indigenous grassland respectively. These are the zones where the production data for each of these vegetation categories were mainly collected.

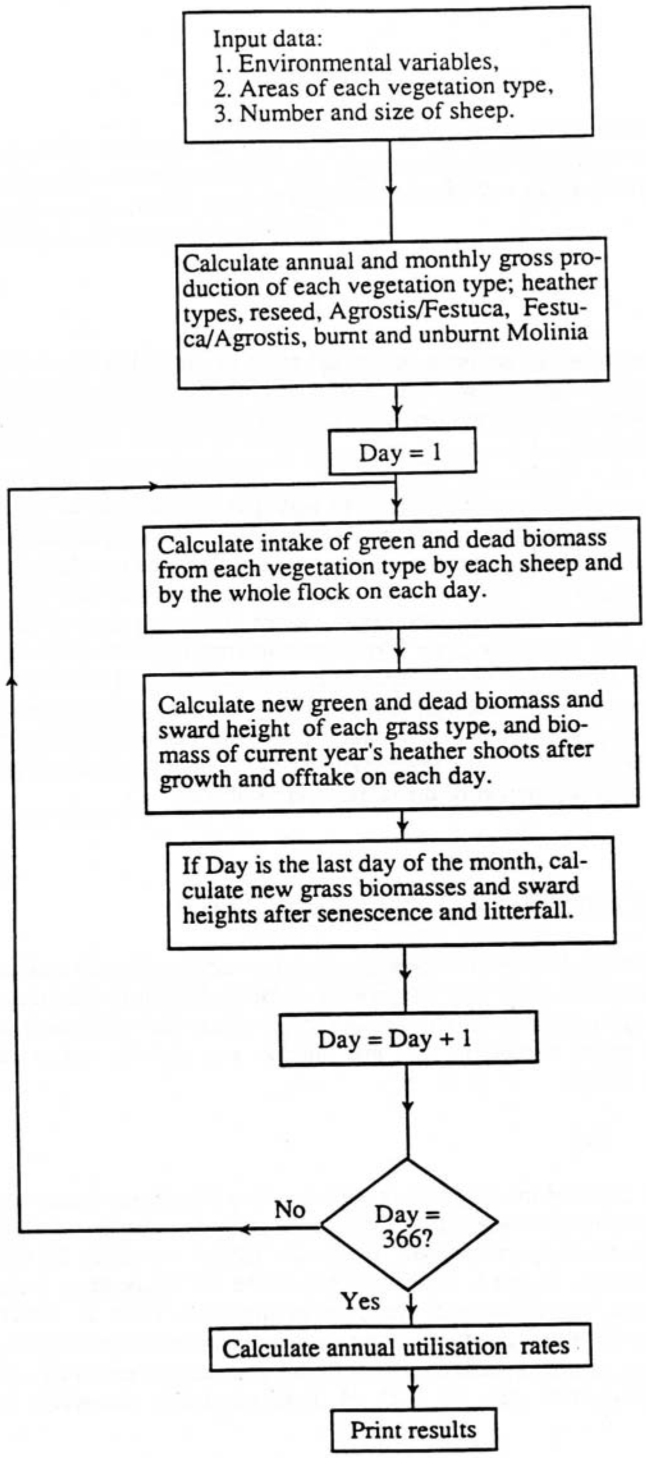

Fig. 1. Flow diagram of the structure of the model.

Figure 2. Temperature zones used in the model. The zones are separated by mean July isotherms corrected to sea level with 0.5°C separating the isotherms. ***(Meteorological Office, 1975)***

Appendix Table 1. Summary of Symbols used in equations

A = unadjusted altitude (m)
A_T = altitude adjusted for temperature zone (m)
B = sward biomass (kg DM ha^{-1})
$G(t)$ = DM production on day t (kg DM ha^{-1} day^{-1})
H = sward height (cm)
L = adjustment factor for change in temperature with altitude (lapse rate)
N_F = annual application of fertilizer nitrogen (kg ha^{-1})
N_S = soil nitrogen (kg ha^{-1})
P_H = annual DM production of heather shoots at 100% heather cover (kg DM ha^{-1})
P_R = predicted gross annual production (kg DM ha^{-1})
R = average summer rainfall (April-September) (mm)
t = time in days from 1 April
W = available water capacity of the soil (mm)
Z = adjustment factor for temperature zone.

Appendix Table 2. Z and L values for each vegetation type and temperature zone.

Temperature	Heather		Reseeded grass		Indigenous grass	
Zone	Z	L	Z	L	Z	L
1	287.05	1.13	574.09	1.26	430.57	1.19
2	222.22	1.09	518.52	1.22	370.37	1.16
3	152.77	1.06	458.32	1.18	305.55	1.12
4	78.70	1.03	393.49	1.15	236.10	1.09
5	0.00	1.00	324.05	1.11	162.02	1.06
6	-83.32	0.97	249.97	1.08	83.32	1.03
7	-171.27	0.95	171.27	1.05	0.00	1.00
8	-263.85	0.92	87.95	1.03	-87.95	0.97
9	-361.05	0.90	0.00	1.00	-180.52	0.95
10	-462.87	0.88	-92.57	0.98	-277.72	0.93

HEATHER

Definitions of the seven heather vegetation types considered by the model are given in Appendix Table 3. Heather growing in other than blanket bog conditions will be found in a number of vegetation communities including those classified under the National Vegetation Classification as H1-H12, H15, H16, H17-22, M15 and M16 (Rodwell 1991). Climatically suppressed heather is classified as H13, H14 and H17 (Rodwell 1991). Blanket bog heather will normally occur within vegetation communities M17-M19 (Rodwell 1991).

Appendix Table 3. Heather types used in the model and the default values for cover of heather.

Heather Type	Cover (%)	
	East[1]	Newly
burnt (less than 2 years since burn)	0	Pioneer[2]
(less than 15 cm tall)	55[3]	Building[2]
(15 - 30 cm tall)	85[3]	Mature[2]
(30 - 40 cm tall)	95[3]	
Degenerate[2] (more than 40 cm tall)	75	
Suppressed (heather in exposed sites kept short by climatic conditions. Usually 10 cm or less)	100	
Blanket bog	75	

[1] The East is taken to be east of (and including) the Pennines in the north of England and the Grampians in Scotland. Default values for cover in the west is assumed to be 0.70 of that in the east.
[2] Categories taken from Watt (1947).
[3] Miller and Watson (1978).

Heaths are classed as upland or lowland. Lowland heaths are those at low altitudes in the south of England where rainfall and soil nutrients are low (Chapman & Clarke 1980) and where annual production is taken to average 2935 kg DM ha^{-1} (Chapman, Hibble & Rafarel 1975).

For upland heath types, including blanket bog but excluding climatically suppressed heather, annual DM production of shoots at 100% cover is predicted using a linear regression on altitude derived from 28 values obtained from the literature (Moss 1969; Rawes & Welch 1969; Barclay-Estrup 1970; Grant 1971; Forrest & Smith 1975; Moss & Miller 1976; Miller 1979, Moss, Welch and Rothery 1981). Most of the measurements were made in north-east Scotland.

The relationship between annual DM production of heather shoots at 100% cover (P_H, kg ha^{-1}) and altitude adjusted for temperature zone to its equivalent in north-east Scotland (A_T, m) is given in Equation 2a:

$$P_H = 3462 - 4.41A_T \quad r^2 = 0.40 \qquad (2a)$$

DM production of climatically suppressed heather is based on the finding that the length of long shoots of suppressed heather at a site in southern Scotland was 0.40 times the length of long shoots of non-climatically suppressed heather (Armstrong & MacDonald 1992). The average altitude of the heather at this site was 600 m for which the above equation predicts an annual DM production of shoots of 1252 kg DM ha^{-1} at 100% cover. If long shoot length is assumed to be directly proportional to production, then the equivalent figure for suppressed heather would be 500 kg DM ha^{-1}. In the absence of actual measurements, this figure has been used for suppressed heather and is not varied with altitude or temperature zone.

