WEED INVASION ON

WIDDYBANK FELL,

UPPER TEESDALE.

by

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ABSTRACT

Maps are presented showing the distribution of weeds along sheep tracks and the Birkdale Track roadway on Widdybank Fell. The two main weeds, Bellis perennis and Poa annua, have contrasting locations. The former grows mainly in grassland areas and the latter in heathland sections. The presence of Cerastium holosteoides, Ranunculus repens, Sagina procumbens, Taraxacum officinale are also recorded. Two main explanations were offered to account for these distribution patterns;

The relative dispersal ability of these weeds did not provide a complete explanation for their location or migration. Spread away from the sheep tracks was extremely limited. On the other hand, weeds could be found growing along the paths some distance away from the main centres of dispersal on the Birkdale Track and in shake holes.

The alternative explanation that the physical environment limits weed distributions is well supported by field evidence. Weeds are concentrated along the sheep tracks where the soil and natural vegetation has been modified by animals. Sheep create an environment in which weeds flourish. The main effects of sheep are trampling, grazing and manuring which together destroy the vegetation mat and produce bare ground for colonisation. Dung also fertilises the soil by providing organic matter and nutrients and this enhances weed growth. Away from the tracks these conditions do not prevail and weeds are not abundant. People trampling along the sides of the Birkdale Track produce physical conditions similar to those on the paths and weeds also flourish here.

The areas of rare plants do not support many weeds. Competition from weeds is not a serious threat to the natural vegetation here. The most immediate danger comes from the sheep grazing which may eliminate some of the small populations of rare species.

ACKNOWLEDGEMENTS

I wish to express my gratitude to my supervisor, Dr. J.A. Pearson, for his advice and guidance during this study and to Dr. M.E.Bradshaw for her help, particularly in the field. My thanks are due to the Nature Conservancy for giving permission to work on Widdybank Fell. I also wish to thank my parents for their encouragement and Miss J. Gates for typing the project. This work was financed by the Natural Environment Research Council.

Plate 1 : Frontespiece : Widdybank Fell

INTRODUCTION

This project is a study of the invasion of weed species in part of Widdybank Fell, Upper Teesdale. The study area is situated on the north bank of a loop in the River Tees opposite its confluence with Maize Beds (Map 1). The land is owned by the Nature Conservancy and overlooks Cow Green Reservoir. There are three main aims to the project:

(a) To plot the distribution of selected "weed" species in relation to Teesdale rarities.

(b) To assess the patterns and extend of migration of the "weeds" from sites of entry i.e.: access roads and sheep tracks.

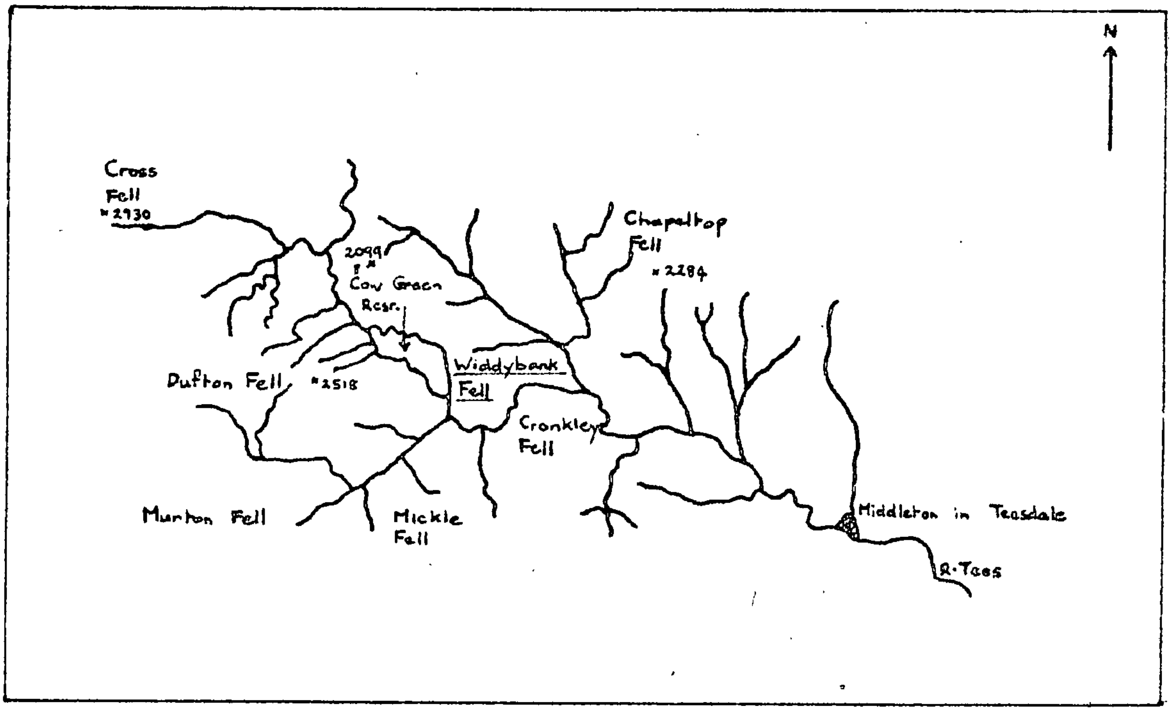
(c) To relate the distribution of the "weeds" to edaphic factors of the habitat.

The definition of a "weed" used throughout this study is a plant "in any specified geographical area, whose populations grow entirely or predominantly in situations markedly disturbed by man (without, of course, being deliberately cultivated plants)" (Baker 1965). In this case a weed is a plant which does not naturally grow on the fell and has been introduced and spread as a result of man and his animals. The two main weeds which are considered are <u>Bellis perennis</u> (Linn.) and <u>Poa annua</u> (Linn.). These were selected after an initial survey which showed them to be the most abundant invaders. However, the presence of the following species was also recorded: <u>Sagina procumbens</u> (Linn.); <u>Cerastium holosteoides</u> (Fr.); <u>Ranunculus repens</u> (Linn.) and <u>Taraxacum officinale</u> (Weber). The weeds are regarded as a possible threat to the rare plants. They may cause interference in terms of space; water, nutrients and light; toxic exudates. The degree of competition will depend on the weather; soil conditions and weed characteristics including population densities. The characteristics of these species which make them a threat to other plants can be enumerated as follows:

(i) Weeds have a wide tolerance of variations in the physical environment e.g.: temperature extremes; high evaporation rates; puddled surfaces and high runoff rates.

(ii) Weeds have adaptations for both long and short distance dispersal, e.g. <u>Taraxacum officinale</u>, and also make use of man as a dispersal agent.

