

*End of Project Reports: Sheep Series No. 16*  
*Project No. 4359*

## **Physical Impact of Livestock on the Hill Environment\***

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*Teagasc and U.C.D. acknowledge the support of the Department of  
Agriculture, Food and Rural Development under the Research Stimulus  
Fund (OPA, RDF, measure 5(b)).*

*\*Abbreviation of title "Evaluation of impact of livestock on the hill  
environment – soil, water and vegetation in western Ireland" ref. T/G 16*

ISBN 1 84170 233 1  
June 2001

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## **ACKNOWLEDGEMENTS**

The authors gratefully acknowledge the contributions of the following:

Dr. J.P. Hanrahan for his input and support in every aspect of the project; Mr G. Scully and advisory colleagues for their keen interest throughout; Mr. T.J. Fahy for technical assistance; Messrs L. O'Malley and P.J. Hastings for assisting and facilitating all research activities on the Leenaun Hill Sheep Farm; the staff and colleagues in the Department of Crop Science, Horticulture and Forestry and the Department of Environmental Resource Management, U.C.D.; the Central Statistics Office, Met Éireann and Department of Agriculture, Food and Rural Development for providing data and finally, colleagues at the Teagasc Research Centre, Athenry for general advice and support.

## SUMMARY

The impact of livestock on the hill and mountain environment in western Ireland was a source of serious concern in the 1980s and 1990s. Livestock numbers, particularly sheep, increased dramatically and sheep farming changed from a predominantly wether to a ewe-based system. The foothills came under increased grazing and animal traffic, pressure mainly during activities associated with changed husbandry practices.

Soils and vegetation of the western hills are among the least resilient in the country and are more susceptible to erosion and loss due to intensified land use. Weather conditions are often harsh for both man and livestock. Annual rainfall averages 2,500 mm and strong winds are frequent. The erosive effect of wind and rain *i.e.* driving rain, is intensified by the relatively abrupt changes in altitude.

The overall objective of this work was to provide quantitative and objective information on the role of livestock on changes over time in vegetation and soils in the hill areas and to develop a suitable monitoring programme.

The methods employed included an initial survey of damaged sites followed by a selection for detailed investigation in counties Donegal, Mayo, Galway and Kerry. Digital photogrammetry using sequential photography was applied together with field and laboratory studies of vegetation and features of soil erosion. The morphology, soils, and vegetation of terracettes, which are common throughout the hills, were studied with emphasis on animal impacts. Vegetation cover, structure and species composition from a number of semi-natural vegetation types were assessed under ungrazed and open to grazing conditions, using exclosures. Livestock statistics and weather data were compiled and assessed.

The vegetation and erosion study presented a scene of complex interactions of a variety of factors. The Donegal site had a substantial increase in the area of eroded surface over the 20-year period, 1977-1996, but intact vegetation cover on adjacent peat surfaces suggested that livestock were not the dominant factor in the progress of erosion. Substantial erosion on one of the sites in Mayo, was related to livestock concentrating on the most accessible portion of the hill for supplementary feeding. The area of eroding soils increased in all sites over the 20-25 year period from the 1970s to the 1990s.

Digital photogrammetry was applied successfully to quantifying even minor changes in erosion features and certain patterns of vegetation which were validated by field surveys. The technique was found to be a very useful tool in identifying and monitoring historical changes in the landscape.

Terracettes are a common feature of this environment and were studied in the Donegal, Mayo and Galway sites. A range of soils – humic and peaty gleys, peaty podzols (some with iron-pans), and peats (mainly blanket/climatic) – were identified. The morphology and vegetation composition of the terracettes were studied in detail. Overall, terracettes were more variable than those that have been studied elsewhere in the world. This variability is considered to be due, primarily, to the influence of animals, particularly sheep. A range of such features can be monitored to assess, quantitatively, the direct impact of livestock in the future, and in similar environments.

The results of the enclosure study indicated that grazing led to a reduction in the height and cover of vegetation, altered species composition but in certain cases increased species diversity.

Livestock data was not available at the level of detail required for definitive correlation of stock density with the areas of soil and vegetation damage in the areas studied. However, changes in livestock husbandry, a shift from the production of wethers to ewes, lead to increased grazing pressure especially in localised areas.

Driving rain, the product of wind speed and rain, increased at virtually all levels of intensity over the period 1957-2000 and is likely to have had a detrimental effect on vegetation vigour and productivity.

A resource databank including soils, vegetation, topography, weather and erosion status, with relevance to the impact of livestock on the hill environment was established for a number of representative sites in the west of the country. Methods for monitoring the impact of livestock, based on photogrammetry, terracettes and vegetation, have also been developed.

Information from the hill flock performance and the vegetation and soil assessment on the Teagasc Hill Sheep Farm, Leenaun, combined with that from the present project enabled a number of guidelines to be suggested for hill management.

# INTRODUCTION

Since the late 1980s there has been a general perception that the condition of the hill resource was deteriorating drastically due mainly to 'overgrazing'. Land management activities involving a substantial increase in livestock (mainly sheep) in the 1980s was cited as causing serious vegetative loss and soil erosion in the hill and mountain environment in the west of Ireland (Bleasdale and Sheehy-Skeffington, 1992).

It is acknowledged that livestock has damaged some areas in the hill and mountain landscape. The damage was mostly associated with the easily accessible and often most visible sectors of holdings, both private and commonage. It consisted mainly of loss of vegetative cover and severe poaching of the soil surface. However, there was no objective information on the role of livestock on changes over time either in the natural vegetation, soils or water in the hill areas.

Two related projects were initiated in 1995 to remedy these deficiencies and to create a useful baseline for future studies. One was based largely on the Teagasc Hill Sheep Farm near Leenaun and involved a detailed description of the vegetation and soil erosion status (Walsh *et al.*, 2000). The other, the subject of this report, includes detailed studies on five from a list of over 40 sites that were identified in counties Donegal, Leitrim, Sligo, Mayo, Galway and Kerry. It also includes results from long term exclosures on the Teagasc Hill Sheep Farm.

## Physical background

*Soils:* Approximately 85% of the hill and mountain soils of western Ireland, because of their humic/organic nature, are particularly susceptible to erosion if overstocked. Table 1 outlines the details of the soils and the area occupied by them (Gardiner and Radford, 1980).

**Table 1: Typical soils of the study sites**

Physiographic division	Soil association			Area (ha)
	No	Principal soil	Associated soils	
Mountain and hill	1	Peaty podzol (0.75)*	Lithosol (0.15) Blanket peat (0.1)	500,029
	4	Lithosol (0.7)	Blanket peat (0.25) Peaty podzol (0.05)	157,492
	5	Blanket peat (1.0) (High level)		387,676
Rolling lowland	24	Blanket peat (1.0) (Low –level)		351,651

\*Represents approximate proportion of area of soil association

Peat results from conditions where the process of breakdown and mixing of mainly dead plant remains with the mineral component of soil (humification) is much slower than the accumulation of these plant remains. The parent materials of the mineral soils are mainly the weathered products of Precambrian, Ordovician, Silurian and Devonian rocks. The rocks consist of various forms of silica-rich sandstones, shales, quartzites, schists, gneisses and granites. Base-rich rocks such as limestones, shales and volcanic materials occur much less frequently. However, the weathered residue of the dominantly acid rocks is poor in both silt/clay particles and plant nutrients.

*Location and Topography:* The present study was located in selected areas in counties Donegal, Mayo, Galway and Kerry. The local topography is mainly hill and mountain, which included a range in elevation from near sea level to over 400 m, as well as a wide range of slopes, aspects and physiographic units. Terracettes, also known as 'sheep tracks' are a common feature of the micro-topography. Processes creating these features are believed to include translational/rotational sliding, soil creep and animal disturbance (Chemakova and Chemakov, 1975; Vincent and Clarke, 1982) in regions with temperate climate. Little attention, other than vegetation composition, (Curran *et al.*, 1983), has been given to these features in Ireland.

Soil erosion (hill-wash, rill and gully formation) is a feature of this topography, especially where the soil is blanket peat (Walsh *et al.*, 1969; McGee and Bradshaw, 1990). Digital photogrammetry using cloud-free, vertical, aerial photographic coverage from the mid-1970s and 1990s enabled a detailed assessment of these processes.