Annual DM production of the different heather types is assumed to vary with their percentage cover (Miller 1979). Values of production at 100% cover are adjusted for actual cover (typical examples are given in Appendix Table 3) to give annual DM production of heather shoots for each heather type. Growth in May, June, July and August is assumed to be 8.1, 32.5, 53.2, and 6.2 percent of total DM production of shoots respectively (Grant 1971). Only the biomass of the current year's shoots are predicted since this is the component most likely to be eaten by sheep (Milne 1974). During one year, senescence and litterfall from the current year's shoots are assumed to be negligible.

RESEEDED GRASSLAND

Pastures, which have been reseeded with perennial ryegrass (*Lolium perenne*) or with a perennial ryegrass and white clover (*Trifolium repens*) mixture, are those considered by the model.

Doyle and Lazenby (1984) used the results of nitrogen fertilizer trials on reseeded pastures under a regime of four-weekly cutting to 2 cm (Morrison, Jackson & Sparrow 1980) to derive equation 3a for the prediction of above ground annual DM production for any lowland site between mid-April and end-October (P_R, kg DM ha^{-1}).

$$P_R = 42.8N_S + 18.3N_F - 0.025N_F^2 - 0.061N_FN_S + 0.049N_FW + 0.031N_FR \quad (3a)$$

$r^2 = 0.96$, $n = 126$ where N_F = annual application of fertilizer nitrogen (kg ha^{-1}), N_S = soil nitrogen (kg ha^{-1}), R = average summer rainfall (April-September) (mm) and W = available water capacity of the soil (mm).

Since it is unlikely that N_S, R and W will be known accurately for every site, Baker, Doyle & Lidgate (1991) have derived mean values for different categories of summer rainfall, past grassland management and soil type. They describe four summer (April-September) rainfall levels (1 = 530 mm, 2 = 410 mm, 3 = 345 mm and 4 = 290 mm), two categories which relate to past grassland management, viz past management category (PMC) 1 = 160 kg ha^{-1} soil N content, relating to permanent grassland containing large amounts of clover, and PMC 2 = 120 kg ha^{-1}, relating to permanent grassland receiving less than 300 kg Nha^{-1}), and two available soil water capacity categories (1 = 142.5 mm, which is found on most soils, and 2 = 60 mm, which relates to shallow soils over chalk or rock, gravelly and coarse sandy soils or organic soils east of, and including, the Pennines in England and the Grampian Mountains in Scotland). These categories are applied to allow the estimation of P_R from Equation 3a. Although P_R represents net annual DM production under cutting managements, the assumption is made that P_R represents gross annual DM production under grazing and Equation 3a is used unaltered to calculate production under grazing.

The distribution of gross DM production under grazing between April and September is predicted using an equation derived by Doyle and Edwards (1986), which predicts daily gross production between mid-April and the end of October. Since Morrison, Jackson & Sparrow (1980) normally took their first measurement of DM production in April and their final harvest at the end of September, the equation of Doyle and Edwards (1986) has been converted to apply to the period between April and September (equation 4a).

$$G(t) = ((65.0 + 0.55t - 0.004t^2) / 12933.2) * P_R \qquad \text{For } 1 \leq t \leq 183 \qquad (4a)$$

Where t = time in days from 1 April and G(t) = DM production on day t (kg DM ha^{-1} day^{-1}).

Since no appropriate information is available for DM production between October and March, DM production in this period is assumed to be the same proportion of total annual DM production as that which has been found for *Agrostis/Festuca* grassland i.e. 0.18 (see Indigenous Grasslands section below). The proportions of total gross annual DM production for each month of the year were derived from the output of equation 4a after including the DM production in the period between October and March (see Appendix Table 4, Column 1, page 18).

Since herbage production is directly related to mean growing season temperature (Grace 1988) and this changes with altitude and latitude (Lance 1987), predicted herbage DM production at a specific site is adjusted for altitude and temperature zone. Gross DM production in each month is adjusted for altitude by interpolating between the correction factors given in Appendix Table 5 and assuming that the actual correction factors apply at the mean values of each altitude class. Since gross DM production in each month has been differentially adjusted, annual production is recalculated as the sum of production in each month.

Sward height of the reseeded pasture is predicted using a relationship between sward height and total biomass derived from established and continuously stocked reseeded swards in May and June in the north-east and south-east of Scotland (Grant *et al.* 1983) (see Appendix Table 6)

Appendix Table 5. Factors for correcting monthly DM production for reseeded and indigenous grasslands for adjusted altitude.

Adjusted Altitude (m)	October-April	Month May,June	July to September
[1]0 - 150	1.00	1.00	1.00
[1]150 - 300	0.75	1.00	0.85
[1]300 - 500	0.50	1.00	0.70
[2]760 - 890	0.10	1.00	0.15
[3]> 890	0.00	1.00	0.00

[1] = from Doyle and Edwards (1986), [2] = Derived from Jones and Tinsley (1980), [3] = Derived by extrapolation.

Appendix Table 6. Relationships between sward height and biomass of the grass vegetation types (H = sward height (cm) and B = sward biomass (kg DM ha^{-1})).

Grassland	Equation	n	r^2(adj)	range(cm) Type
Reseed	H = 0.00199B + 0.5	12	0.61	1.1-6.4
Agrostis/Festuca	H = 0.00170B + 1.2	130	0.74	0.9-7.6
Festuca/Agrostis	H = 0.00170B + 1.9	130	0.74	1.6-9.2
Molinia (≥1284 kgDMha^{-1})	H = 0.00464B - 4.9	9	0.89	5.5-22.8
Molinia (≤1284 kgDMha^{-1})	H = 0.00232B	-	-	-

INDIGENOUS GRASSLANDS

Two types of grassland dominated by *Festuca* spp. and *Agrostis* spp. are included in the model. Those which are on more base-rich soils and tend to have a higher component of herbs and of *Agrostis* spp. are termed *Agrostis/Festuca* vegetation types and include communities CG10 and CG11 (Rodwell 1992). Those which are on more acid soils are termed *Festuca/Agrostis* vegetation types and include communities U1, U3, U4 and CG12 (Rodwell 1992). Communities with a large component of *Molinia caerulea* are termed *Molinia* vegetation types and include community M25 (Rodwell 1992). Two *Molinia* types are considered; burnt and unburnt. Communities with a large component of *Nardus stricta* are termed *Nardus* vegetation types and include communities U5 and U7 (Rodwell 1992).

The model also takes account of *Festuca/Agrostis* growing amongst any heather type, except climatically suppressed, and amongst *Nardus* and *Molinia*. The cover of each type within each mosaic vegetation type requires to be entered as an input to the model.

Monthly gross DM production values have been taken from Job and Taylor (1978). This study provides measurements of production for three indigenous vegetation types, *Festuca/Agrostis* and burnt and unburnt *Molinia*, in the same year, at the same site (Plynlimon, Wales) and using the same measurement techniques. Other information on gross DM production available in the literature could not be used due to the diversity of methods and the variable amount of site information available for each study.

By measuring the standing biomass of live and dead material in caged and uncaged quadrats, Job and Taylor (1978) obtained values for monthly gross DM production, senescence and litterfall of species-poor *Festuca/Agrostis* (at four sites), unburnt *Molinia* (at two sites) and burnt *Molinia* (at one site) between May and October 1973. Biomass measurements in March 1974 also allowed estimates to be made for the winter period.

Job and Taylor (1978) reported that the seasonal production curves for *Festuca/Agrostis* showed a bimodal pattern with production falling in August and rising again in September and October. To assess whether this was likely to be a general feature of *Festuca/Agrostis* seasonal production curves, information was collated for a range of sites and years. Of the fifteen seasonal production curves obtained in this way, twelve did not show a bimodal pattern (one from a site in west Perthshire, Scotland (G. Tiley, unpublished data), three from three sites on the Isle of Rum, Scotland (G.R. Iason, unpublished data), six from three sites near Aberystwyth, Wales (Stapledon and Thomas 1930; Milton 1934; Milton and Davies 1947) and two from one site in the Pennines, England (Rawes 1963; Rawes and Welch 1969)). Three other sites on Rum (G.R. Iason, unpublished data) did show a bimodal production pattern. This difference in pattern was not related to grazing intensity, hence, since a unimodal production pattern was apparently more common, the results obtained by Job and Taylor (1978) were smoothed to obtain a unimodal pattern.