MAP 1: THE LOCATION OF THE STUDY AREA



Scale: 0 — 5 — 10 miles

Key:

- River
- Town
- × Spot height

(iii) Weeds are self-compatible so that there is no need for other weeds of the same species to be present.

(iv) Weeds have good powers of vegetative reproduction and the ability to regenerate when divided into fragments e.g.: Ranunculus repens.

(v) Weeds have a strong competitive ability. Their physiological attributes include efficient ion uptake and rapid root growth. Their morphological attributes include an ability to shade out competitors and the production of rosettes of leaves which spread close to the ground and smother competitors, e.g. Bellis perennis and Taraxacum officinale.

Annual weeds such as Poa annus and Sagina procumbens have other competitive characteristics.

(i) Annuals have a high output of seeds in favourable conditions and at least some output even in very poor conditions.

(ii) Seed production begins after only a short period of vegetative growth.

(iii) Seed production is spread over a long period of the growth of the weed e.g.: Poa annua has seed production and germination all year round.

(iv) Annuals have variable seed dormancy and considerable longevity of seeds in the soil.

(v) Annuals have no special environmental requirements for germination e.g.: 90% of Sagina procumbens seeds germinate within five days of the first germination (Salisbury 1961); Poa annua is capable of germination between 8 and 25^{o}C.

(vi) Annuals have rapid seedling growth and establishment.

Bellis perennis is a weed which has grown on Widdybank Fell for a long time (probably over 150 years) since it is a common member of calcareous pasture communities. Indeed Shimwell (1969) argues that it is a natural member of limestone grasslands. This may not be true because Bellis perennis is certainly more abundant in areas where there has been trampling and intensive grazing. Nevertheless it is well suited to a dry grassland type habitat. In contrast Poa annua is a much more recent weed in the area. It was not recorded in a survey along the Birkdale Track in 1968 and 1970 (Ennis and Simpson) and is only mentioned once by Piggot (1956). Poa annua has only become abundant since the war and particularly in the last decade as visitors have come in increasing numbers. Therefore it is probably a much better indication of the extent of the weed problem. Bellis perennis and Poa annua together represent a large proportion of the weed growth on Widdybank Fell.

The two main agents which are regarded as the cause of the weed problem are sheep and man. There are approximately 5,000 Swaledale and Cheviot sheep on the fell with an average of 2-3 ewes + lamb/ha. They will graze on the fell throughout the year if the weather is good. However, in bad years the fell is used just for summer pasture. This grazing practice has been used for over one hundred years. Visitors have come to the area in large numbers for the last 20-30 years. Numbers are particularly high at weekends during the summer when between 1,000 and 2,000 people may walk along the Birkdale Track to Cauldron Snout during one day. There are also local farmers who use both the Birkdale Track and the sheep tracks across the fell. The invasion of weed species in Widdybank Fell is regarded as a serious problem because the area is a major location of species rare in Britain. There have been many studies of the vegetation in the area including work by Pigott (1956), Bradshaw and Clark (1965), Bradshaw (1966) and Jones (1973). A study of weed invasion is an important supplement to this work. The Nature Conservancy are making every effort to preserve the vegetation of Widdybank Fell and one of the major threats to the natural plant communities are weed species.

CHAPTER 1 - MAPPING THE DISTRIBUTION OF WEEDS

The mapped area is the land bordering Red Sike to the north and east where a large number of sheep tracks can be found (Map 2). This location also includes several sites containing many of the Teesdale rarities (Table 1).

Four sheep tracks were selected for detailed analysis. They were chosen because they are well worn, appear to be used frequently by the sheep and harbour the weed species selected for study. The four paths run approximately parallel to the contours at different altitudes. They will be referred to as the Summit Track (at 512m); the Top Track (at 508m); the Middle Track (which crosses the contours obliquely and connects the Lowest Track with the Top Track); and the Lowest Track (at 496m). The Summit Track was followed for 300m. At either end of this section additional segments of track which connected the path with the Top Track were studied as well. The Top Track was followed from the Birkdale Track for 1200m until it entered an area of limestone flushes overlooking the River Tees south of the dam. Here the path subdivides and weeds are very sparse. Beyond the flushes the track passes through meadows down to the river and weeds are again present. Originally it had been intended to follow the path until no more weeds were found. However, since weeds were observed alongthe whole length of the track, the study concentrated on the first section as far as the limestone flushes. The Middle Track was followed for 300m from Nameless Sike where it joins the Lowest Track to its junction with the Top Track. Finally, the Lowest Track was followed from the Birkdale Track to the junction of the Sugar Limestone and the Whim Sill where no more weeds were found, a total length of 1000m. Therefore the network under study is completely linked. Weeds in any one section of the path can in theory be carried by sheep to any other part of the tracks.

Along each sheep track a 30cm quadrat was taken at 5m intervals. The quadrat size corresponded to the width of the tracks so that the initial records were confined to the tracks themselves. In each quadrat, the percentage cover of <u>Bellis perennis</u> and <u>Poa annua</u> was recorded. The presence of the other named weeds and the percentage bare ground was also noted. The nature of the vegetation bordering the track was described - whether <u>Calluna vulgaris</u> heathland or open