*Vegetation:* Grazing has a major influence in determining the dynamics and succession of semi-natural vegetation (Welch, 1984). Changes in floristics and vegetation structure, following the removal of herbivores, were studied in a range of plant communities using exclosures (fenced plots). Data recorded from a number of exclosures established since 1991/1992 (Little, 1995), at the Teagasc Hill Sheep Farm, Leenaun were used. The physical environment, vegetative cover and the results of controlled grazing on the farm have been reported in Walsh *et al.* (2000).

*Climate:* The climate of the seaboard counties is typical of temperate, west maritime conditions with relatively mild, moist winters and cool, moist summers (Rohan, 1986). Increasing elevation results in an increase in

rainfall and wind velocity and a decrease in temperature. Exposed surfaces of peat soils, which have an innately high moisture content and weak structure, are especially vulnerable to the combined effect of wind and rain.

### **Land use and socio-economic background**

Hill sheep production is the most widespread form of agricultural land use in the uplands of Ireland. It is difficult to estimate the total number of sheep in these areas. The number of ewes in counties Donegal, Mayo, Galway and Kerry, on which ewe premium was applied in 1999, was 1.84 million. The majority are likely to be maintained in the uplands.

Hill sheep contribute approximately half of the total gross margins throughout most of the uplands (Lafferty, Commins and Walsh, 1999). Were it not for subsidies, however, sales from the Blackface Mountain system, in recent years, would have failed to cover expenses, resulting in a negative net margin (Connolly, 2000). Details of the stock carrying capacity of this environment with the exception of the Teagasc Hill Sheep Farm, Leenaun, however, are not known.

A significant proportion of peat-covered landscape of western Ireland has been proposed as Natural Heritage Area (NHA) and/or Special Area of Conservation (SAC). A 1997 survey of tourists in rural areas of county Galway indicated that viewing scenery accounted for almost 40% of their first choice activities (Connolly, 1999).

The management of the hill and mountain landscape requires balancing the demands of agricultural land use, conservation and socio-economic interests.

## OBJECTIVES

The objectives of the project were to build a data-bank, including vegetation, soils, topography, erosion features, livestock density and climate, and develop therefrom methodologies to:

- assess, objectively, the impact of livestock on the hill and mountain environment,
- quantify the evidence for changes over time, particularly in erosion features and vegetation, and
- develop a, response-oriented, monitoring programme.

The expected benefits included a quantification of the effects of livestock on a range of hill soil/vegetation environments; provision of indicators for appropriate management and suggestions for the elimination/attenuation of damage due to inappropriate agricultural land use systems.

## METHODS

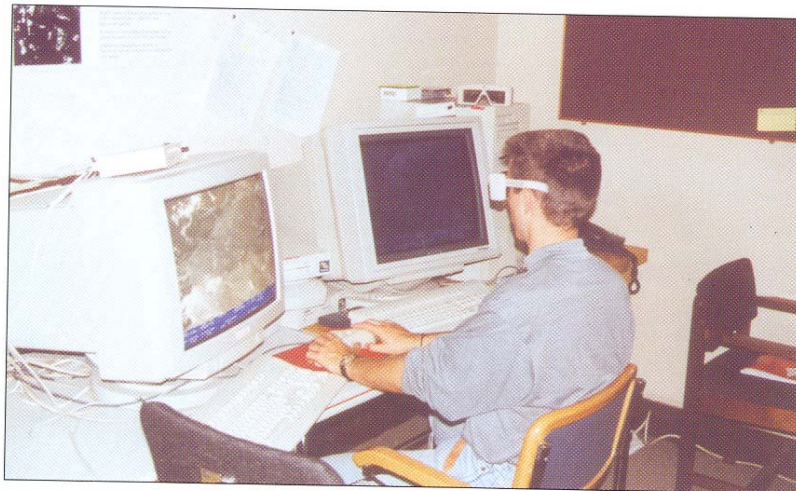
A combination of conventional methods, and specialised adaptation of modern techniques, i.e. digital photogrammetry, was applied. The use of available facilities in unison with related projects was maximised.

Included were:

- An initial survey to estimate the relative extent of damage to the vegetative cover and to the surface soil putatively due to livestock.
- Selection of sites for detailed botanical and photogrammetric study involving field and laboratory techniques. The latter was completed by using cloud-free, black & white aerial photographic coverage from the mid-1970s (1:30,000), mid-1990s (1:40,000) and custom flown photography in 1996 and 1998 at the more detailed scale of 1:15,000. Diapositives were scanned at 25 micron resolution, which gave a 'ground' pixel size ranging from *c.* 0.4 m x 0.4 m to 1.0 m x 1.0 m for the scales 1:15,000 and 1:40,000 respectively. PC-based, digital photogrammetric software, using individually ground-controlled (GPS) stereo-models, enabled mapping of areas of vegetation and erosion at approximately twenty times the original photographic scale; it also allowed comparisons to be made at similar levels of photographic resolution. Ground validation was applied throughout.
- Descriptions of vegetation using the standard relevé method, and visual assessment of the cover of each species using the Braun-Blanquet 5-point scale (Muller-Dumbois and Ellenberg, 1974).
- Comparative study of semi-natural vegetation, enclosed and open to grazing on the Teagasc Hill Sheep Farm using 11 exclosures (10 m x 5

m), that were established in 1991/1992. Vegetation cover and composition at ground level were recorded using a point analysis technique reported in Mitchell *et al.* (1996). One hundred contacts (species *or* bare ground) were recorded per quadrat. Four quadrats were recorded within and outside each enclosure giving 88 quadrats in total. The average height of the dominant plant species and peat depth were measured. Slope gradient, aspect, physiognomy of the plants and species with low occurrences, not detected by the recording methodology, were also noted.

- A study of terracettes, which quantified aspects including morphology, soils and animal impact, on a number of the selected sites and on the Teagasc Hill Sheep Farm.
- Livestock statistics and weather data in relation to the selected sites.



*Photogrammetrist wearing Crystaleyes® stereo glasses examining digital images*

## RESULTS AND DISCUSSION

### Study sites

An initial survey in the hill and mountain environment of the western seaboard counties revealed over 40 sites with damage to the vegetative cover and poaching of the surface soil.

A number of these sites, representing mainly commonage areas in the principal hill sheep counties, were selected for detailed study. They were; Malin Head, Co. Donegal, Carrowmore, north west Mayo, Sheeffry foothills and Teagasc Hill Sheep Farm, south west Mayo, Tully Mountain, west Co. Galway and Brandon area, Dingle peninsula Co. Kerry (Table 2).

**Table 2: Main characteristics of selected sites**

<b>Location</b>	<b>Altitude range (m)</b>	<b>Principal soils</b>	<b>Main habitats</b>
Malin Head, Co. Donegal	150-282	Organic lithosols, peaty podzols	Dwarf shrub heath (wind clipped)
Carrowmore Lake, Co Mayo	20-239	Blanket peat, peaty podzols	Low-level Atlantic blanket bog
Tully Mountain, Co Galway	50-356	Shallow blanket peat , peaty iron-pan podzols	Dwarf shrub heaths, upland blanket bog, upland grassland
Sheeffry foothills, Co. Mayo	60-200	Blanket peat	Low-level Atlantic blanket bog
Brandon area, Co Kerry	50-429	Blanket peat	Coastal heaths, upland grassland, low-level and upland blanket bog

## Erosion and vegetation

Photogrammetric analyses showed clear evidence of progressive erosion at all sites but the extent and patterns varied greatly among the sites. One extensive and several small plots were studied at each site. The extensive plots, several hundred ha in area, were described using point observations based on 100/125 m grid system. The study of the smaller plots (1 to 10 ha) consisted of detailed mapping of individual features. The following is a summary of results.

The **Malin Head** site is located in the northern part of the Inishowen peninsula, county Donegal. The soils are organic lithosols, peaty podzols and blanket peat, overlying Precambrian schists and quartzites. The terrain is gently to moderately sloping and altitude extends to 282 m.