Grant (1968) found a linear relationship between leaf elongation of *Festuca rubra* and temperature at mean air temperatures below about 10°C. This relationship was used as a basis for converting the mean monthly temperatures for each of the months from October to April into a relative rate of growth for each month. This was then multiplied by mean daylength to give an index of relative potential production in each month. Since there was already a production value for October in the data of Job and Taylor (1978), the potential DM production in the months from November to April was calculated. The monthly production values were corrected to equivalent values at sea level using the same adjustment factors as were used for reseeded pasture (See Appendix Table 4) and by interpolating between the mean values of each altitude class.

Appendix Table 4. Proportion of annual growth at sea level of each grass vegetation type in each month.

Month	Reseed	*Agrostis/Festuca* *Festuca/Agrostis*	Unburnt *Molinia*	Burnt *Molinia*
Jan	0.013	0.013	0.0	0.0
Feb	0.015	0.015	0.0	0.0
Mar	0.038	0.037	0.0	0.0
Apr	0.137	0.067	0.006	0.001
May	0.160	0.115	0.072	0.115
Jun	0.159	0.136	0.303	0.303
Jul	0.153	0.286	0.619	0.581
Aug	0.127	0.147	0.0	0.0
Sep	0.083	0.068	0.0	0.0
Oct	0.061	0.061	0.0	0.0
Nov	0.034	0.034	0.0	0.0
Dec	0.020	0.020	0.0	0.0

The data of Job and Taylor (1978) for the live biomass of *Molinia* have been used to calculate the DM production of this species using a similar method as that used by Job & Taylor (1978) but making the assumption that growth only occurred when live biomass was increasing (Torvell, Common and Grant 1988). DM production of *Molinia* was corrected for the content of *Molinia* in the sward (taken from the early August live biomass data, D Job, unpublished data) to make it equivalent to one of 100% *Molinia*. Since *Molinia* is deciduous, it was assumed that there was no production in winter.

Values for mean monthly DM production at Plynlimon of *Festuca/Agrostis* and burnt and unburnt *Molinia*, adjusted from the original as described above and after adjustment to sea level, are given in Appendix Table 7. Using this information, the proportionate growth in each month was derived for each vegetation type at sea level (see Appendix Table 4, columns 2, 3 and 4). Production is adjusted for latitude using the same method as is used for reseeded pastures.

An extensive review of the literature revealed no difference in the gross DM production between *Festuca/Agrostis* and *Agrostis/Festuca* pastures and they have been treated similarly in relation to the production of monthly gross DM production. Relationships between height of live leaf and total sward biomass for *Agrostis/Festuca* and *Festuca/Agrostis* swards were derived using data collected on the Isle of Rum (I. J. Gordon, unpublished data). The relationships obtained for the two vegetation types in summer were also used for winter (see Appendix Table 6).

Data on height and biomass (minimum 1284 kg DM ha^{-1}) of ungrazed *Molinia* swards (S.A. Grant and T.G.Common, unpublished data) have been used to derive a linear height:biomass relationship for above 1284 kg DM ha^{-1} for this vegetation type. At sward biomasses below 1284 kg DM ha^{-1}, a linear relationship between sward height and sward biomass was developed which passed through the origin (see Appendix Table 6). It is assumed that with *Nardus* communities the only vegetation resource available to sheep is *Agrostis-Festuca* and, therefore, biomass production of *Nardus* is not considered in the model.

Appendix Table 7. Mean monthly production (kg DM ha^{-1}) of the three vegetation types at Plynlimon after adjustment to sea level.

Month	*Festuca/Agrostis*	Unburnt *Molinia*	Burnt *Molinia*
Jan	65	0	0
Feb	75	0	0
Mar	181	0	0
Apr	331	18	3
May	568	206	309
Jun	670	867	813
Jul	1407	1770	1562
Aug	725	0	0
Sep	333	0	0
Oct	299	0	0
Nov	170	0	0
Dec	98	0	0
Total	4920	2860	2687

SENESCENCE AND LITTERFALL OF GRASSES

Senescence is defined as movement of biomass from the live component to the standing dead component of the sward. Litterfall is defined as loss of standing dead material above ground; either by decomposition or into the soil litter layer. The model has four age classes of live and three of dead biomass. The youngest live material is that which has grown in the current month. At the end of the month each age class moves into the next oldest unless it is already at the oldest age class. The oldest live biomass moves into the youngest dead age class and the oldest dead biomass moves out of the system at a rate dependent upon the senescence and litterfall set for each month (see Appendix Table 8).

There are six combinations of rates of litterfall and of senescence depending on the time of year and the grass type (Appendix Table 8). These have been set so as to replicate the general pattern of senescence and litterfall observed by Job and Taylor (1978) i.e. high litterfall in spring, high senescence in late summer and negligible litterfall or senescence over winter

Appendix Table 8. Senescence and litterfall rates. Conditions apply to all grass vegetation types unless otherwise stated.

Conditions	Senescence (transfer to litterfall pool)	Litterfall (transfer to a soil pool)
January - March	None	None
April, October	50% oldest live leaf	50% oldest dead leaf
May - September	100% oldest live leaf	100% oldest dead leaf
November - December	50% oldest live leaf	50% oldest dead leaf
August - September)	50% second oldest live leaf	100% oldest dead leaf
)		
(Molinia))	100% oldest live leaf	
October (*Molinia*)	100% life leaf	50% oldest dead leaf

OFFTAKE

OVERVIEW

Monthly and daily DM production of a range of vegetation types common in the hill areas of the U.K. are predicted for an average year at any site using the vegetation sub-model and this provides an input of vegetation biomass and grass height to the grazing sub-model described below. On each day the model predicts intake by sheep and offtake by the whole flock. Standing biomass and sward height of each grass vegetation type and biomass of the current year's shoots of each heather vegetation types are adjusted daily. At the end of each month, senescence and litterfall are estimated and standing biomasses and sward heights further adjusted. The model estimates standing live and dead biomass, sward height and utilisation rate of each vegetation type in addition to intake and digestibility of the total diet and its components throughout the year.

INTAKE OF POTENTIAL DIGESTIBLE DRY MATTER FROM EACH VEGETATION TYPE

Predicted potential daily intakes of digestible DM from each vegetation type, assuming it alone was being grazed, are combined with a model of foraging behaviour by sheep to predict actual daily DM intake from each vegetation type. Potential daily intake of digestible DM from any vegetation type is limited either by the harvestable biomass or by its digestibility.

In order to predict the potential intake of digestible DM limited by harvestable biomass, estimates of bite weight, bite rate and maximum grazing time are used. Bite weight is predicted from bite depth, bite area and grazed stratum bulk density. For the grass vegetation communities where data are available, bite rate is predicted from sward height. Otherwise it is set as a constant. Maximum grazing time is assumed to be the same on all vegetation types at all times of the year. If DM intake is not limited by harvestable biomass, a relationship between DM digestibility of the diet ingested from the vegetation type and DM intake is used to predict DM intake. DM digestibility of the diet from each vegetation type is predicted from an estimate of bite depth, the distribution of live and dead material in the grass sward and the DM digestibility values of the live and dead material. Values for the DM digestibility of live and dead components of all vegetation types, derived from literature values, are given in Appendix Table 9.

Appendix Table 9. Dry matter digestibility of current year's shoots of heather and of live and dead components of each grass vegetation type.