Map 2: The Location of the Mapping Units on Widdybank Fell

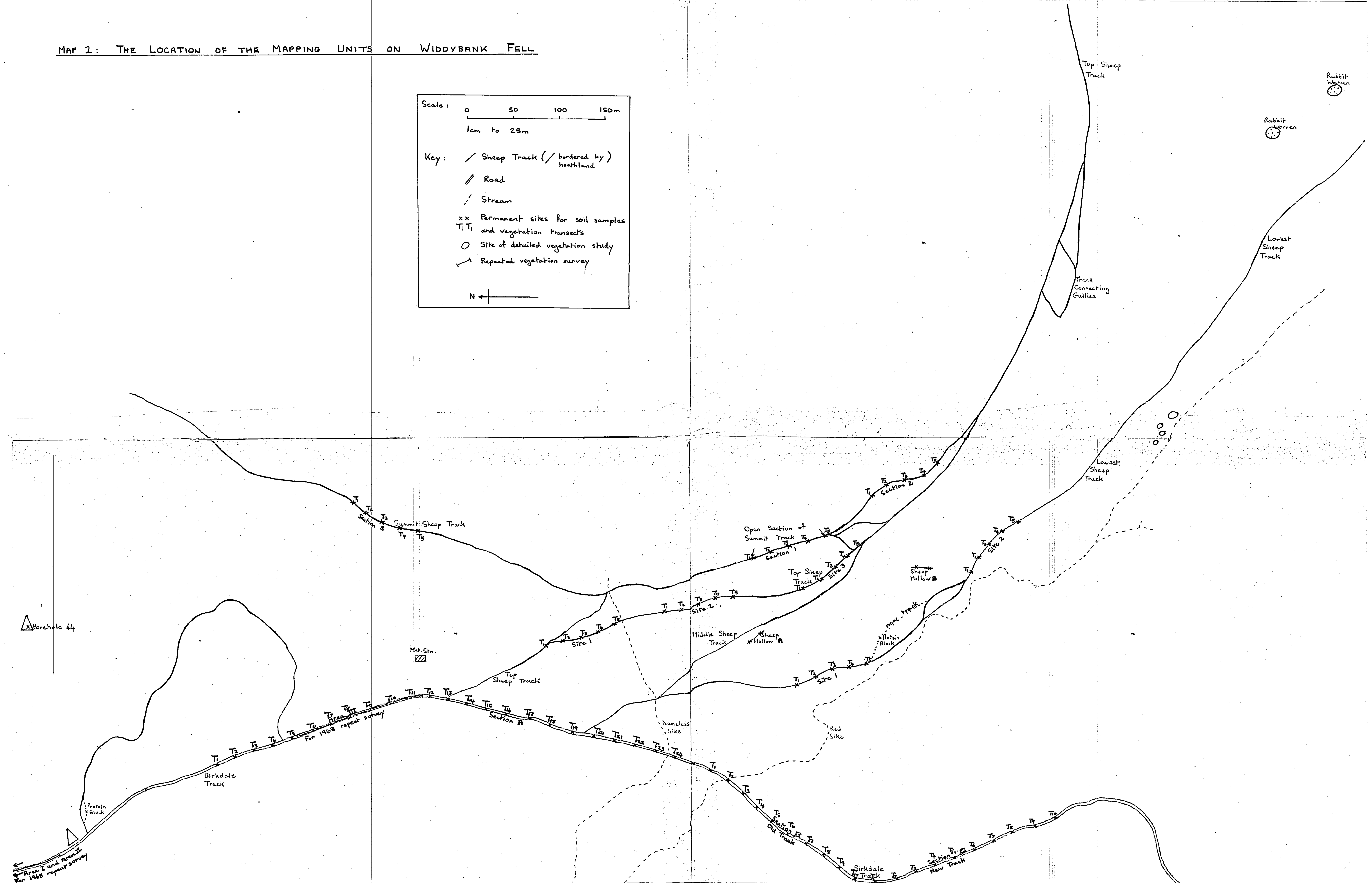


TABLE 1 : LIST OF RARE PLANTS FOUND ON WIDDYBANK FELL

Helianthenum canum	Carex capillaris
Carex ericetorium	Draba incana
Eriophorum latifolium	Dryas octopetala
Galium boreale	Kobresia simpliciuscula
Polygala amara	Minuartis stricta
Sedum villosum	Polygonum viviparum
Viola rupestris	Potentilla crantzii
Alchemilla subcranata	Gentiana verna
Antennaria dioica	Thlaspi alpestre
Juncus alpimo-articulatus	Myosotis alpestris
Leucorchis albida	Saxifraga aizoides
Listera cordata	Saxifraga stellaria
Potentilla fruticosa	Sedum rosea
Primula farinosa	Thalictrum alpinum
Trollius europeaus	Tofieldia pusilla
Bartsia alpina	Botrychium lunaria

grassland. This is a simple division which was adopted because initial observation suggested a marked correlation between the weed species recorded and these two vegetation types (Plates 2 and 3). Two new sections of track created where the farmer has placed protein blocks for the sheep had no weeds but they were mapped for future reference.

The complete mapping of weeds in two sheep hollows was also carried out using 30cm quadrats. These areas were selected for detailed analysis because of their high concentration of weeds. Both hollows are sheltered spots where sheep tend to congregate. One hollow is located just below the Middle Track in an area of grassland and is connected to the track by a side path (Plate 4). The other is in a heathland zone on a minor track connecting the Top Track to the Lowest Track. Finally the presence of weeds was also recorded at two rabbit warrens deserted during the 1950's myxamatosis outbreak.

Once this initial survey work had been completed it became evident that the four tracks had very different concentrations of weeds. The Top Track had the highest concentration and was consequently selected for detailed study. The distribution of weeds off the track was plotted at fifteen sites. Five of the sites were at 20m intervals in a zone where both _Bellis perennis_ and _Poa annua_ were present; five in an area of open grassland where only _Bellis perennis_ was found and five in a heathland section with _Poa annua_. At each of these permanent sites a transect was taken. A 30cm quadrat was used to record the percentage cover of the weeds on the track. The quadrat was then placed immediately either side of the track and continuously outwards until no more weeds were recorded. The same procedure was adopted at ten sites on the Lowest Track where it passes through grassland areas containing Teesdale rarities. However, there were very few weeds along these sections of the track. Initially it had been intended to survey the areas with rare plants in more detail but these transects confirmed the absence of weeds there.

Mapping of weed distribution was also carried out along a section of the Birkdale Track. The length chosen for analysis included the area where the Lowest and Top Tracks meet the road. In this way it was hoped to link up the pattern of weed distribution by the road with that on the sheep tracks. On the Birkdale Track transects were taken at 20m intervals using a 50cm quadrat. The larger scale of this analysis reflects the greater abundance and spread of weeds here.

Plate 2 : Bellis perennis growing in a grassland section of the Top Sheep Track.

Plate 3 : Poa annua growing in a heathland section of the Top Sheep Track

Plate 4 : Sheep Hollow A with a high concentration of weeds

The presence of weeds was also recorded along the path from the Birkdale Track to Gas Borehole 44 used in 1966. Fifty random quadrats were taken in funnel shaped areas (12 x 15 x 1.5 x 15m) at either end of the path. The same 30cm quadrat was also used to record weeds at 5m intervals along the connecting path. It was hoped that this survey would reveal the importance of human disturbance in causing weed colonisation and migration. One sheep track which led off this path was also followed in a loop connecting back to the Birkdale Track near the Meteorological Station. The presence of weeds along this track was recorded using the techniques described earlier.