**Table 3: Stereo air-photo analysis of terrain features from 1977 and 1996 coverage of Malin Head site<sup>1</sup>, Co. Donegal.**

<b>Feature</b>	<b>1977</b>	<b>1996</b>	<b>Change</b>
	<b>(% of study site<sup>2</sup>)</b>		
Roads/Tracks/Buildings	3.6	3.4	- 0.2
Enclosed- fields/boundaries/open water/drains/trees	17.2	13.8	-3.4
<b>Intact semi-natural vegetation surface</b>	<b>24.0</b>	<b>10.3</b>	<b>-13.7</b>
<b>Eroding semi-natural vegetation surface</b>	<b>44.6</b>	<b>60.7</b>	<b>+16.1</b>
Cut-over peat	10.2	11.4	+1.2
Ravine/cliff face	0.4	0.4	0

<sup>1</sup>814 ha; <sup>2</sup>n = 814

Three stereo-models from the photographic coverages of 1977 and 1996 were examined. Table 3 summaries the changes that have taken place in this 20-year period. Land mapped as intact surface occupied by semi-natural vegetation decreased by 14 percentage points since 1977. Eroding semi-natural vegetation surface, which consisted of a number of individually mapped features, increased over the 20-year period by 16 percentage points.

Clearly definable erosion features (exposed sub-soil, gullies etc.) in a number of 1-ha plots throughout the site were digitised and compared using both sets of photography (Table 4).

**Table 4: Eroding surfaces (% of plot area) from 5 selected geo-referenced plots in the 1977 and 1996 images, Malin Head site, Co. Donegal.**

Plot	Area ha	Eroding surfaces (%)		Change
		1977	1996	
1 (220)*	1.0	22.3	22.8	+0.5
2 (240)	2.25	7.2	8.7	+1.5
7 (230)	1.0	7.1	19.3	+12.2
8 (230)	1.0	10.4	43.6	+33.2
9 (220)	1.0	51.3	51.4	+0.1

\*Altitude (m)

In some cases (plots 1 and 9) little or no change was recorded; however in the case of plot 7 and 8 a large proportion of intact vegetation had been removed exposing the underlying shattered quartzite rubble. The dominant vegetation of the intact peat surfaces can be described as wind-clipped

dwarf shrub heath, overlying shallow humic soils and characterised by low-growing (<15 cm), prostrate *Calluna vulgaris* (heather) and *Erica cinerea* (bell heather) often in association with *Vaccinium myrtillus* (billberry) and *Empetrum nigrum* (crowberry). Species-poor *Nardus* grassland occurs along the margins of roads (tracks). The most likely causes of the progressive erosion are long-term natural phenomena, i.e. weather and nature of soils.



*Remnants of original peat surface lying on quartzite rubble, Malin Head.*

The **Carrowmore Lake** site is situated in northwest Mayo. The soils consist of blanket peat and peaty podzols which overlie a variety of rocks such as schists, quartzites, gneisses and limestones. The terrain is mainly gently to moderately sloping and attains an altitude of 239m. A study site (254 ha) with air-photo coverage from 1974 and 1996 was examined. Table 5 outlines the main changes to surface features observed over the 23-year period.

**Table 5: Stereo air-photo interpretation of terrain features from 1974 and 1996 coverage of Carrowmore lake site<sup>1</sup>, Co. Mayo.**

<b>Feature</b>	<b>1974</b>	<b>1996</b>	<b>Change</b>
	(% of study site <sup>2</sup> )		
Roads/Buildings	4.3	4.9	+0.6
Field margins	1.8	1.8	0
Drain/stream	0.0	1.2	+1.2
Low-land pasture	22	22.3	+0.3
Hill pasture (moderate slope)	1.8	1.8	0
Cut-over peat	5.5	4.9	-0.6
<b>Intact surfaces</b>	<b>30.7</b>	<b>17.8</b>	<b>-12.9</b>
<b>Eroding surfaces</b>	<b>33.8</b>	<b>44.2</b>	<b>+10.4</b>

<sup>1</sup>254 ha; <sup>2</sup>n = 163

The area with an intact cover of peat and vegetation decreased by approximately 13 percentage points, which was reflected mainly in an increase in eroding surfaces. ‘Eroding surfaces’ included the following features; runnels (small surface channels), gullies, severely dissected peat, residual peat, peat hags, exposed subsoil/bedrock, bog-slips/bursts and summit erosion.

The number of gullies and their cumulative length were mapped and calculated in a selection of smaller plots throughout the site (Table 6).

**Table 6: Number of gullies and their cumulative length from selected, geo-referenced plots in the 1974 and 1996 images, Carrowmore Lake site, Co. Mayo**

Plot	Area Ha	1974		1996		Percentage change
		Gullies		Gullies		
		No.	Length (m)	No.	Length (m)	
1 (70-100)*	8.03	151	6487.6	211	6613.3	+2
2 (120)	2.0	76	2186.9	167	2661.2	+22
5 (110)	1.0	49	1417.5	62	1680.4	+18.5
10 (110)	1.0	67	1484.3	66	1499.9	+1.0

\* Altitude (m)

The table shows a substantial increase in both the number and cumulative length of gullies in the 23- year period.



*Gullies in blanket peat  $\geq 1m$ ; subsoil exposed.*

The vegetation of the lower slopes is typical of low-level Atlantic blanket bog and dominated by *Molinia caerulea* and *Schoenus nigricans*. This grades into heath vegetation as slope and altitude increases. Heather communities are well represented in the southern part of the site but less so in the northern part where erosion is most intense. Heather, indeed all vegetation, as well as the soil in this area showed widespread evidence of damage by livestock.

The damaged area is the most accessible portion of the hill and is nearest to the associated greenland. The evidence suggests that supplementary feeding practices have changed grazing behaviour and led to livestock neglecting the more distant grazing areas with resultant excessive grazing pressure on one part of the site. The damage at this site has involved effects by both sheep and cattle.

The **Sheeffry foothills** site is located in south Mayo. The soil consists of deep blanket peat with gentle slopes. Photogrammetric analysis was not completed as ground control could only be achieved via aerial-triangulation. This would have involved establishing points in the surrounding mountain ranges and was outside the capacity of the project.

Extensive damage to the vegetation cover was obvious. Vegetation relevés (n = 40) indicated a mean bare ground cover of 80%. However, the root mat appeared to be intact in most cases, indicating a strong potential for recovery of the vegetation. The vegetation cover at present is sparse but, significantly, over one third of the vegetation at this site is *Nardus stricta*, which is accepted as an indicator species for overgrazing. Therefore, at this site, the only tenable interpretation is that an inappropriate increase in grazing pressure is responsible for the very high proportion of bare ground.

The **Tully Mountain** site is located in a peninsular part of west Galway and rises to 356 m. The soils consist of shallow blanket peat and peaty podzols overlying quartzites and psammitic schists, and have steep slopes with a north-easterly aspect.

A study plot of 449 ha was selected. Interpretation of terrain features based on a 26-point legend was undertaken for both sets of stereo air photographs (1973 and 1998) at the intersection of a 100 m x 100 m grid. A summary of the main surface features recorded in 1973 and 1998 and the changes observed over the 26-year period are presented in Table 7.

**Table 7: Stereo air-photo interpretation of terrain features from 1973 and 1998 coverage of Tully Mountain site<sup>1</sup>, Co. Galway**

Feature	1973	1998	Change
	(% of study site <sup>2</sup> )		
Roads	1	1	0
Enclosed low-level pasture	4	5	+1
Intact <i>Calluna</i> -dominant vegetation	58	42	-16
<b>Moderately eroding <i>Calluna</i>-dominant vegetation</b>	<b>2</b>	<b>8</b>	<b>+6</b>
Intact grassland vegetation	12	14	+2
<b>Moderately eroding grassland vegetation</b>	<b>3</b>	<b>4</b>	<b>+1</b>
Intact <i>Calluna</i> -grassland mosaic	6	5	-1
<b>Exposed sub-soil/rock</b>	<b>13</b>	<b>19</b>	<b>+6</b>
<b>Summit (climatic) erosion</b>	<b>0</b>	<b>1</b>	<b>+1</b>

<sup>1</sup>449 ha; <sup>2</sup>n = 446

The main change at this site was a decrease of 16 percentage points in the area occupied by intact *Calluna vulgaris* (heather)-dominated vegetation between 1973 and 1998. Grassland-dominated vegetation increased slightly. The proportion of exposed subsoil/bedrock also increased. Features that were recorded in the 1998 but not in the 1973 photography included erosion of summit peat and moderately eroded grass and heather mosaic vegetation.