Month	Heather[1]	Reseed		*Molinia*		*Agrostis/Festuca*		*Festuca/Agrostis*	
		live[2]	dead[3]	live[4]	dead[5]	live[5]	dead[5]	live[5]	dead[5]
Jan	0.41	0.77	0.41	0.48	0.34	0.69	0.34	0.66	0.33
Feb	0.41	0.77	0.41	0.48	0.34	0.71	0.34	0.66	0.33
Mar	0.41	0.77	0.41	0.48	0.34	0.73	0.34	0.67	0.33
Apr	0.41	0.77	0.41	0.48	0.34	0.73	0.34	0.67	0.33
May	0.56	0.77	0.41	0.67	0.34	0.73	0.34	0.68	0.33
Jun	0.56	0.77	0.41	0.66	0.34	0.72	0.34	0.67	0.33
Jul	0.56	0.77	0.41	0.64	0.34	0.71	0.34	0.67	0.33
Aug	0.48	0.77	0.41	0.56	0.34	0.71	0.34	0.66	0.33
Sep	0.46	0.77	0.41	0.48	0.34	0.70	0.34	0.65	0.33
Oct	0.46	0.77	0.41	0.48	0.34	0.69	0.34	0.65	0.33
Nov	0.46	0.77	0.41	0.48	0.34	0.68	0.34	0.66	0.33
Dec	0.41	0.77	0.41	0.48	0.34	0.69	0.34	0.66	0.33

[1] from Milne (1974), [2] from Bircham (1981), Armstrong, Common and Smith (1986), Hepp (1989), [3] from Illius (1985), [4] from Grant and Campbell (1978), [5] from Eadie and Black (1969). Values given in Eadie and Black (1969) for broad-leaved grasses have been used for *Molinia* and *Agrostis/Festuca* and those for fine-leaved grasses used for *Festuca/Agrostis*. The values for digestibility of dead material are the means of those given in Eadie and Black (1969), those for green material have been interpolated for months not given. Dry matter digestibility has been assumed to equal 0.94 organic matter digestibility plus 0.037 (Ministry of Agriculture, Fisheries and Food *et al.* 1975).

Appendix Table 10 Summary of symbols used in equations

A_j = area of vegetation type $_j$ (adjusted for cover) (ha).

B = total bite weight (mg DM).

B_D = amount of dead material in a bite from a grass vegetation type (mg DM).

B_E = bite weight adjusted to take account of the underestimate produced by using bite volume to calculate bite weight (Burlison, Hodgson & Illius 1991) (mg DM).

B_H = bite weight of heather (mg DM).

B_L = amount of live material in bite from a grass vegetation type (mg DM).

B_R = rate of biting (bites minute^{-1}).

B_V = bite weight calculated as the product of estimated bite volume and grazed stratum bulk density by Burlison, Hodgson and Illius (1991) (mg DM)

D_B = DM digestibility of vegetation in a bite (proportion).

D_D = DM digestibility of dead grass biomass (proportion).

D_G = DM digestibility of grasses.

D_H = DM digestibility of heather.

D_{H1} = adjusted heather DM digestbility (proportion).

D_L = DM digestbility of live grass biomass (proportion).

H = mean sward height before grazing (cm).

H_G = mean sward height after grazing (cm).

I = incisor breadth (m).

I_{DG} = daily intake per kg metabolic live weight by sheep ingesting grass vegetation types (g DM (kg live weight)$^{-0.75}$).

Appendix Table 10 continued

I_{DH} = daily intake per kg metabolic live weight by sheep ingesting grass vegetation types (g DM (kg live weight)$^{-0.75}$).

I_j = actual daily intake per ewe from vegetation type $_j$ (g DM).

I_T = total daily intake per ewe from all vegetation types (g DM).

IP_j = potential daily intake per ewe from vegetation type $_j$ if only $_j$ is available (g DM).

IPD_j = potential daily intake of digestible material per ewe from vegetation type $_j$ if only $_j$ is available (g DM).

M = total standing biomass in a grass sward (g DM m_{-2}).

M_D = standing biomass of dead material in a grass sward (g DM m_{-2}).

M_H = standing biomass of current season's heather growth at 100% cover (g DM m^{-2}).

M_L = standing biomass of live material in a grass sward (g DM m^{-2}).

P_L = proportionate change in intake of a ewe with a single lamb compared to that of a dry ewe.

R_D = ratio of dead biomass in the bite to that in the sward within the bite area.

R_L = ratio of live biomass in the bite to that in the sward within the bite area.

R_S = ratio of the proportion of live biomass in the bite to that in the sward. This is pre-set to 0.5 during November to March inclusive.

T_G = grazing time (minutes).

T_L = number of days since lambing.

W = average live weight of a dry ewe in November (kg).

W_L = lamb live weight (kg).

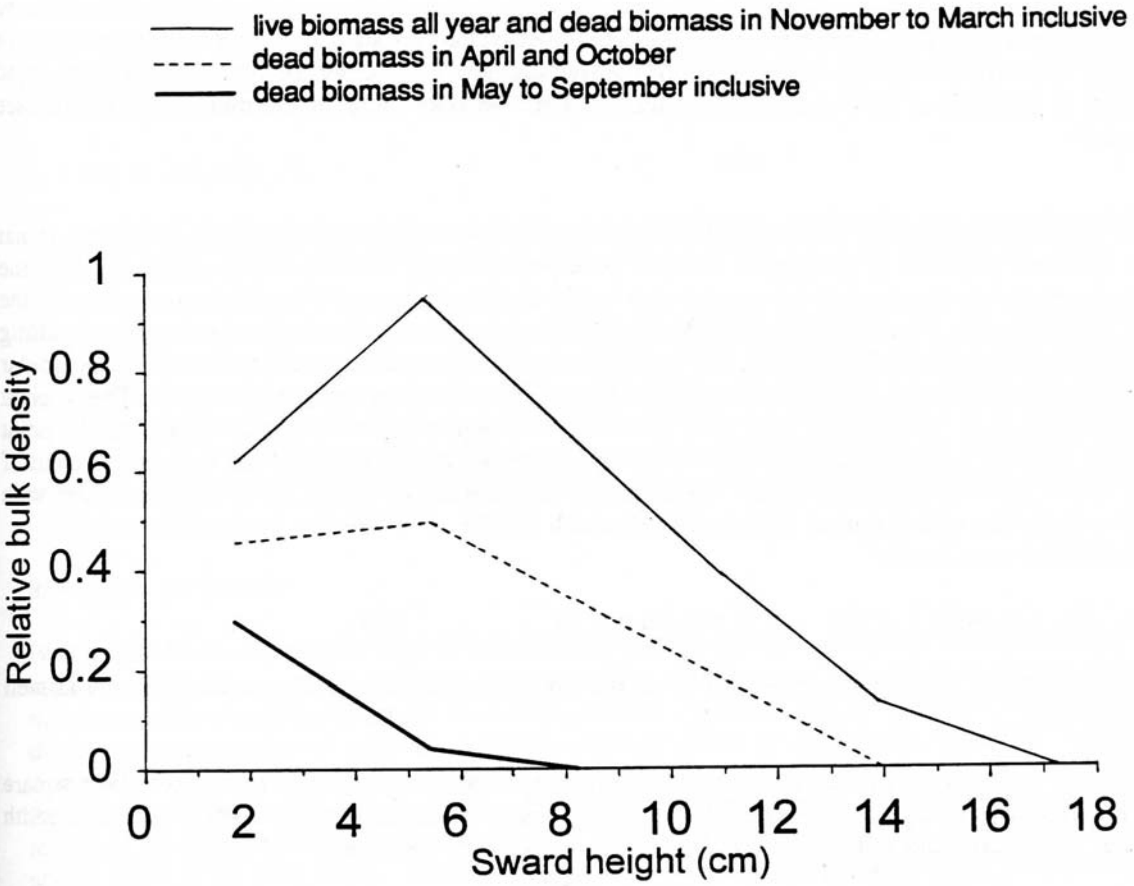

Figure 3. Assumed distribution of live and dead biomass in grass swards (from Hodgson 1985).

Bite weight for grass vegetation types

The biomasses of live and dead material in the sward, and sward height, are required for the prediction of bite weight. From May-September live and dead biomass are assumed to be distributed within the sward as described by Hodgson (1985). The relative distribution of live and dead biomass is assumed to be the same regardless of sward height. In November-March the distribution of both dead and live biomass is assumed to be the same as that of the live biomass in summer. In October and April, dead biomass is assumed to have a distribution intermediate between those in the other two periods (see Figure 3).