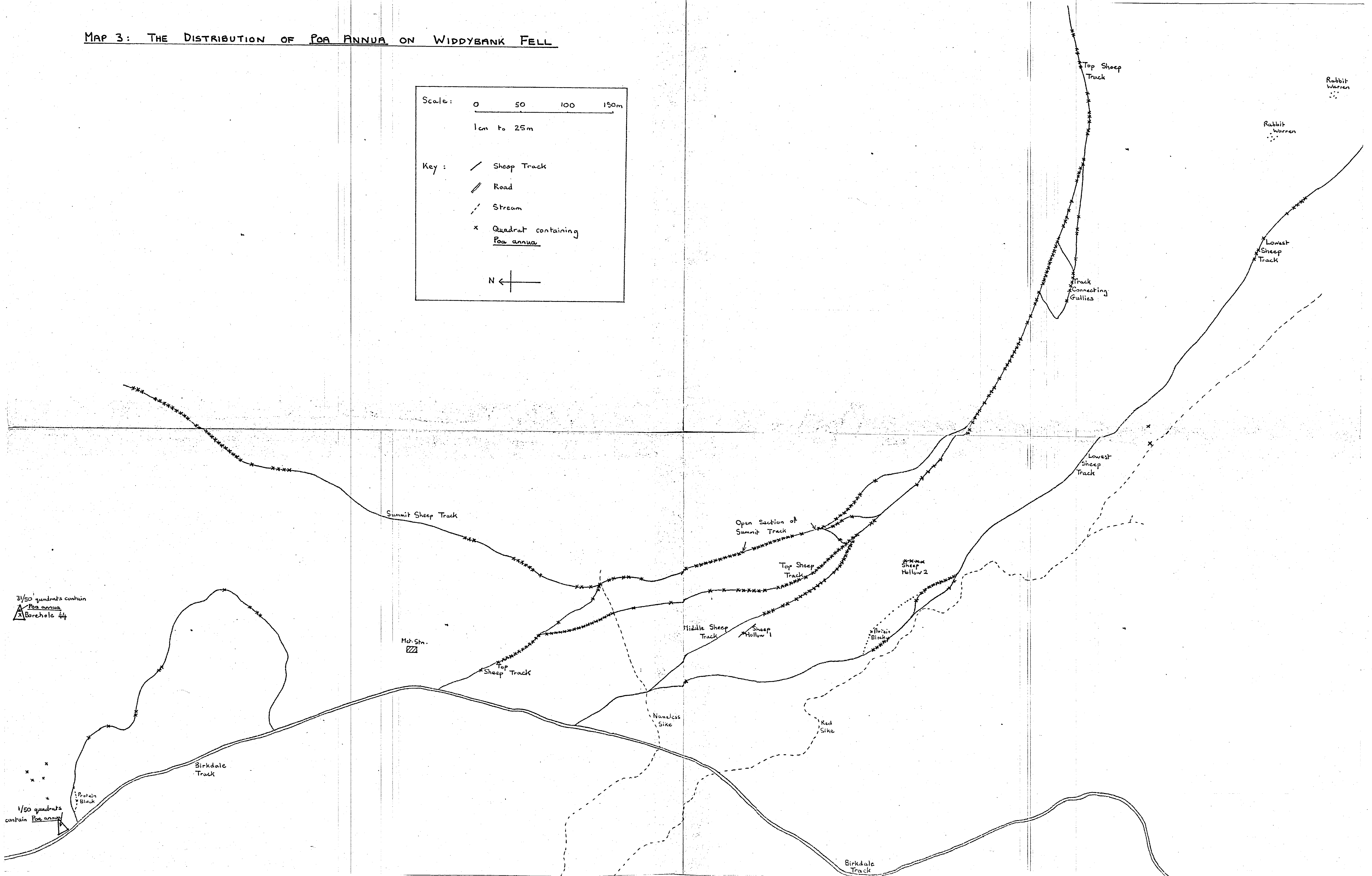
The results of this first phase of the fieldwork are presented in statistical and cartographic form. This section is descriptive and simply gives some idea of the scale of the problem of weed invasion. The calculations are shown in Appendix A.

RESULTS AND DISCUSSION

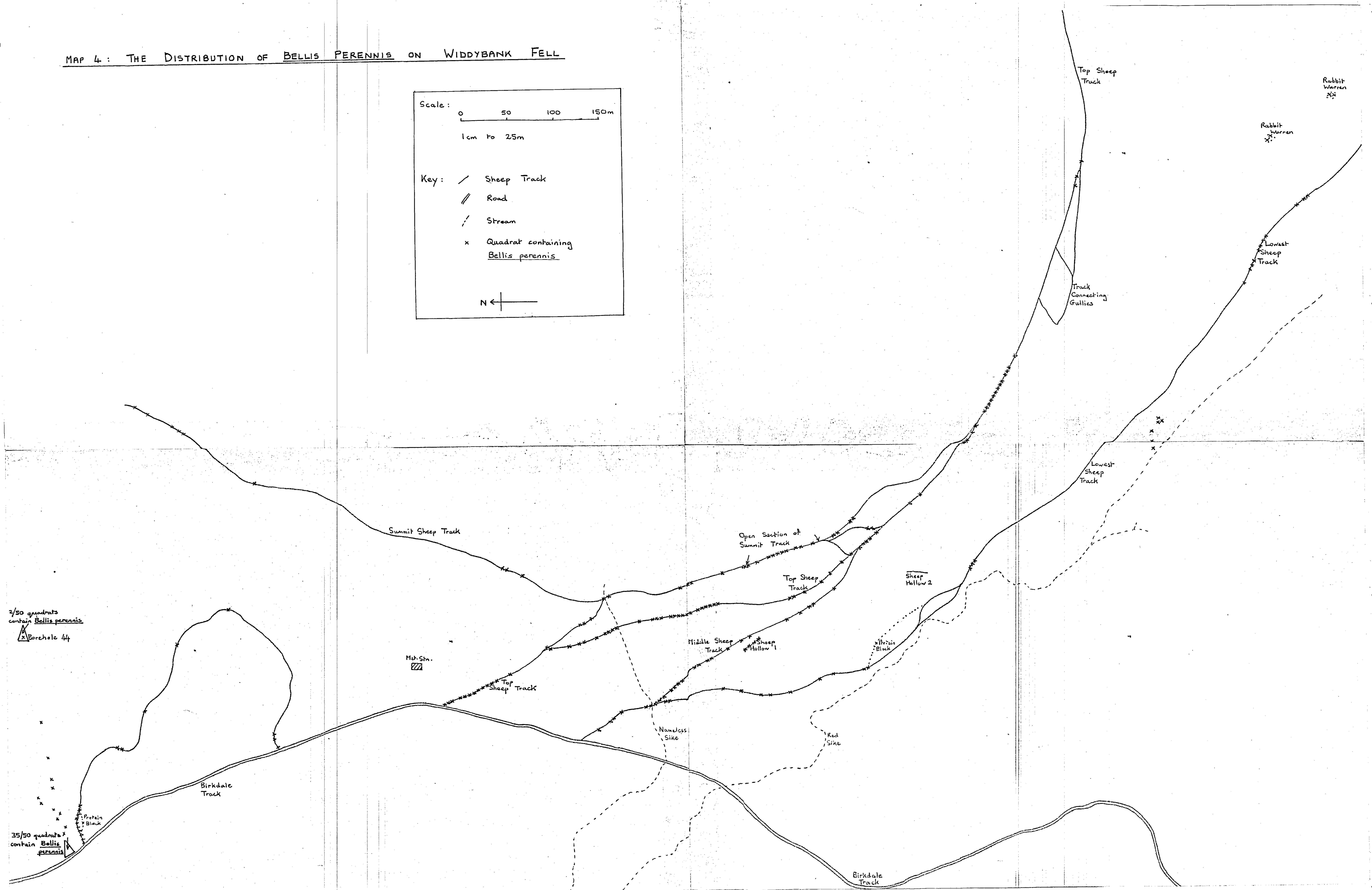
The Maps 3 and 4 record the presence of the selected weed species. The highest concentrations of Poa annua and Bellis perennis exist on the Top Track. This is measured as the proportion of quadrats along the path in which the weeds were found. The Middle and Summit Tracks have intermediate weed concentrations while the Lowest Track supports very few weeds. The percentage cover of the two weeds on these tracks also follows the same pattern. This observation is confirmed by statistical analysis using the Chi-squared test. Furthermore, neither Bellis perennis nor Poa annua are evenly distributed along any of the tracks. The Chi-squared test shows that there is a significant difference in the location of these weeds. Poa annua is found almost exclusively along sections of the track bordered by plant associations in which Calluna vulgaris is dominant. Bellis perennis is located mainly in areas of open grassland. It shows no significant decline in abundance along the Lowest and Top Tracks as they are followed away from the Birkdale Track. This distribution is also observed in the case of Poa annua which is equally abundant in all areas of heathland along the two tracks. The Summit Track has a significant decline in weeds in both directions away from a central area where the path widens and weed concentrations are very high. Several paths were followed away from these high concentrations of weeds, most of them connecting with the Top Track. However, the weeds have not spread very far along these tracks either from the central area on the Summit Track or from the Top Track. The Middle Track does not show a significant trend in the distribution of Bellis perennis and Poa annua along its length. Isolated patches of both weeds were also found on the Lowest and Summit Tracks over 250m from the main stretch of weeds.