The vegetation is characterised by *Calluna vulgaris-Erica cinerea* dry heath. This community dominates the site occurring on moderately sloping (12 to 15<sup>0</sup>) peat soils particularly above 150 m. The heather canopy shows a predominately ‘topiary’ growth form and is heavily browsed. Towards the south-eastern end of the site on the lower slopes, heavy grazing of dwarf shrubs has led to reduced vigour and stunted reproduction. Heather plants have become excessively woody and degenerate. The pattern indicates that livestock and associated feeding/management practices were the primary drivers of change.

The **Brandon Area** site occurs in the Dingle peninsula, county Kerry. The soils consist of blanket peat overlying Devonian sandstone and shale rocks. The terrain has gentle to steep slopes and attains an altitude of over 400 m.

An extensive plot occupying 449 ha was studied on the basis of a 100 m x 100 m grid using stereo-models from photographic images of 1973 and 1998 flights.

Table 8 shows the terrain features expressed as a percentage of the total grid intersection points. Many of the individual features that were identified have been grouped for ease of presentation.

**Table 8: Stereo air-photo interpretation of terrain features from 1973 and 1998 coverage of the Brandon Area site<sup>1</sup>, Co. Kerry**

Feature	1973	1998	Change
	(% of study site <sup>2</sup> )		
Roads	0.9	0.2	-0.7
Field boundaries	1.3	1.1	-0.2
Drain (man-made)	0	0.7	+0.7
Lowland and hill pasture	11.8	11.6	-0.2
Permanent (non-active) gullies	0.2	0.2	0
Cut-over peat	0.7	0	-0.7
Rock outcropping	0	1.6	+1.6
Streams (natural)	0.7	1.1	+0.4
<b>Intact surfaces</b>	<b>32.1</b>	<b>24.9</b>	<b>-7.2</b>
<b>Eroding surfaces</b>	<b>52.3</b>	<b>58.6</b>	<b>+6.3</b>

<sup>1</sup>449 ha; <sup>2</sup>n = 449

Intact surfaces decreased by 7 percentage points and conversely there was a 6-percentage point increase in eroding surfaces. Bare peat was widespread throughout the site and peat cover has been removed in many areas leaving underlying rock exposed.

The changes in two 1-ha plots relating to the number of gullies that were identifiable and their cumulative length are shown in Table 9.

**Table 9: Number of gullies and their cumulative length from selected, geo-referenced plots in the 1973 and 1998 images, Brandon Area site, Co Kerry**

Plot No.	Area ha	1973		1998		Percentage change
		No.	Length (m)	No.	Length (m)	
4	1.0	52	925.2	152	1921.3	+107.7
6	1.0	45	750.4	116	1646.8	+119.7

Substantial intensification of erosion channels (gullies) occurred in these plots in the 26-year period. In addition, exposed rock increased by 4.6% at plot 4 over the same time period. Evidence from field studies suggests that inappropriate livestock management was a significant factor in the progression of erosion.

### **Terracettes**

Four hill sites with distinct terracette (Figure 1) development were selected in counties Donegal, Mayo and Galway (Clavin, 2000). The sites ranged in altitude from 40 to 210 m above sea level and occurred on climatic peat, peaty gley and peaty podzol soils. Twenty-three transects representing a total of 407 terracettes were subjected to detailed morphological measurements. Soil profiles were examined in selected sites using long soil cuttings. The effects of recent animal traffic and resting were recorded.

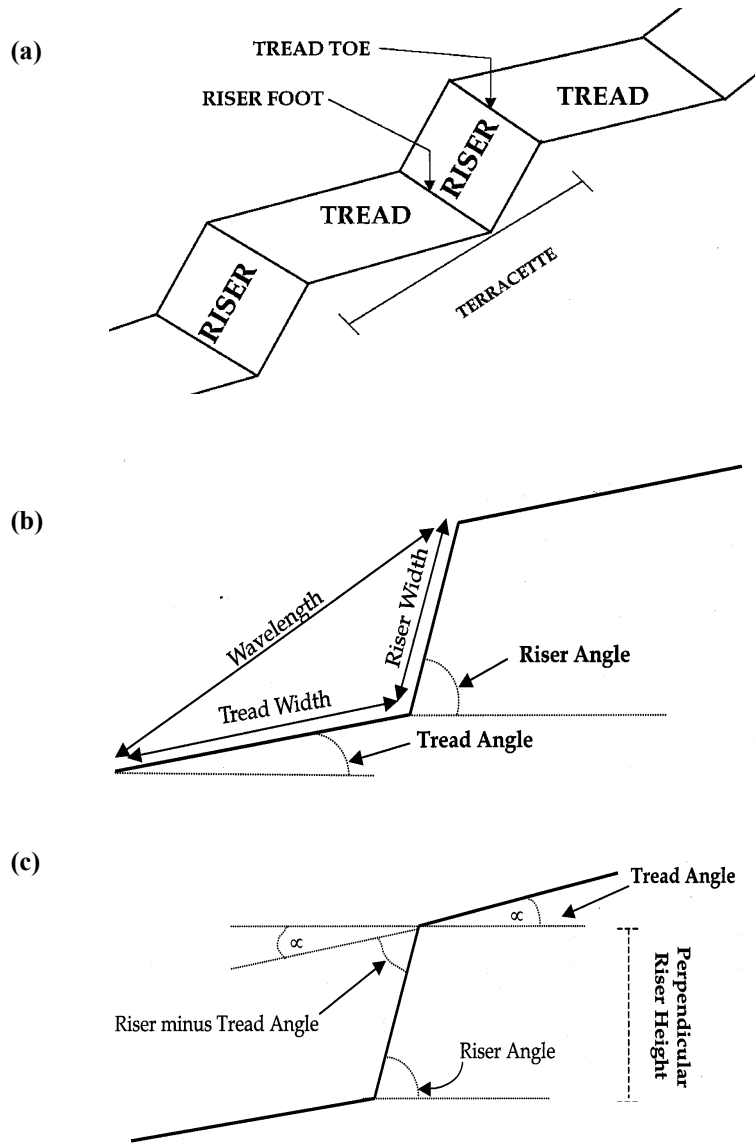


Figure 1: Terracette morphology: (a) terminology; (b) & (c) elements measured

Table 10 compares the dimensions of the terracettes studied with those in the published literature (Clavin, 2000).

**Table 10: Comparison of terracette dimensions from present study with those from published literature**

<b>Terracette dimension</b>	<b>Present study</b>	<b>Literature</b>
Slope gradient	11 to 57°	5 to 51°
Wavelength	17 to 455 cm	30 to 347 cm
Tread width	13 to 423 cm	10 to 240 cm
Riser width	5 to 167 cm	7 to 290 cm
Tread angle	-14 to 39°	0 to 39°
Riser angle	18 to 90°	19 to 90°
Riser angle <i>minus</i> Tread angle	2 to 93°	17 to 71°

A broad similarity exists between both sets of data. Negative *tread* angles, however, i.e. sloping into the hill, were not found in the literature but were recorded in this study particularly in terracettes where animal influence was dominant. The *riser angle minus tread angle* is an important derived terracette diagnostic feature. A high value is linked with well defined ‘stairs-like’ terracettes and a low value with poorly defined ‘flat’ terracettes. The sites studied had a much wider range than that in the literature.

All transects displayed some evidence of recent animal activities, i.e., preferred tracks, poaching of the surface, concavities in *treads* and *risers* and trampling of vegetation.