From April-October, sheep are assumed to bite from the top of the sward (Burlison 1987) and to eat dead and live biomass in proportion to their occurrence within the bite depth. Bite depth is the difference between the pre-grazing mean sward height and the mean sward height post-grazing. Milne *et al.* (1982), using ryegrass/clover swards in the height range, 6 - 19 cm, derived an equation relating mean sward height after grazing (H_G, cm) to mean sward height before grazing (H, cm). It is similar to an equation derived by Burlison, Hodgson & Illius (1991) for a variety of plant types. The original data of Milne *et al.* (1982) have been used to modify their equation so that it passes through the point (0.5,0.5), thereby ensuring that individual bites cannot go below a sward height of 0.5 cm. The cutoff point of 0.5 cm was chosen to enable the model to simulate a bite weight of 14 mg on swards with an average height of 1.2 cm, as recorded by Bircham (1981).
The modified equation is:

$$H_G = 0.748H + 0.126 \qquad r^2 = 0.86, n = 24 \qquad (1b)$$

It should be noted that the symbols used in all the equations are given in Appendix Table 10 as well as in the text.

Bite weight is predicted by first estimating bite depth. Horizontal bite area is assumed to be a square with a length of side equal to the predicted incisor breadth (Illius and Gordon 1987). Incisor breadth (I, m) is predicted from liveweight (W, kg) (Illius and Gordon 1987) as:

$$I = 8.6 \times 10^{-4}\, W^{0.36} \qquad (2b)$$

From bite depth, and the vertical distribution of live and dead material in the sward, the ratio of biomass in the bite to that in the sward can be estimated. The amount of live (B_L, mg DM) and dead (B_D, mg DM) material in the bite can then be estimated as the product of the ratio of biomass in the bite to that in the sward for live (R_L) and dead (R_D) material, the standing biomass of live (M_L, g DM m^{-2}) and dead (M_D, g DM m^{-2}) material and bite area (I^2). This estimation is summarised in equations 3b and 4b and the total bite weight (B, mg DM) is then the sum of B_L and B_D (equation 5b).

$$B_L = R_L M_L I^2 \qquad (3b)$$
$$B_D = R_D M_D I^2 \qquad (4b)$$
$$B = B_L + B_D \qquad (5b)$$

Burlison, Hodgson & Illius (1991) showed that bite weights, calculated in this way, are consistently smaller than bite weights measured directly from oesophageal extrusa samples. Calculated bite weights are therefore adjusted using two equations derived from their data; equation 6b for $B \geq 6.84$ mg and equation 7b for $B < 6.84$ mg.

$B_E = 1.125\ B + 44.7$ $r^2 = 0.94$, $n = 17$ (6b)
$B_E = 7.656\ B$ (7b)

where B_E = adjusted bite weight (mg DM).

From November-March sheep are assumed initially to bite only live biomass from the top of the sward. B_L is estimated as described in equation 3b. A selection ratio (R_S) is then used to determine the amount of dead biomass in a bite (equation 8b).

$$B_D = (M\ B_L / R_S M_L) - B_L \quad (8b)$$

where R_S = the ratio of the proportion of live biomass in the bite to that in the sward and M = the total standing biomass in the sward ($M_L + M_D$, g DM m^{-2}).

The selection ratio used in the model was derived by running the model for the *Agrostis/Festuca* pasture described by Sibbald, Maxwell & Eadie (1979). They give values for the DM digestibility of intake by sheep in each month of the year when the pasture was grazed at 1.5 sheep ha^{-1}. The model was run with the selection ratio set to both 2 and 3. Setting the selection ratio to 2 gave values for DM digestibility for November-March close to those observed by Sibbald *et al.* (1979). A selection ratio of 2 results in the bite consisting entirely of live material when the proportion of live material in the sward is greater than 0.50.

Bite weight on heather

Bite weight from each heather type is calculated by assuming that a sheep eats a set proportion of the biomass of the current season's growth on offer within the bite area. Armstrong & Macdonald (1992) measured utilisation rates by sheep on building heather and from this study it can be calculated that the average proportion of total shoot length removed from grazed shoots was 0.58 ± 0.037 (H. Armstrong & A. Macdonald unpublished). Bite weight for heather can be predicted if it is assumed that, as for the grass, bite area is equal to I^2 and bite depth is equal to the average proportion of the length of the current year's shoots removed in a bite. It is assumed that the current year's growth of shoots grow in an even layer. The biomass of shoots removed in a bite can be estimated then as follows:

$$B_H = 0.58\ M_H I^2 \quad (9b)$$

where B_H = bite weight of heather (mg DM) and M_H = biomass of current season's heather growth at 100% cover (g DM m^{-2}).

DM digestibility of bites from each vegetation type

The DM digestibilities of live and dead material in each month for each grass type used in the model are given in Appendix Table 9. DM digestibility of a bite (D_B) from a grass vegetation type is calculated from the amount of live and dead material in the bite as follows:

$$D_B = (B_L D_L + B_D D_D) / B \quad (10b)$$

where D_L and D_D are the DM digestibility of live and dead biomass respectively. The DM digestibility of each bite of heather is taken to be that of the current year's growth of heather (Armstrong *et al.*)

Bite rate

On reseeded pasture and *Agrostis/Festuca* and *Festuca/Agrostis* swards, bite rate (B_R, bites minute^{-1}) is assumed to be a function of sward height. Penning *et al.* (1991) derived a relationship for a ryegrass sward with a range of height of 2 to 12 cm (equation 11b).

$$B_R = 87 - 3.9H \quad RSD = 7.51, n = 80 \qquad (11b)$$

The same relationship is applied to *Agrostis/Festuca* and *Festuca/Agrostis* swards. Bite rate on the other vegetation types is assumed to be constant throughout the year (see Appendix Table 11).

Appendix Table 11. Values for bite rate for vegetation types other than reseeded pasture, *Agrostis/Festuca* and *Festuca/Agrostis* types.

Vegetation type	Bite rate (bites/minute)
burnt Molinia	45[1]
unburnt Molinia	45[1]
pioneer heather	68[2]
building heather	51[2]
mature heather	34[3]
degenerate heather	23[2]
blanket bog heather	23[2]
suppressed heather	50[2]
Festuca/Agrostis growing amongst heather, Nardus and Molinia	50[4]

[1] Mean sheep bite rate measured on a *Molinia* community between June and October by Hodgson *et al.* (1991).
[2] From internal model calibration step.
[3] Mean sheep bite rate (n=303) measured on a stand of mature heather 30 cm tall with 100% cover was 34.2±1.3 bites per minute (A. Duncan unpublished data).
[4] Mean sheep bite rate measured on a *Nardus* community between May and November by Hodgson *et al.* (1991).

Potential intake of digestible DM

Armstrong, Common & Smith (1986) derived a relationship between organic matter intake and organic matter digestibility for a variety of relevant vegetation types excluding heather. Since this model predicts DM digestibility and requires DM intakes, the data collected by Armstrong, Common & Smith (1986) were re-analysed. The following relationship was obtained and is used to estimate total potential intake of DM from each grass vegetation types:

$$I_{DG} = 166.6\, D_G - 43.6 \quad r^2 = 0.79, \; n = 24 \qquad (12b)$$

where I_{DG} = daily intake per kg metabolic live weight by sheep ingesting grass vegetation types (g DM (kg live weight)$^{-0.75}$) and D_G = DM digestibility of the grass diet.

Potential daily intake of heather is estimated from a relationship between intake and digestibility derived by Milne, Bagley & Grant (1979). The original relationship used organic matter digestibility and organic matter intake but these have been converted to DM using relationships derived from Milne (1974):

$I_{DH} = 66.8\ D_H + 2.17$ (D_H range = 0.36 - 0.62) (13b)

where I_{DH} = daily intake per kg metabolic live weight by sheep ingesting heather (g DM (kg live weight)$^{-0.75}$) and D_H = DM digestibility of heather.

The time taken to harvest this intake (T_G, minutes) from each vegetation type is calculated as follows:

$T_G = IP_j / (B_R\ B)$ (14b)

where IP_j = potential daily intake per ewe from vegetation type $_j$ if only vegetation type $_j$ is available (g DM). Maximum possible grazing time is set at 13 hours (Bircham 1981). If the time calculated to harvest the predicted intake is greater than this then intake of digestible DM is assumed to be limited by that which can be harvested in 13 hours. Intake is then multiplied by digestibility to give the potential daily intake of digestible DM for each vegetation type.