The distribution of the other four weed species along the sheep tracks is also described statistically and cartographically (Map 5). The Chi-squared test indicates that there is a significant difference in the location of these weeds between heathland and grassland areas. Ranunculus repens and Sagina procumbens are found mainly in the grassland sections of the tracks. However, Taraxacum officinale and Cerastium holosteoides show no significant difference in their distributions between the two vegetation types. Indeed all four weeds are found in both environments. This contrasts with the almost complete confinement of Poa annua to the heathland zones. With the exception of Taraxacum officinale these weeds also decline in

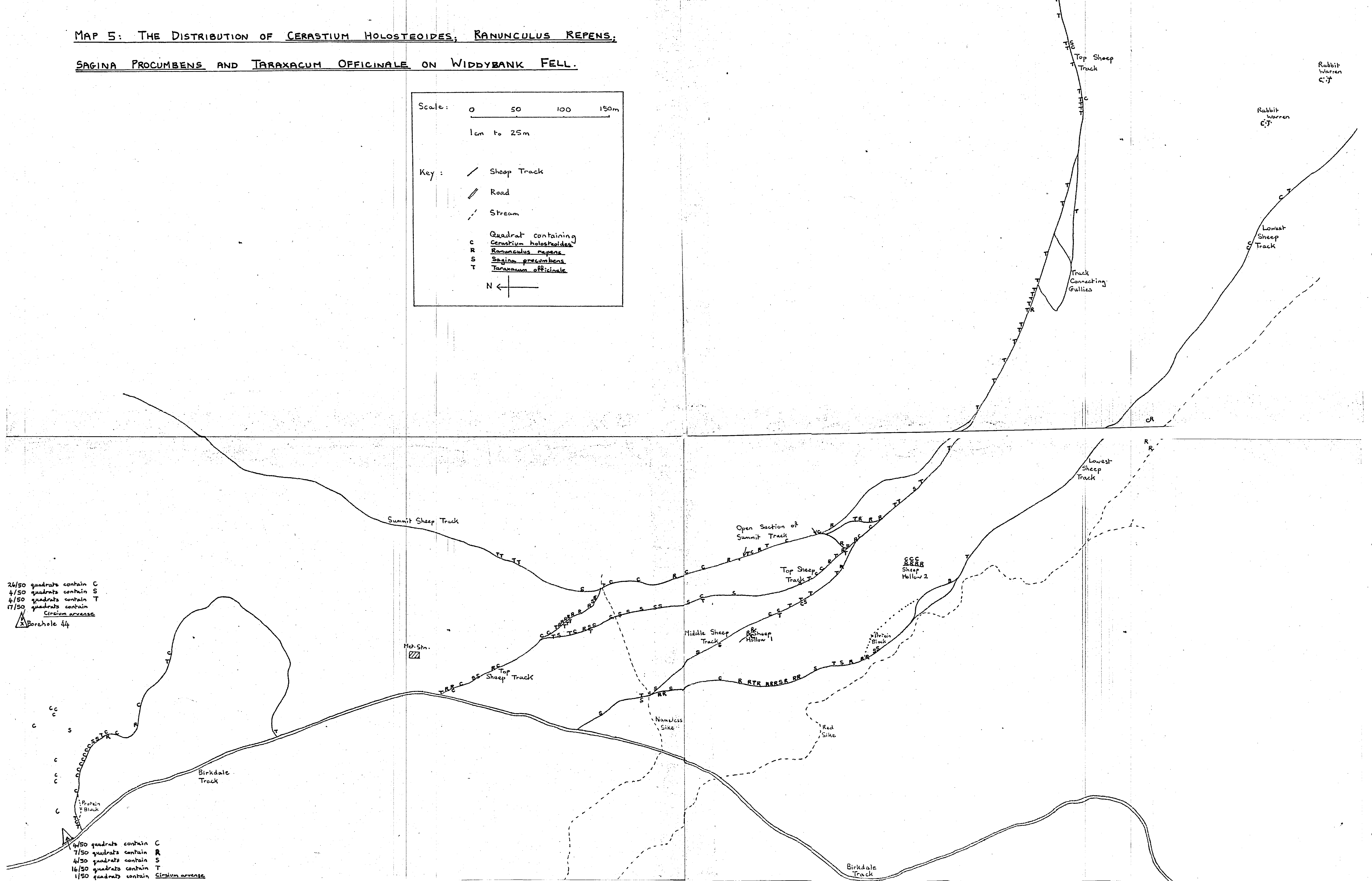
Map 3: The Distribution of Poa annua on Widdybank Fell



Map 4: The Distribution of Bellis perennis on Widdybank Fell



Map 5: The Distribution of Cerastium holosteoides, Ranunculus repens, Sagina procumbens and Taraxacum officinale on Widdybank Fell.



abundance on the Top Track as distance from the Birkdale Track increases. They were not recorded in sufficient numbers on the other tracks to test their distributions statistically.