A total of 77 terracettes, which occurred in four transects in southern county Mayo, were classified as ‘inner track terracettes’ due to features resulting from treading by sheep. They were associated with slopes, 15° or less,

which rarely feature in the literature. The majority exhibited distinct sheep hoof activity mainly at the inner *tread* near the *riser* foot, resulting in a definite and alternating *tread/riser* micro-topography. The tracks, where dense, displayed an intricate pattern of linkages between adjacent terracettes. The width of inner sheep tracks (30 to 62 cm) was significantly wider than those reported in the United States (18 to 30 cm) for ‘sheep trail widths’ (Higgins, 1982). The inner track to *tread* width ratio in Ireland was relatively wide - 1:1.33. The soil profile of the inner track terracettes was dominated by the displacement of some or all of the topsoil (mainly O horizon) from the inner to the outer *tread* area. Table 11 summarises the main differences between ‘inner track’ and other terracettes. The frequency of exposure of subsoil, of concavities in the tread and of negative tread angles was significantly higher in the former.

**Table 11: Occurrence (%) of features due to animal tracking in ‘inner track’ and other terracettes**

Features of terracettes due to animal tracking	Terracettes	
	‘Inner track’ (n=77)	‘Other’ (n=330)
Exposure of subsoil at riser foot	10	1
Concavity in <i>tread</i>	35	13
Negative <i>tread</i> angle*	12	< 2

\*Angle of *tread* slopes into hill.

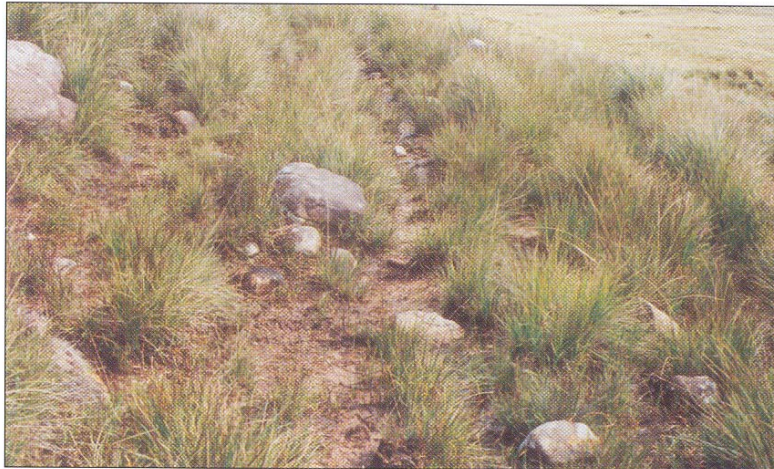
Cattle tracks, which also occurred on the inner *tread* near the *riser* foot, were much less common and occurred in some terracettes in the Donegal site. The width of cattle tracks (45 to 63 cm) was wider than those reported in the United States (33 to 41 cm) for ‘cattle trail widths’ (Higgins, 1982).

They occupied 50 to 80% of the *tread* width and resulted in the formation of rills 15 to 20 cm deep in the surface O horizon.

Both sheep and cattle tracks showed varying degrees of vegetative cover in *Molinia/Schoenus* and in *Calluna* dominated areas of the hillside.

Sheep resting areas or ‘sheep burrows’ occurred on the west Galway (Tully site) and are associated with wide, steep, bare *risers* often concave in shape. These features facilitate erosion and the dislodgement of peat from exposed surfaces.

All the ‘inner track’ terracettes were located on the Teagasc Hill Sheep Farm where the ground cover of vegetation had actually increased over the period 1995-1999 (Walsh *et al.*, 2000). This indicates that stocking density had a less severe impact on the micro-topography in the other sites. This, in conjunction with results from the vegetation and erosion studies, points to an uneven use of the hill resource.



*Terracettes with livestock track on ‘inner’ thread*

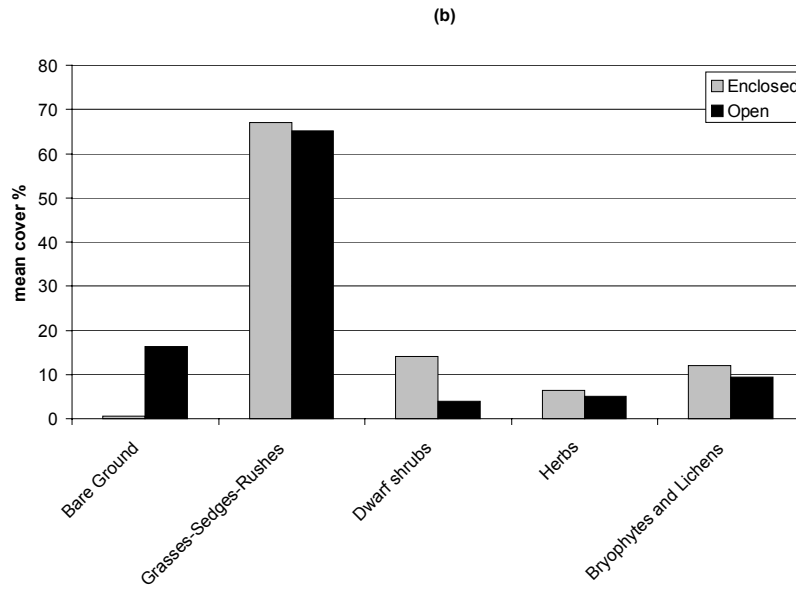
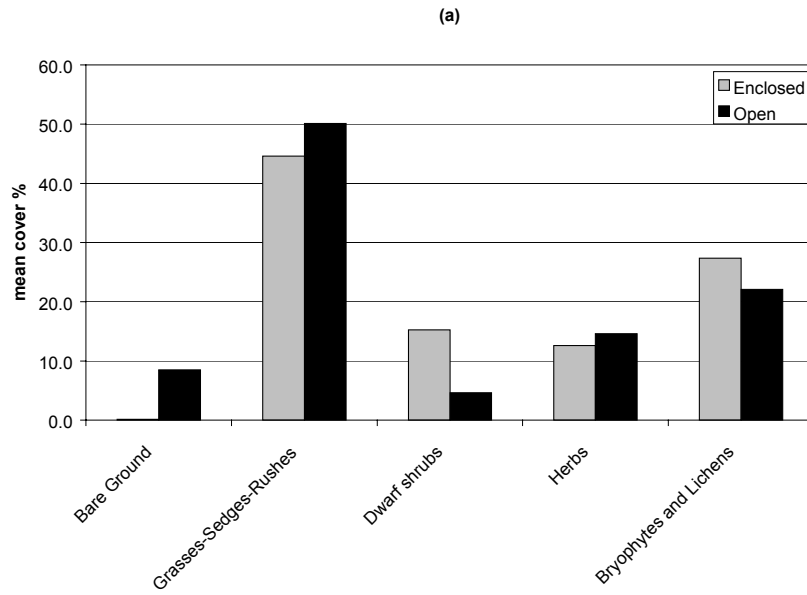
### **Exclosures (Teagasc Hill Sheep Farm, Leenaun)**

A detailed comparison between the vegetation within exclosures (enclosed plots excluding large herbivores), where vegetation was ungrazed for six to seven years, and that surrounding them (10 to 15 m outside each corner of the exclosure), was completed. The surrounding area was open to an annual stocking rate of 0.9 ewes/ha (Hanrahan and O'Malley, 1999).

Results from a selection of these areas, which represent three of the main hill-land vegetation types, are presented in Figures 2 and 3

*Low-level Atlantic blanket bog:* The vegetation was represented by two exclosures which were located on deep (>1.5 m) low-level, blanket peat. Bare ground was negligible in the exclosures but accounted for 8.5 percent of ground in the adjacent open areas. Grasses and sedges dominated the vegetation with little difference in cover recorded between vegetation open to grazing and that enclosed. Species, such as *Molinia caerulea*, *Schoenus nigricans* and *Rhynchospora alba*, typical of wet blanket peat, were dominant. Dwarf ericaceous shrubs, *Calluna vulgaris* (heather) and *Erica tetralix* (cross-leaved heath), attained a cover of 15% in the enclosed plots compared with 4.5% cover in the surrounding vegetation. In enclosed plots heather plants were flowering profusely and attained a height ( $\pm$ s.e.) of 25.6 ( $\pm$ 0.73) cm and species of *Sphagnum* mosses were well represented in the ground flora. The number of species recorded within the exclosures, however, was slightly less than that in the surrounding vegetation.

*Wet heath:* The two exclosures representing this vegetation were located at the transition between the steep transportational mid-slope and the gentle colluvial slope below. The vegetation was classified as *Molinia caerulea*-*Erica tetralix* wet heath.