Total DM intake

The assumption is made that foraging behaviour is the major determinant of sheep movements between vegetation types and that sheep are not shepherded between vegetation types. If foraging were the only determinant of sheep movements and sheep optimized their movements accordingly then they would be expected to spend all their time on the vegetation type which gave the highest daily intake of digestible DM. Observations of the distribution of sheep across hill vegetation (Hunter 1964) indicate that, although there is strong preference for the nutritionally most rewarding vegetation types, the flock as a whole will be found distributed among vegetation types. This may be due to a combination of effects, such as social interactions between sheep, sampling of different vegetation types by individual sheep and instinctive movements of sheep, for example moving uphill in the evening and down in the morning. In order to simulate this behaviour, the foraging behaviour algorithm used in the model assumes that intake from any vegetation type is dependent not only on the potential daily intake of digestible material from the vegetation type but also on its area in relation to the potential intakes from, and areas of, all other vegetation types.

The following equation (modified from Noble 1975) was used:

$$I_j = I_T \times \frac{(IPD_j)\,A_j}{\sum_{j=1}^{n} (IPD_j)\,A_j} \qquad (15b)$$

where I_j = actual daily intake per sheep from vegetation type $_j$ (g DM)), I_T = total daily intake per sheep from all vegetation types (g DM), IPD_j = potential daily intake of digestible material per ewe from vegetation type $_j$ if only vegetation type $_j$ is available (g DM) and A_j = area of vegetation type $_j$ (adjusted for cover) (ha). The use of equation 15b resulted in insufficient selection for the vegetation types with the highest IPD values. Milne and Grant (1987) found that IPD was stronger than area in determining selection between communities by sheep. Therefore, power function was used to increase the effect of IPD. The power was set by running the model for two contrasting sites, a heather moor in Grampian Region, Scotland and an acid grassland in the Scottish Borders, for which expert knowledge was available. IPD values were adjusted to the power 5 to give equation 16b:

$$I_j = I_T \times \frac{(IPD_j)^5 A_j}{\sum_{j=1}^{n} (IPD_j)^5 A_j} \qquad (16b)$$

Since bite weights for heather, predicted by the model, are generally higher than those from grass but heather generally has a lower digestibility, daily intake from the heather types is seldom limited by harvestable biomass but instead is limited by digestibility. The potential daily intakes of digestible DM are, thus, the same for all heather types since they are assumed to have the same digestibility (see equation 13b). The heather vegetation types are therefore treated as one vegetation type in the evaluation of equation 16b. To distribute offtake between the heather types, the rate of intake of digestible material per minute is used in an equation of similar form to equation 16b but with potential daily intake of digestible DM replaced by rate of intake of digestible DM and areas not adjusted for cover.

From the digestibility of the intake of each vegetation type, the digestibility of the total intake can be calculated and used to derive total DM intake from equation 12b. Before this can be done, however, a computational adjustment has to be made to heather digestibility in order that the intake of heather can be calculated correctly using equation 13b instead of equation 12b because the relationship between intake and digestibility is different for heather. This is done using the following equation:

$$D_{H1} = 0.401D_H + 0.2747 \qquad (17b)$$

where D_{H1} = adjusted DM digestibility of heather.

After adjustment of total intake for reproductive state if necessary (see below), total grazing time is calculated by summing the time taken to remove the predicted intake from each vegetation type (equation 16b). If this is greater than 13 hours then the intake from each vegetation type is reduced by the same proportion so that total grazing time is equal to 13 hours.

Adjustment of intake for reproductive state of ewe

A reproductive rate of 1.0 is assumed with lambing occurring in mid-April (Julian day 105) and removal of lambs from the system in mid-August (day 228). It is assumed that there is no effect of gestation on intake (Elsen, Wallach & Charpenteau 1988). Vera, Morris & Koong (1977) (quoted in Elsen, Wallach & Charpenteau 1988) give the following equation for correcting voluntary intake for the effect of lactation and its duration: $P_L = 0.969 + 0.1395(T_L/7) - 0.01035(T_L/7)^2$ (18b)

where P_L = proportionate change in intake of a lactating ewe with a single lamb compared to that of a non-lactating ewe and T_L = number of days from lambing.

This equation is used because it closely resembles the intake of lactating Scottish Blackface ewes grazing reseeded and *Agrostis/Festuca* pastures found by Doney *et al.* (1983). They found maximum intakes occurred at about 56 days after parturition. Equation 18 predicts the maximum intake at 47 days after parturition when intake is 1.44 that of a non-lactating ewe. It also predicts that intake of a lactating ewe will fall to 1.0 of that of a non-lactating ewe by 97 days after parturition.

Intake by lambs

It is assumed that lambs start to eat vegetation at six weeks after parturition. Intake then increases by 0.8 g (kg live weight)$^{-1}$d^{-1} (Doney & Peart 1976) until it equals that calculated using equation 13b after which equation 13b is used.

Lamb live weight (W_L,kg) is estimated from the number of days postpartum (T_L) and the live weight of the ewe in the previous November (W, kg). Equation 19b was derived from live weights of Scottish Blackface and Cheviot lambs at birth, six weeks and eighteen weeks post partum between 1973 and 1985 (A R Sibbald, unpublished data):

$$W_L = (0.00458T_L + 0.0783)\ W \quad r^2 = 0.96,\ n = 66 \qquad (19b)$$

It is assumed that the lamb will always be able to obtain its voluntary intake within 13 hours. Intake by lambs is divided between the vegetation types in the same manner as is intake by ewes.

Offtake by the whole flock

The total offtake per hectare from a vegetation type is estimated from the product of DM intake per sheep from each vegetation type and the number of sheep in the flock divided by the area of each vegetation type. Total offtake of DM of live and dead biomass from each grass vegetation type is estimated from the product of the total offtake of DM from each grass vegetation type and the proportion of live or dead material in a bite taken from that vegetation type. It is theoretically possible that total offtake of live, dead or total biomass could be greater than the standing biomass. If this is the case, offtake is set equal to the standing biomass.

UPDATING BIOMASS

Offtake of live and dead biomass is divided between the age classes of live and dead grass vegetation in proportion to the contribution made by each age class to the total live or dead biomass on the previous day. Standing live and dead biomasses are updated daily. The current year's growth of each of the heather types is adjusted for offtake daily. At the end of each month, total monthly offtake from each vegetation type is calculated. Utilization rate, cumulative from the start of the growing season (April for grass vegetation types and May for heather), is also calculated at the end of each month for each vegetation type.

To achieve an approximate steady state in year 2 the model runs for two years from 1 April.

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MLURI

HILL GRAZING MANAGEMENT MODEL

Windows version 1.0

User Manual

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1 INTRODUCTION

This manual provides the user of the Hill Grazing Model Software with detailed guidance in using the system.

It is assumed that the user is familiar with Microsoft Windows, and reference should also be made to the user manual for Windows where necessary.

This manual is divided into five sections, as follows :-

Section 1 This section.

Section 2 Installation guide.

Section 3 Describes the use of the input data screens.

Section 4 Describes the use of the output results screen.

Section 5 Describes the use of the graph window.

A new user should work through these section in order for the most thorough understanding of the system.

This manual may be used in conjunction with the online help system which may be accessed from all the major system screens.

2 INSTALLATION

2.1 System Requirements

The system requires the following :-

Hardware

* IBM or compatible AT class computer (i.e. 286 or above, but 386 recommended)
* 1 MB or greater system memory (2 MB recommended)
* Hard Drive with at least 2 MB of free space
* EGA or greater resolution monochrome or colour display

Software

* PC-DOS or MS-DOS version 3.1 or greater
* Microsoft Windows version 3.0 or greater

2.2 Installation

The installation of this software is handled by an automated setup program. This may be activated as follows :-

* At the Dos prompt (C:\> etc.) start Microsoft Windows :-

  C:\>**win**

* With the Program Manager on the screen, select **Run** from the **File** menu.

* Place the distribution disk marked **Setup** in a floppy drive. Assuming drive A is being used, type the following into the dialog box that appears :-

  a:setup

  and press the **OK** button.

  A message saying "Initialising setup" will appear, and after a short time, the setup screen will appear asking for the name of the directory into which the software will be installed.

* If the name of the directory (default is C:\MODEL) is not acceptable, modify it to contain the drive / directory where you would like the software installed. When this is done, press the **CONTINUE** button to continue the installation. You may also abort the installation now by pressing the **EXIT SETUP** button.