In the two hollows which were studied in detail weeds were very abundant - Bellis perennis in the hollow bordering grassland and Poa annua in the hollow within heathland. Ranunculus repens and also Cerastium holosteoides were also recorded very frequently. Indeed, Ranunculus repens had the highest percentage cover of any weed. Taraxacum officinale was fairly abundant but Sagina procumbens was completely absent from these hollows. (Tables 2 and 3).

The permanent quadrats on the Top Track gave an indication of the weed distribution away from the path (Figures 1, 2 and 3). In general, neither Bellis perennis nor Poa annua are found further than 1m from the track. Poa annua tended to have a slightly more restricted distribution than Bellis perennis. Its occurence is negatively correlated with the presence of Calluna vulgaris. In the grassland areas no species showed significant positive or negative correlations with Bellis perennis. The vegetation here is much more open. The only other weed recorded frequently away from the track was Cerastium holosteoides. All the weeds show a rapid decline in abundance away from the track. They do not possess a patchy distribution or reappear even further away from the main path. However, there are small pockets of weeds where minor tracks traverse the area.

On the Lowest Track the permanent quadrats failed to record any weeds off the track in the two grassland sections where several species of rare plants occur. This situation applied even along the few sections of track where Bellis perennis grows on the path itself. At present the danger of weeds and rare plants growing in the same localities and coming into competition is very slight. There are two rare species which are recorded frequently in the same quadrats as weeds both on and off the tracks. These are Gentina verna and Primula farinosa. They did not appear to be suffering any ill-effects from the presence of weeds or from trampling (Plates 5 and 6). However, a repeat survey in a few years would be necessary to determine whether the rare plants were declining in abundance along the tracks and neighbouring ground. Botrychium lunaria and Pinguicula vulgaris were each recorded once in quadrats on the sheep tracks, the former in close proximity to Bellis perennis. Again a repeat survey would be

TABLE 2 : DISTRIBUTION OF WEEDS IN SHEEP HOLLOW A

Continuous 30cm quadrats along the hollow from north-west to south-east.

"X" records the presence of weeds on bare ground.

Bellis perennis	Poa annua	Cerastium holosteoides	Ranunculus repens	>10% Bare Ground
X	X		X	X
X				X
X				
X	X			X
	X		X	
	X		X	X
	X			X
X	X			X
X				
X	X			
		X	X	
X	X		X	
X			X	
X			X	X
	X	X	X	X
		X	X	X
	X	X	X	
	X	X	X	
			X	
	X	X	X	
	X		X	X
	X		X	
	X		X	X
X	X		X	
X	X		X	
	X		X	
	X		X	
X	X		X	
X				X
	X		X	X
			X	
			X	
		X	X	X
X	X	X	X	X
	X		X	
X			X	
X			X	
X				
X				X
X				X
			X	
			X	

TABLE 3 : DISTRIBUTION OF WEEDS IN SHEEP HOLLOW B

Continuous 30cm quadrats along the hollow from north to south.

"X" records the presence of weeds or bare ground.

Poa annua	Cerastium holosteoides	Ranunculus repens	Taraxacum officinale	>10% Bare Ground
				X
				X
		X		X
		X		X
	X	X		X
X	X	X		
X	X	X		
X	X	X		
X		X		
X		X		X
X		X		
X	X	X		X
X		X		X
X	X	X		X
X	X	X		X
X	X	X		
X		X		
X	X	X		
X		X		X
X	X	X		X
X	X	X		
X	X	X		
X	X			X
X	X	X	X	X
X		X	X	X
X		X		
X		X		X
X		X		
X				X
X	X	X		
		X		X
X		X		X
X		X		
X		X		
X		X		
X	X	X		
X		X		
X				
X		X		
	X	X		X
	X	X		
X		X		
X		X		X
X	X	X		
X	X	X		
X		X		
X		X		
X		X		
X		X		
X		X		

TABLE 3 cont.

Poa annua	*Cerastium holosteoides*	*Ranunculus repens*	*Taraxacum officinale*	>10% Bare Ground
X		X		X
X		X		X
		X		X
X		X		
X		X		X
X		X		
		X		X
				X
				X
X				X
				X
				X
				X
				X
				X
		X		
		X		
	X			X
X				X
				X
				X

KEY TO FIGURES

T_1, T_2, T_3 etc.	:	Transect numbers.
Q_{1W}, Q_{2W} etc.	:	Quadrat numbers for western side of track.
Q_{1E}, Q_{2E} etc.	:	Quadrat numbers for eastern side of track.
4	:	Percentage cover of *Bellis perennis*.
4	:	Percentage cover of *Poa annua*.
C	:	Presence of *Cerastium holosteoides*.
R	:	Presence of *Ranunculus repens*.
S	:	Presence of *Sagina procumbens*.
T	:	Presence of *Taraxacum officinale*.
X	:	Presence of *Cirsium arvense*.
G	:	Presence of *Gentiana varna*.
P	:	Presence of *Primula farinosa*.
	:	More than 10% bare ground.