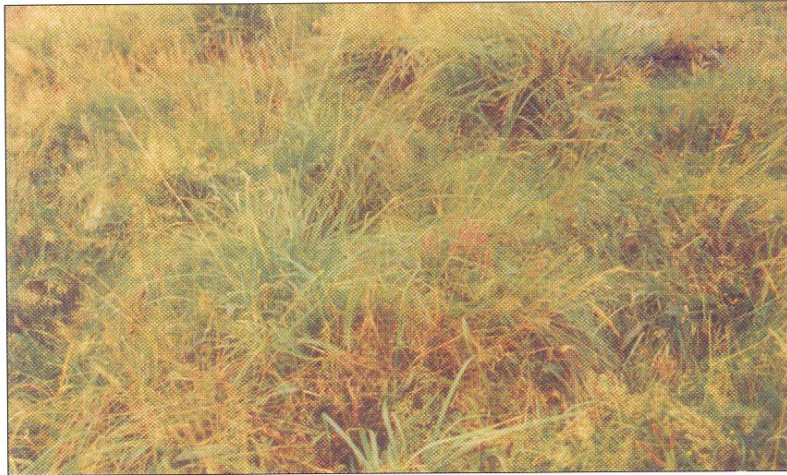
**Figure 2: Mean ground cover (n=800) in enclosed and open (subject to grazing) areas; (a) Low-level Atlantic blanket bog, (b) Wet heath**

Grasses, sedges and rushes formed the largest component of the vegetation with little difference in cover between open and enclosed areas. The vegetation surrounding one of the exclosures showed greater species diversity with ten species of grass, sedge and rush recorded as opposed to two within the exclosure. The average height ( $\pm$ s.e) of this component of the vegetation in exclosures was 59.7 ( $\pm$ 2.3) cm compared with 41.7 ( $\pm$ 2.1) cm outside. The herb, *Potentilla erecta*, showed a positive response to protection from grazing. Dwarf shrubs occupied 14.1% ground cover within the exclosures as opposed to 4% cover in surrounding vegetation. with *Erica tetralix* the dominant species recorded. The occurrence within exclosures of bare ground was < 1% with 16.5% cover recorded in surrounding areas.

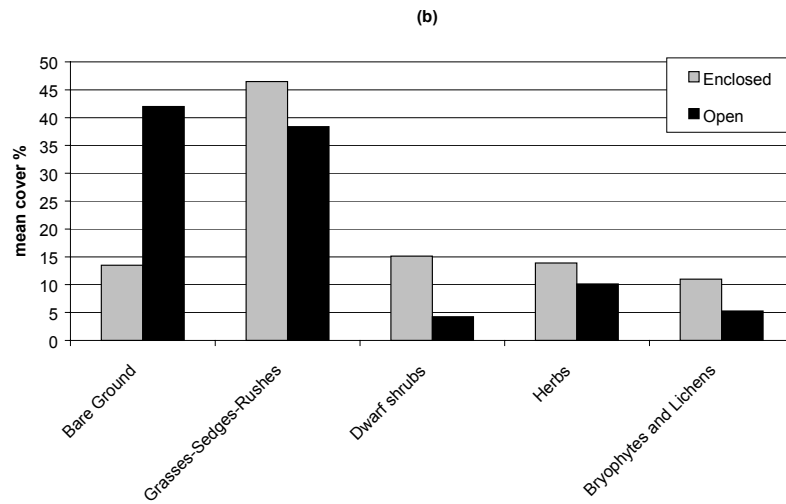
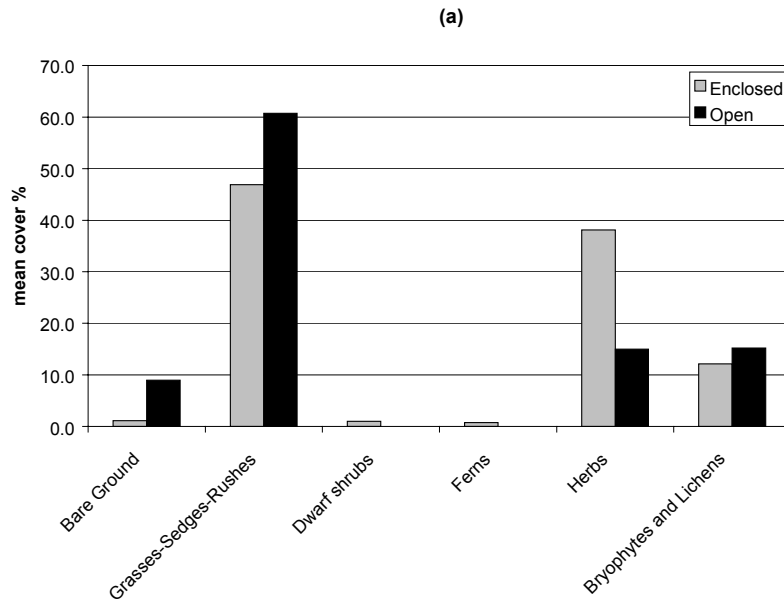
*Agrostis-Festuca upland grassland*: Acid grassland vegetation with a dominance of *Agrostis* and *Festuca* species, occupies <4% of the unimproved hill on the Teagasc Hill Sheep Farm. This vegetation is confined to the better-drained soils of the transportational mid-slope and was represented by two exclosures. Sheep favour these drier areas as resting places, increased dung and urine deposition, associated with animals may have altered the nutrient status of the soil but this effect was localised. The impact of animal activity in the areas surrounding the exclosures was much more marked than in other vegetation types. Species that showed a significant increase in cover when protected from grazing included *Agrostis stolonifera*, *Anthoxanthum odoratum*, *Potentilla erecta*, *Molinia caerulea* and the pleurocarpous moss *Rhytidiadelphus loreus*. Bare ground cover was 1% and 9%, within and surrounding the exclosures, respectively. Species that had the highest cover in the surrounding areas included *Nardus stricta*, *Carex binervis*, and *Carex demissa*. Species diversity was greater in the surrounding vegetation as some low-growing or stoloniferous plants in enclosed conditions seemed to be out-competed by more vigorous growing

grasses. Vegetation structure showed marked differences, the mean height ( $\pm$ s.e.) of grasses in one enclosure was 33.8 ( $\pm$ 1.6) cm, compared with 8.3 ( $\pm$ 0.5) cm in the surrounding area. Bracken (*Pteridium aquilinum*), an invasive and resilient species, was recorded within the enclosures but not in the surrounding vegetation.

*Summit enclosures:* The annual stocking density of the area surrounding the enclosures, in these exposed elevated sites, was reduced from 0.9 to 0.3 ewes/ha, three years prior to recording. Bare ground was considerably less in the enclosures than in the surrounding grazed areas, *i.e.* 13.5% compared with 42% respectively. Mosses thrived in the enclosed compared to open conditions occupying, 11% and 5%, respectively. Dwarf shrubs cover in the enclosed plots was 15% compared with 4% in the surrounding areas. Bryophytes cover was approximately 5 percentage points more in the enclosures than outside.



*Grassland vegetation protected from grazing for seven growing seasons*



**Figure 3: Mean ground cover (n=800) in enclosed and open areas; (a) *Agrostis-Festuca* upland grassland, (b) summit deep blanket bog**

*Species diversity.* Species diversity was greater in vegetation open to grazing than that enclosed in many areas (Table 12). Several authors suggest that grazing may increase species diversity (Marrs *et al.*, 1988; Welch, 1984). However, where the more selective grazers (i.e. sheep) are dominant and avoid unpalatable species, such as *Nardus stricta* and *Juncus squarrosus*, the opposite finding is the more likely.

**Table 12: Mean, range and total number of species recorded, in enclosed and open conditions for the main vegetation types on Teagasc Hill Sheep Farm, Leenaun, Co. Mayo.**

Vegetation <sup>1</sup>	Mean <sup>2</sup>		Range		Total	
	Encl.	Open	Encl.	Open	Encl.	Open
Low-level Atlantic	15.25	17.25	15-16	13-22	26	27
banket bog	14.25	15.0	13-17	13-19	26	23
Wet Heath	10.0	12.5	9-11	9-14	18	23
	11.75	16.25	9-16	14-18	23	29
<i>Agrostis-Festuca</i>	10.0	13.5	9-13	12-15	12	18
upland grassland	14.5	16.5	12-16	12-20	26	24

<sup>1</sup>Two exclosures were erected in each of the main vegetation types

<sup>2</sup>Based on 4 x 100-point quadrats in each exclosure and the surrounding area.