  The screen will change to contain a bar which signifies the percentage of the installation currently done. The names of the files being transferred are also displayed.

  If your distribution disk set contains more than one disk, you may be asked during the installation to change the disks. The screen will prompt you with the disk name to insert.

  Shortly after the bar on the screen reaches 100%, a message will appear saying "Hill Grazing Model installation is complete".

* Press the **OK** button, and a new program group will be created on the Program Manager desktop. This group will contain one icon representing the model unless the research version has been supplied, in which case there will be a second icon. The installation of the Hill Grazing Model software is now complete.

* Start one of the two versions by **double-clicking** on the relevant icon. The input data screen for the model will appear.

3 USING THE INPUT DATA SCREEN

3.1 Introduction

The modelling routine processes the data entered into this screen, and generates results which may be viewed on the Output Results screen.

3.2 Data Entry

Modification of any of the items on the screen is achieved by selecting the item to be modified, and changing its value.

Selection of the screen items is achieved by moving the mouse pointer over it and clicking on the left mouse button. Alternatively, the TAB key may be used to move around the screen from top left (Site Name) to bottom right (Grassland Data Button).

The way in which the value of any item is changed depends upon what type of Windows control is used for the item.

3.2.1 Windows Controls

The following controls are used on this screen.

* Text Box - Allows entry of free form text via the keyboard using standard Windows editing procedures (e.g. Site Name).

* Value Box - Allows entry of a numeric value via the keyboard (e.g. Altitude). If an invalid character is entered, the machine will beep and the character will not appear in the box. These boxes may allow only integer values, in which case a decimal point will count as an invalid character.

  Some value boxes may only allow entry of values within a certain range. If a value outwith this range is entered and another item is selected, the machine will beep and move the selection back to the invalid item so that its value may be re-entered.

* Combo List - Allows selection from a drop-down list of values (e.g. Location). When a combo list is selected, the list of possible choices will be displayed. A choice should then be made from the list. The selected item will appear in the box.

* Options Buttons - A list of choices is presented within a cluster of buttons. Only one of the buttons can be selected at any time; selecting another cancels the first.

The "Sheep on farm" question uses a button for each of the answers "Yes" or "No".

3.2.2 Subwindows

One other Windows control is found on this screen. A Command Button does not have a value, instead an action is performed when the button is pressed. The three command buttons on this screen (Heather, Sheep & Grassland Data) display subwindows containing more data entry items.

Each of these subwindows accepts data entry in the same way as described for the Input Data screen. A command button marked **Dismiss** is found on each window. This will remove the window from the desktop, and should be pressed when data entry on that window is completed.

3.3 Menu Options

The menu bar is found at the top of the screen, below the title bar. A menu may be selected by clicking on it, or holding down the ALT key while the underlined letter is pressed on the keyboard. The menu will drop down allowing further choices.

3.3.1 File Menu

The File Menu is responsible for the storage and retrieval of data, and contains the following choices :-

* New - This will clear any data currently on the screen. If the data has not been saved, a box will appear prompting you to do so.

* Load - Loads an existing input data file for editing. If any unsaved data is on the screen prior to selecting this option, you will be prompted to save it. A box will then appear prompting for a filename. When this is selected, the data will be loaded.

* Save - Saves the data on the screen to a file. The data will be checked for consistency. If any problems are found, a box will appear informing you of the error. On acknowledgement of this error, the value which caused the error will be highlighted on the screen.

  If no problems are found, a box will appear prompting for a filename. When this is entered, the data is saved.

- Quit - Quits the model program. You will be prompted to save any data which has not previously been saved.

3.3.2 Model Menu

The Model Menu provides access to the other system functions, as follows :-

- Run Model - Starts the modelling process using the most recently saved set of data. If any data has been changed since it was last saved, you will be prompted to save it again. If no data has been loaded, you will be prompted for a file to load.

  A screen will appear, showing the current status of the modelling process. A box will appear when the process is complete which can then be dismissed.

- View Results - Displays the Output Results screen, where the results of the modelling process may be viewed.

3.3.3 Help Menu

The Help Menu provides access to the online help system. The following functions are available from the menu :-

- Contents - Displays the contents page for the help system

- This Window - Displays help on using the current screen.

- Using Help - Displays general help on using the help system.

4 USING THE OUTPUT RESULTS SCREEN

4.1 Introduction

The results of a model run may be viewed using this screen. The modelling process generates a file containing the data from the model run, the filename being the same as the input file with a .OUT extension.

Multiple data files may be loaded, allowing the user to compare different model runs.

This screen has two different modes of operation; View Mode where data is viewed on the screen, and Report Mode where data is sent to an output device or file.

Various menu options are available from this screen, the majority of which are common to both operational modes; these will be described as follows :-

4.2 Menu Options

4.2.1 File Menu

The file menu contains the following options :-

* Load - Loads a data file into memory. You will be prompted for a filename which you may choose from a list of possible files. Upon selecting a file, there will be a short delay before the filename appears in the Select File list.

* Remove Current File - Removes the currently highlighted file in the Select File list from memory.

* Close Window - Closes the Output Results window, removing all output data from memory.

4.2.2 View Menu

The view menu alters various options for the screen, as follows :-

* Array Data - Switches the screen into **View Mode** and lists all available array items in the Select Data list.

* Monthly Data - Switches the screen into **View Mode** and lists all available monthly items in the Select Data list. This includes all monthly extracted items, i.e.

monthly data extracted from daily data.

* Daily Data - Switches the screen into **View Mode** and lists all available daily items in the Select Data list. **(Only available in the Research version of the software).**

* Display Single Item Window - Calls up a subwindow containing all annual items (names and values). Available in both screen modes.

* Generate Spreadsheet / Report - Switches the screen into **Report Mode** and lists all items (array, monthly and daily) in the Select Data list.

* Long Tag Names - When marked with a tick (checked), uses long descriptive names (as seen in the Select Data list) for displaying on the Data Grid and Graph Window. When unchecked, short tag names are used. This may be useful when the long names are too long for displaying properly. Selecting this menu option toggles between the checked and unchecked state. Note that if this option is changed, any data will have to be reselected for the change to take effect.

4.2.3 Help Menu

Calls up the online help system, as described in section 3.3.3.

4.3 View Mode Operation

When the Output Results screen is called up, it is in View mode. The screen will contain no data initially, therefore one of the first tasks to be performed will be to load a data file. This is done using the **Load** option on the **File Menu** as described in section 4.2.1.

When the file has been loaded, the filename will appear as the first item in the Select File list (the list at the top left-hand corner of the screen). A list of items found in that file will be displayed in the Select Data list (top right). The title "Monthly Data" will be displayed in the centre of the screen, indicating that the screen is in View mode, and is using monthly data.

Selecting any item from the Select Data list will load the values for that item onto the **Data Grid**, which will appear at the bottom of the screen. The data may be graphed by selecting sections of the data and pressing the **Graph** button.

The function of each object on the screen will now be described more thoroughly.

4.3.1 Select File List

Each time a file is loaded, it is added to this list and assigned a number. Multiple files may be loaded at one time, and any data item on the grid, graph or single data list may be distinguished by the number at the start of it.

The Select Data list contains all the items found in the highlighted file in the Select File list. If another file is selected, the Select Data list is updated to show all items in the newly selected file. Any values placed on the grid from now on will be taken from the new file until another file is selected.

Selecting **Remove Current File** from the **File Menu** will remove the highlighted file in the list (and all its associated data) from memory.

4.3.2 Select Data List

This list contains a list of all the data for the current type in the file highlighted in the Select File list. The current type is selected using the **View Menu**, and may be array, monthly or daily (the latter only being available in the Research version). Each time the type is changed using the menu, or a new file is selected, this list is updated with a new set of data.

Clicking on any item in the list will transfer it to the **Data Grid** at the foot of the screen, where the values for that item are displayed.

When the current type is monthly or daily, the list is split into groups, with each data item in that group being indented in the list following the group description. Selecting a group will transfer all items in that group to the grid. Selecting one item within a group will only transfer that item.

When the current type is array, only one array item may be on the grid at one time. Selecting any item from the list will clear anything currently on the grid and replace it with the newly selected item.