Scale : 1 cm to 30 cm

FIGURE 1: TRANSECTS ALONG SITE 1 ON THE TOP SHEEP TRACK

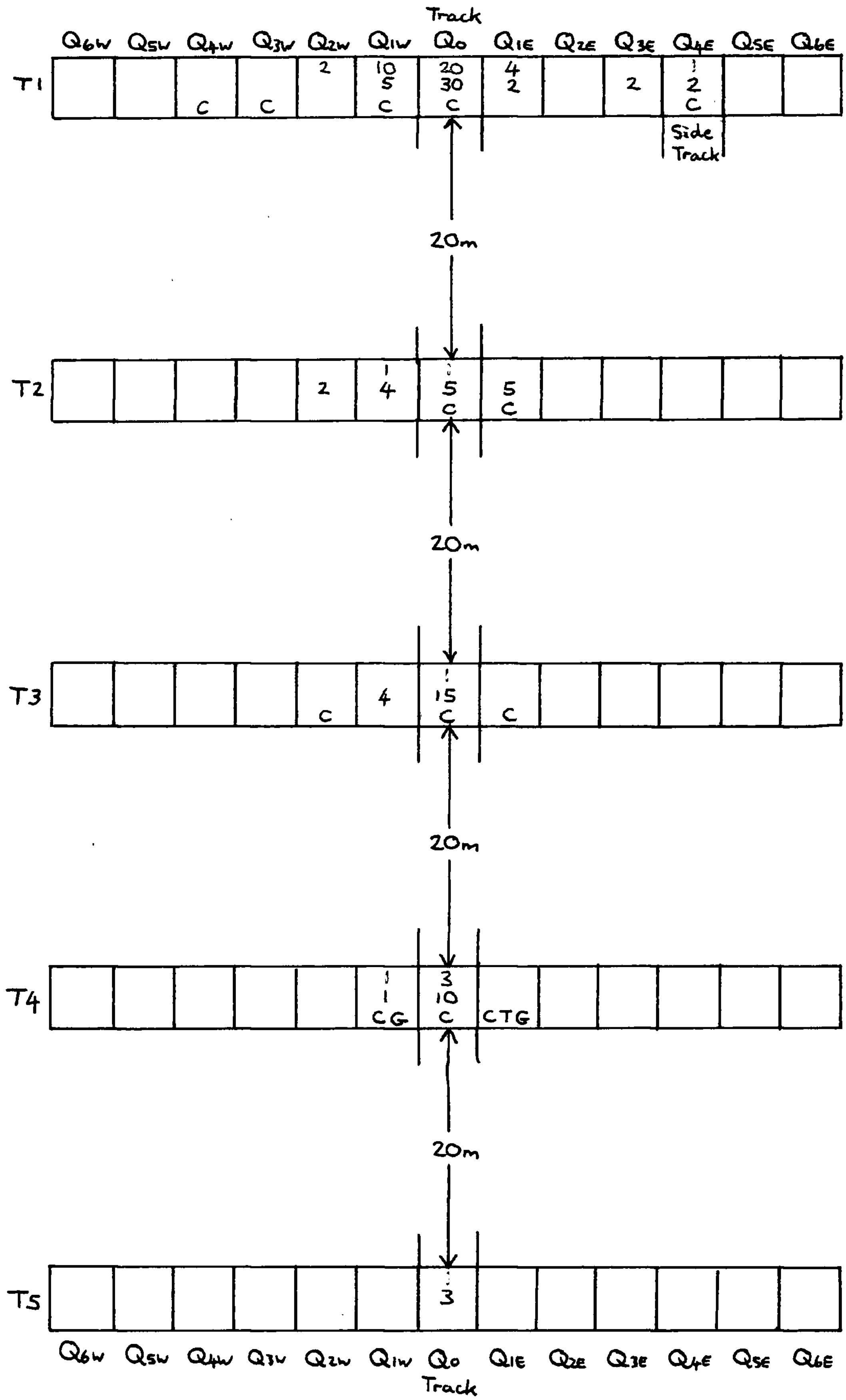


FIGURE 2: TRANSECTS ALONG SITE 2 ON THE TOP SHEEP TRACK

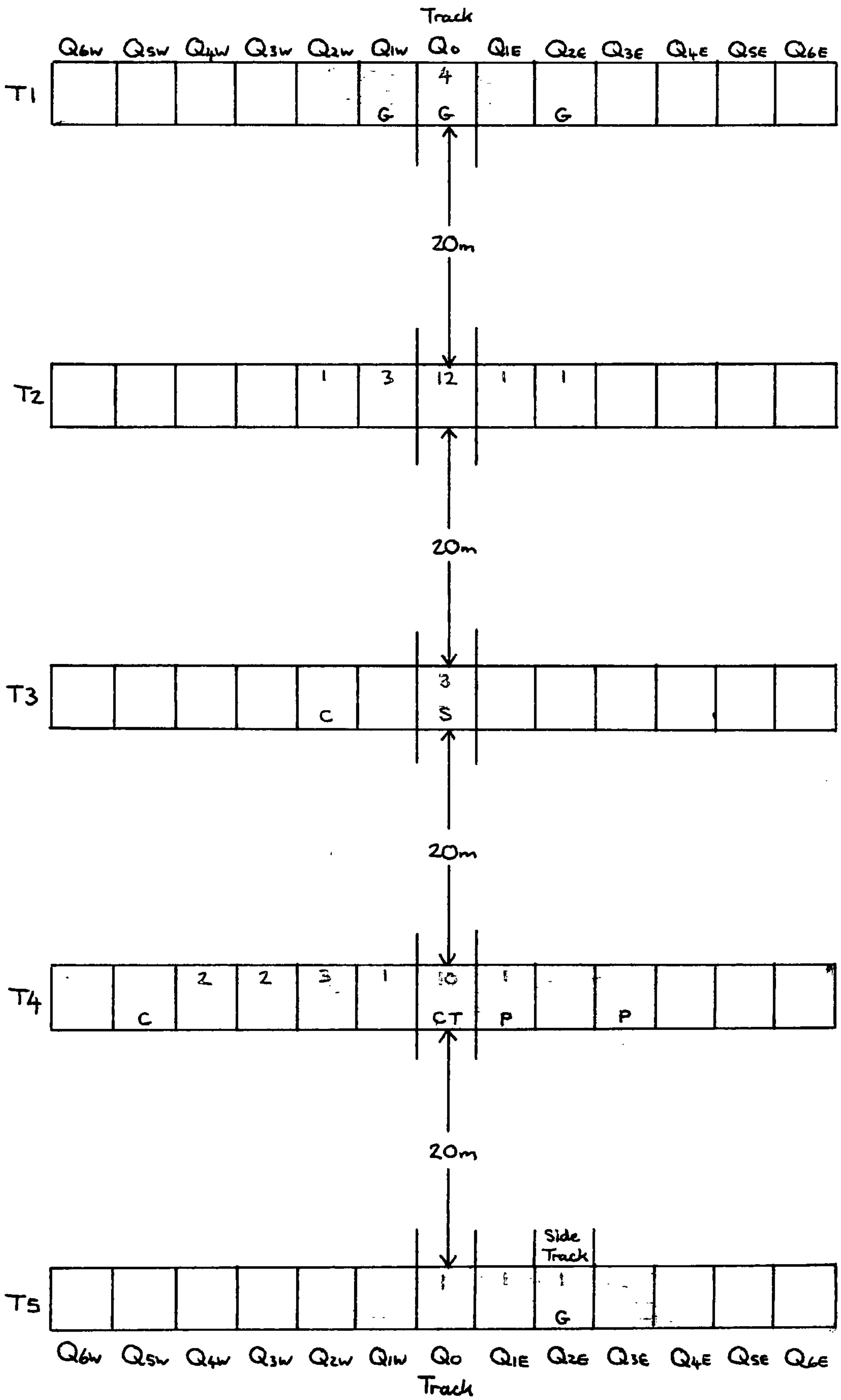


FIGURE 3: TRANSECTS ALONG SITE 3 ON THE TOP SHEEP TRACK

	Q6W	Q5W	Q4W	Q3W	Q2W	Q1W	Q0 (Track)	Q1E	Q2E	Q3E	Q4E	Q5E	Q6E
T1							2	2					
T2							3	1 C					
T3						2	22	1					
T4			T	CT	T	7	25 C	2					
T5							12	2					

Plate 5 : _Gentiana verna_ - a rare plant growing on the Lowest Sheep Track

Plate 6 : _Primula farinosa_ - a rare plant growing on the Lowest Sheep Track

necessary to assess the performance of these plants. The rarity of the speies involved makes it difficult to give a statistical measure of the changes occuring along the tracks.