The highest species diversity, 29 species, (i.e. total number of species recorded in any group of 4 quadrats), occurred in an area open to grazing surrounding an exclosure located on wet heath vegetation. The lowest, 18 species occurred in *Agrostis-Festuca* grassland from which herbivores had been excluded for 7 growing seasons.

The results show the dynamic nature of vegetation in hill landscapes and the influence that management and local environmental conditions have on its structure and composition. The mean percentage occurrence of bare ground within all exclosures (n=10) was low, (<4%), in comparison with 20% in surrounding areas. Grazing reduces the competitive ability of tall or fast-growing species thus allowing low-growing species to co-exist. Bracken (*Pteridium aquilinum*), a notoriously unpalatable and difficult to control invasive species, had begun to encroach in one of the exclosures. This species is likely to spread because the physical damage caused to fronds by trampling of livestock, which helps control its spread, is absent. Bracken reduces the grazing value of hill-land and can have a negative effect on animal welfare (Marrs and Pakeman, 1995). An indirect effect of sheep grazing is the damage caused to surface vegetation by trampling and treading of animals in search of food and shelter. Non-vascular plants, especially *Sphagnum* mosses not believed to be eaten by sheep, but sensitive to trampling, responded positively to the cessation of grazing.

Miles *et al.* (1978) estimated that, due to many controlling factors, it usually takes 10 to 50 years for semi-natural vegetation to pass from one community type to another. Thus, the observations recorded at the Teagasc Hill Sheep Farm, Leenaun, can at best be described as initial trends.

### **Livestock statistics**

Despite intensive efforts with livestock data collected (CSO, DAFRD), current stocking (sheep) density could not be correlated definitively with the areas of soil and vegetation damage in the sites studied. The livestock data relate to District Electoral Division (DED) level (Av. size 5 – 8 sq. km<sup>2</sup>) while damaged areas, in many cases, only occupied portions of townlands. However, the shift in sheep farming emphasis from wethers to ewes, which was encouraged by subsidies, forced a change in farming practice. This led

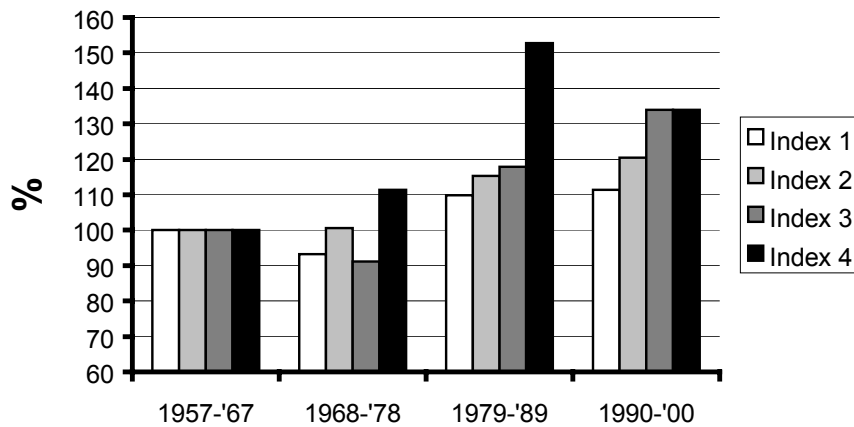
to increased grazing pressure especially on the foothills due to more time-consuming husbandry practices associated with a dominantly ewe flock.

Applications for the ewe premium in 1999 indicated that about 1.8 million ewes were present in counties Donegal, Mayo, Galway and Kerry. Most are based in the uplands regions. While there was a large increase in the national numbers of sheep over the period 1980-1991, the West region, which already had the highest numbers, had the lowest average annual increase in that period, i.e. 10% compared with 13 to 28% in other regions (Lafferty, Commins, and Walsh, 1999). Sheep numbers in the succeeding period 1991-1997 have declined in all regions by an average annual rate of 0.3 to 2.6% (*op. cit.*). Over the two-month period, November to December 1998, about 153,000 sheep were removed from targeted areas (commonages) in counties Donegal, Leitrim, Sligo, Mayo, Galway and Kerry. Further stocking rate adjustments are anticipated with the implementation of the forthcoming Commonage Framework Plans.

### **Climatic influence**

The observation of erosional features that were inconsistent with excessive impact of livestock on vegetation and soils led to a consideration of other possible influences contributing to the progress of erosion in western hills. While the Irish climate is typically free of extremes, sharp increases in elevation can result in significant increases in rainfall and wind velocity and a decrease in temperature. The mean annual number of days with gales is much higher on the west coast than inland, 42.4 days at Malin Head compared with 7.6 days at Clones (Rohan, 1986). Exposed surfaces of peat soils, which have an innately high moisture content and weak structure, are especially vulnerable to the combined effect of wind and rain i.e. 'driving rain'.

‘Driving rain’ values for hours with 2 mm or more rainfall in the period 1957-2000 were calculated and expressed in cm<sup>2</sup>/sec for five western synoptic stations; Malin Head, Belmullet, Claremorris, Shannon and Valentia. The values ranged from 0 to a high of 2,390 (Valentia, December 1994). The values were grouped in four indices; **index 1**, 100 to 299, **index 2**, 300 to 599, **index 3**, 600 to 999 and **index 4**,  $\geq 1,000$ . Figure 4 indicates the percentage change in the indices for all five stations from 1957 to 2000 with the total for the sub-period 1957-’67 being set equal to 100 for each index.



**Figure 4. Percent change in the total occurrence of ‘driving rain’ indices for 5 stations by 11-year period from 1957 to 2000.**

Source of data: Met Éireann

A clear increase in the occurrence of the more severe driving rain indices, index 3 and 4, is evident in the latter half of the period 1957-2000. The peak for the most severe index coincides with the highest increases in sheep numbers in the decade of the 1980s.

This coincidence must have further exacerbated the likelihood of damage and erosion in an environment where the vegetation and soils are least resilient.

Tables 13 and 14 show the frequency of the various indices by station for the 44-year period. Indices 1 and 2 accounted for 78 to 85% of all values.

**Table 13: Frequency of ‘driving rain’ indices 1 and 2 by 11-year period from 1957 to 2000**

Year Station/Index	1957-'67		1968-'78		1979-'89		1990-'00	
	1	2	1	2	1	2	1	2
Malin Head	646	366	637	402	664	408	732	477
Belmullet	746	335	652	331	892	413	856	507
Claremorris	856	203	829	197	1001	264	964	219
Shannon	708	168	648	141	747	157	767	181
Valentia	1205	600	1113	611	1270	686	1313	631

Source of data: Met Éireann

**Table 14: Frequency of ‘driving rain’ indices 3 and 4 by 11-year period from 1957 to 2000**

Year Station/Index	1957-'67		1968-'78		1979-'89		1990-'00	
	3	4	3	4	3	4	3	4
Malin Head	50	14	46	8	57	24	84	28
Belmullet	36	14	39	14	56	16	84	20
Claremorris	19	4	16	1	13	3	13	3
Shannon	20	3	15	3	5	3	11	3
Valentia	99	18	88	33	133	35	108	17

Source of data: Met Éireann

## Monitoring

Quantitative assessment of the impact of livestock on the hill environment must necessarily focus on elements of that environment which are permanent/semi-permanent, i.e. vegetation, soils and physiography. However, there were no generally recognised methods to achieve this assessment.

Two new methods were developed.

- ***Digital photogrammetry and sequential aerial photography:*** This technique, using individually ground-controlled and geo-referenced stereo-models, enables the identification and quantification of even minor changes in erosion features and certain patterns of vegetation. The preferred nominal scale of photography is 1:15,000. Ground verification is essential.
- ***Terracette morphology and vegetation – sequential measurements:*** Terracettes, which are a common feature of the hill environment, often include features that are unambiguously associated with livestock. They include animal tracks devoid of vegetation, concavity in *tread* and/or *riser*, negative *tread* angle, mounding of soil at outer *tread*, and track/*tread* width ratio. Sequential measurements of these features using geo-referenced transects, *c.* 25 m long, at right angles to the direction of the terracettes coupled with vegetation analysis provide a robust and repeatable assessment of the impact of livestock on such environments.