4.3.3 Data Grid

The Data Grid displays the values of any currently selected data.

The top row and left column on the grid are reserved for descriptions of the rows and columns on the grid, and appear shaded. The other cells in the grid are for data, and may be white if unselected, or blue if selected.

For array data, the top row will contain descriptions (units in brackets) for each column. The left column will contain descriptions for each row in the following format :-

File:Array_Name - Row_Name

where File is the file number as seen in the Select File list, and Array_Name is the name of the item selected from the Select Data list. Row_Name is an internal name given to each row of the array.

For monthly or daily data, the top row will contain dates (Jan - Dec for monthly, 01-01 - 31-12 for daily) and the left column will contain descriptions for each item selected from the Select Data list in the following format :-

File:Group_Name - Item_Name

where File is the file number as seen in the Select File list, and Group_Name and Item_Name are the names of the group and item selected from the Select Data list.

These long descriptive names may be replaced by shorter tag names if you find that they take up too much room on either the grid or the graph (described in section 5) by selecting the **Long Tag Names** menu item to remove the tick from it. Any subsequent selections from the Select Data list will use the new format.

Rows may be removed from the grid by double-clicking on the row description of the row to be removed. The whole grid may be cleared by double-clicking on the top left cell of the grid (the shaded empty cell above the row descriptions and to the left of the column descriptions).

If more data is on the grid than may be displayed on the screen at one time, horizontal and vertical scroll bars will appear, allowing the data section of the grid to be moved around (the shaded description section does not scroll).

Selecting data to graph may be done by moving the mouse pointer over the cell at one corner of the data to be graphed, then holding down the left mouse button while the pointer is dragged to the opposite corner. If the opposite corner is off the screen, the grid will scroll as you try to reach it until it appears on the screen. When the mouse pointer is at the opposite corner the mouse pointer may be released. The selected data will now appear in blue while the unselected data stays white.

NOTE - If the mouse pointer is positioned over a border between two columns or two rows, the pointer changes from an arrow to a drag pointer. This is a feature of the grid control which unfortunately cannot be turned off. Make sure than when starting to select data, the mouse pointer is an arrow, otherwise the grid borders may move.

4.3.4 **Graph Button**

The graph button calls up a **Graph Window** containing a graph of the currently selected data on the grid. If less than one set's worth of data was selected, a message will appear saying "Not enough points to graph".

All selected data should be of the same units for the graph to be generated properly. If the data selected is made up of values with different units, then a box will appear informing you of this. You may continue and generate the graph, however, any rows not matching the units of the first row will not be included in the graph.

4.3.5 **Orientation**

This defines how the data on the grid is used for the graph.

Orientation "X-Y" means that the columns of the graph will be used as the X axis for the graph, and the rows used as different data sets. "Y-X" is the opposite of this.

The correct orientation should be chosen before pressing the Graph button. It does not affect any graphs currently displayed on the screen.

4.4 **Report Mode Operation**

Report Mode is selected when **Generate Report / Spreadsheet** is chosen from the **View Menu.**

The grid (if visible) will disappear and be replaced with the **Selected Data list.**

The screen works in much the same way as for View Mode except that any selected data appears in the Selected Data list instead of the grid. Output is generated when the **Save Button** is pressed, and the user selects various output options.

Some of the screen objects behave in a slightly different manner however. These differences are described below.

4.4.1 **Select File List**

See section 4.3.1.

4.4.2 Select Data List

See section 4.3.2.

All data types are displayed in this list (array, monthly, daily/monthly extracted), and are selected in the same way as before.

Double-clicking on this list in Report Mode transfers all data in the list to the Selected Data list.

4.4.3 Selected Data List

Data selected from the Select Data list appears in this list. All items in this list will appear in the report / file when it is generated.

Clicking on any item will remove it from the list, Clicking on a group will remove all items on that group. Double-clicking on the list will clear the list.

4.4.4 Generate Report Button

The Generate Report button generates the output. Before it is generated, a box will appear allowing the user to select various output options.

4.4.4.1 Output Options

The following types of output may be selected :-

* Output to Printer - The report will be sent to the Windows default printer, using the font as shown. A different printer may be selected by pressing the **Change Printer** button. A different font or font size may be selected by pressing the **Change Font** button.

* Output to File - The report will be sent to a given filename. The default filename may be changed by pressing the **Change Filename** button.

* Output to Spreadsheet - The selected items will be sent to a file in comma delimited tabular form. This format is commonly used to import data into a spreadsheet and is compatible with Lotus 1-2-3 amongst others, The filename may be changed by pressing the **Change Filename** button.

Pressing the **Cancel** button will abort the operation, otherwise, pressing **OK** will begin the generation of output.

Status messages will appear at the bottom left hand corner of the screen for printer and spreadsheet options.

4.4.5 Report Menu

An extra menu will appear when in report mode. Options on this menu are as follows :-

* Use Daily Values - Daily data will be included in the report / spreadsheet file if this menu option is checked (**only available in the Research version of the software**).

* Add Single Data - Adds a list of all the annual data values at the start of the report. Not applicable to spreadsheet style output.

5 USING THE GRAPH WINDOW

5.1 Introduction

The Graph Window lets you view the data from the Data Grid graphically. Multiple graph windows may be called up and may be viewed at the same time.

When the window is first called up, the graph will be in the form of a 2D bar chart. The X axis will be marked with the column descriptions of the grid for X-Y orientation, or the row descriptions for Y-X orientation. If more than one row (column for X-Y) was selected, multiple sets will be shown on the graph in different colours with a key at the right of the graph to each set.

The graph type may be changed using the Type menu. Note that pie charts may only display one set at a time, therefore if multiple sets were selected only the first one will be shown on a pie chart.

If set descriptions are too long, or too many sets are selected, the set key to the right of the graph may not be displayed. Likewise, if the X Axis descriptions are too long using Y-X orientation, they may not be readable. Using short descriptions (see section 4.2.2) may alleviate this problem.

5.2 Menu Options

5.2.1 Type Menu

The Type Menu allows the graph type to be changed. Graph types available are :-

* 2D Pie
* 3D Pie
* 2D Bar
* 3D Bar
* Line
* Area
* Scatter

5.2.2 Style Menu

There are up to 8 different styles available (numbered 0 to 7) and these are dependent on the graph type. Style 0 is the default in each case.

<u>2D & 3D Pie</u>

0	Lines join labels to pie
1	No label lines
2	Coloured Labels
3	Coloured labels without lines
4	% labels
5	% labels without lines
6	% coloured labels
7	% coloured labels without lines

<u>2D & 3D Bar</u>

0	Vertical bars, clustered
1	Horizontal
2	Stacked
3	Horizontal stacked
4	Stacked %
5	Horizontal stacked %
6	Z-Clustered (one set behind another, 3D only)
7	Horizontal Z-Clustered

<u>Line</u>

0	Lines
1	Spaced bars
2	Sticks
3	Sticks and symbols
4	Lines
5	Lines and symbols
6	Lines and sticks
7	Lines, sticks & symbols

<u>Area</u>

0	Stack data sets
1	Absolute
2	Percentage

<u>Scatter</u>

0	Symbols

5.2.3 Options Menu

Controls various graph options :-

* Grid Lines - Displays grid lines when checked (default), otherwise no grid lines are displayed.

* Thick Lines - Displays lines on a line graph as a thicker line than normal if checked, otherwise thin lines are used (default). Useful when printing to or viewing on a low resolution device.

* Print in Colour - If checked, the graph, if printed, is sent to the printer in colour, otherwise, colours are converted into shadings and symbols to distinguish colours (default). If this option is enabled and the graph is sent to a monochrome printer, all bars will appear the same as grey scaling is not used.

* Change Title - Brings up a box allowing the graph title to be edited.

* To Print - The graph is sent to the printer. A box will appear asking which printer the graph is to be sent to.

* To Clipboard - The graph is sent to the Windows Clipboard. From here it may be pasted into other Windows applications.

5.2.4 Help Menu

Accesses the online help system. See section 3.3.3.

Further Reading

Grant, S.A. and Armstrong, H.M. (1993). Grazing ecology and the conservation of heather moorland: the development of models as aids to management. *Biodiversity and Conservation* **2**, 79-94.