While the first method must take full advantage of the best flying conditions, the second is generally independent of seasonality of plant growth and farm management requirements. The methods are complementary and together provide a ‘remote’ and ‘hands-on’ assessment of the impact of livestock on the environment.

## **Management guidelines**

The results of the present project together with those of related projects suggest a number of management guidelines for hills.

- Concentration of sheep in specific areas of hill grazing, particularly in winter, should be avoided.
- If the above is not possible then concentration points should be changed at regular intervals and located on the drier, more resilient, areas.
- Plot studies on the Teagasc Hill Sheep Farm, Leenaun, indicate that semi-natural vegetation is especially sensitive to intensive winter grazing (Walsh *et al.*, 2000). Housing and/or in-bye land may be necessary to reduce stocking density during this period.
- The animal body condition can be used as a barometer of upland vegetation supply. Hill grazing, which is stocked at 0.9 ewes/ha, on the Teagasc Hill Sheep Farm, Leenaun, supplies 50% of maintenance requirements of the flock (Hanrahan and O'Malley, 1999). The current stocking density is considered to be at or near maximum for this type of vegetation, mainly *wet heath*. Thus, if more production were expected of this vegetation, the stocking density would have to be reduced accordingly.

Stock carrying capacity varies greatly from hill to hill due to variations in soil, vegetation and physiography. Thus, it is suggested that a set of representative, geo-referenced, monitoring points be established on a number of hill grazings to provide an annual, quantitative measure of bare ground. This, in addition to ewe body condition assessment, would determine the appropriate stocking density and assure the sustainable use of the resource.

A crucial point is that defined management practices and information on flock performance are essential elements of the sustainable use of hill areas.

## CONCLUSIONS

- A geo-referenced data bank of a range of features (vegetation, soil, erosion and topography) which are relevant to assessing the impact of livestock was established for a number of representative sites. It provides a comprehensive benchmark for on-going monitoring of hill areas.
- Digital photogrammetry, which is used almost exclusively for map making, was successfully adapted, using sequential photography and individually ground-controlled stereo models, to quantify and monitor even minor changes in erosion features and certain patterns of vegetation.
- A variety of features, which gave visually similar, photographic tonality, emphasised the necessity for comprehensive field validation.
- Erosion of mainly hill and organic soils and the semi-natural vegetation was progressive in all sites from the early 1970s to the late 1990s. This progression appears to be due to a complex interaction of natural and anthropogenic factors.
- Livestock, due to an increase in numbers and/or associated changes in husbandry and farming practices, were clearly a major contributory factor to erosion in many areas, especially easily accessible foothills.
- Erosion-sensitive, peat-dominated soils and erosive climatic conditions constitute an inevitable combination on most physiographic positions on west of Ireland hills and mountains. The concept of driving rain appears to be a useful tool in understanding the dynamics involved.

- Terracettes, which are a common feature of the hill environment, included a number of characteristics that were clearly related to livestock. These enable a quantitative assessment of the impact of livestock over time to be completed.
- Part-time farming and off-farm employment trends have led to the uneven use of the hill resource in a number of areas, to the detriment of the soil and vegetation.
- Grazing is necessary to promote species diversity in semi-natural vegetation and removal of grazing can lead to a reduction in species diversity in some habitats resulting in one or two of the more competitive species dominating the sward.
- Two new methods for quantitative monitoring of the impact of livestock on the hill environment involving digital photogrammetry and terracette morphology were successfully developed.
- A number of management guidelines for the hills have been proposed based on the results from the present and related projects

## REFERENCES

- Bleasdale, A. and Sheehy-Skeffington, M., (1992). The influence of agricultural practices on plant communities in Connemara. In: *Environment and Development in Ireland*, (ed. J. Feehan), 331-336. The Environmental Institute, University College, Dublin.
- Chemakova, T.Y. and Chemakov, Y.F. (1975). Hillslope terracettes. *Soviet Geography: Review and Translation*, **16 (9)**, 609-615.
- Clavin, D.J. (2000). *Terracette studies in the hill and mountain environment of western Ireland with emphasis on the role of livestock*. M. Agr. Sc., thesis, Department of Crop Science, Horticulture and Forestry, Faculty of Agriculture, U.C.D., Dublin. 178 pages.
- Connolly, L., (1999). *Alternative enterprises: economic performance and viability*. Teagasc Research Centre, Athenry, Co. Galway. 26 pages.
- Connolly, L., (2000). *Economic performance in Irish sheep production*. Teagasc Research Centre, Athenry, Co. Galway. 21 pages.
- Curran, P.L., O'Toole, M.A. and Kelly, F.G. (1983). Vegetation of terraced hill grazings in north Galway/south Mayo. *Journal of Life Science*, 195-202. Royal Dublin Society.
- Gardiner, M. J. and Radford, T., (1980). *Soil Associations of Ireland and their Land-Use Potential*. An Foras Taluntais, Dublin. 142 pages.

Hanrahan, J.P. and O'Malley, L., (1999). *Hill sheep production system*. Sheep Series No. 4, Teagasc Research Centre, Athenry, Co. Galway. 36 pages.

Higgins, C.J. (1982). Grazing-step terracettes and their significance. *Zeitschrift für Geomorphologie*, **26**, 59-472.

Lafferty, S., Commins, P. and Walsh, J.A., (1999). Sheep. In: *Irish agriculture in transition – A census atlas of agriculture in the Republic of Ireland*. Teagasc, Dublin. 100-104.

Little, E. (1995). *A study of mixed species grazing in hill and lowland pastures in the west of Ireland*. M.Sc. thesis (N.U.I.) (unpublished). University College Galway.

Marrs, R.H., Bravington, M. and Rawes, M. 1988. Long-term vegetation change in the *Juncus squarrosus* grassland at Moor House, northern England. *Vegetatio*, **76**, 179-187.

Marrs, R.H. and Pakeman, R.J. (1995). Bracken invasion: lessons from the past and prospects for the future. In: *Heaths and Moorland: Cultural Landscapes*, (eds. D.B.A. Thompson, A.J. Hester and M.B. Usher) 180-193. Scottish Natural Heritage.

McGee, E. and Bradshaw, R., (1990). Erosion of high level blanket peat. In: *Ecology and conservation of Irish peatlands*, (ed. G.J. Doyle), 109-120. Royal Irish Academy.

Miles, J., Welch, D. and Chapman, S.B. (1978). Vegetation and management in the uplands. In: *Upland Land Use in England and Wales*, (ed. O.W. Heal), 77-95. Country Commission, Cheltenham.

Mitchell, S., (1995). Vegetation cover of un-improved area of Teagasc hill sheep farm, Leenaun. Project report in part fulfilment of M.Sc. in Environmental Resource Management, University College, Dublin. 70 pages.

Muller-Dombois, D. and Ellenberg, H. (1974). *Aims and Methods in Vegetation Ecology*. Wiley, New York.

Rohan, P.K., (1986). The climate of Ireland. (2<sup>nd</sup> ed.). Dublin. The Stationery Office. 112 pages.

Vincent, P.J. and Clarke, J.V., (1982). A note on the detection of slip-planes in terracettes. *Biuletyn Peryglacjalny*. **29**, 147-149.

Walsh, M., Ryan, M. and van der Schaaf, S., (1969). Soils, in: West Donegal Resource Survey, Part I., 20-54, An Foras Taluntais, Dublin.

Walsh, M., Mulqueen, J., Grennan, E., Rogers, M., Marren, N., Guinan, L., Nixon, D. and Collins, J.F. (2000). *Evaluation of the impact of livestock on the hill environment*. Sheep Series No. 10. Teagasc Research Centre, Athenry, Co. Galway. 43 pages.

Welch, D. (1984). Studies in the grazing of heather moorland in north-east Scotland. I. Site descriptions and patterns of utilisation. *Journal of Applied Ecology*, **21**, 179-195.