There are no weeds actually on the Birkdale Track which is a tarred road surface. However, people tend to wander off the track and weeds are abundant on either side. The weed distribution recorded on the Birkdale Track can be divided into three main sections. The first northern section runs through an area of open grassland vegetation and includes the start of the Top and Lowest sheep tracks. Here weeds spread up to 10m from the side of the road (Figures 4, 5 and 6). On the west side of the track the average width of the weed belt is 2.3m, on the east side it is 3.1m. The Chi-squared test indicates a significantly greater spread of weeds on the eastern edge of the Birkdale Track (Plate 7). This is probably because more people walk on this verge where ground is flatter and the vegetation more open. As in the areas of open grassland on the sheep tracks Bellis perennis predominates. There is a significantly greater concentration of Bellis perennis 1m into the verge compared with the ground immediately bordering the Birkdale Track. In contrast, all the Poa annua recorded is confined to the immediate edge of the road. The other weeds recorded are much more abundant than on the sheep tracks with the exception of Ranunculus repens. The presence of Cirsium arverse was also noted in several transects. In most cases the first quadrat in each transect recorded a very high percentage of bare ground consisting largely of loose gravel. The weeds declined very gradually away from their peak of abundance. Their spread was much more extensive than that observed from the sheep tracks.

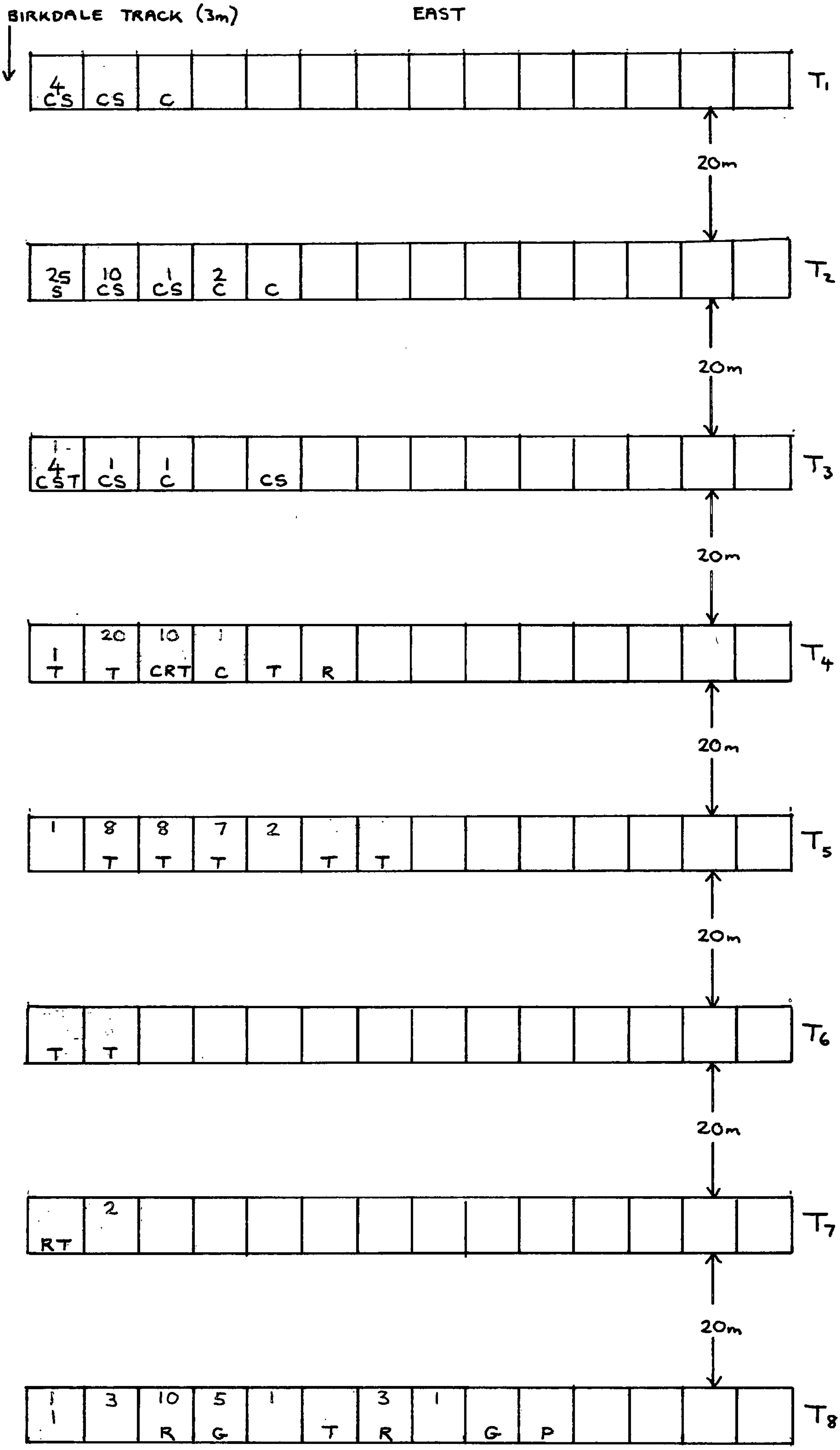
The middle section of the Birkdale Track runs for 200m through a heathland zone from Red Sike south to the start of the new section of road built in 1970 at the time of dam construction. The roadside verge has a significantly lower concentration and spread of weeds than the previous zone (Figures 7 and 8). Poa anmua is the dominant weed and Bellis perennis is only recorded once. The other weeds were not recorded very frequently with the exception of Sagina procumbens. In some transects this species gave higher percentage cover than Poa anmua. Unlike the previous section the weeds are most abundant in the first quadrat of the transect. They also decline much more rapidly away from the road. The present of Calluna vulgaris was negatively correlated with that of Poa annua. This is the same type of distribution as recorded on the heathland parts of the sheep tracks.

WEST — BIRKDALE TRACK (3m)

T_1														2 CR
T_2													1 C	10 CS
T_3													C	4 S
T_4													CST	1 T
T_5							4		4 T	2 T	12	20 T	3	
T_6				C		7	5	7 R	1 CT	1	2	15	20	
T_7				C	G	1	4	6	4	1	2	2	1	
T_8				G	G	1 RG	1 G	3 G	GT	1 G	1 G	5 RG	1 RT	T

20m between each transect (T_1–T_2, T_2–T_3, T_3–T_4, T_4–T_5, T_5–T_6, T_6–T_7, T_7–T_8)

FIGURE 4: TRANSECTS ALONG SECTION A OF THE BIRKDALE TRACK



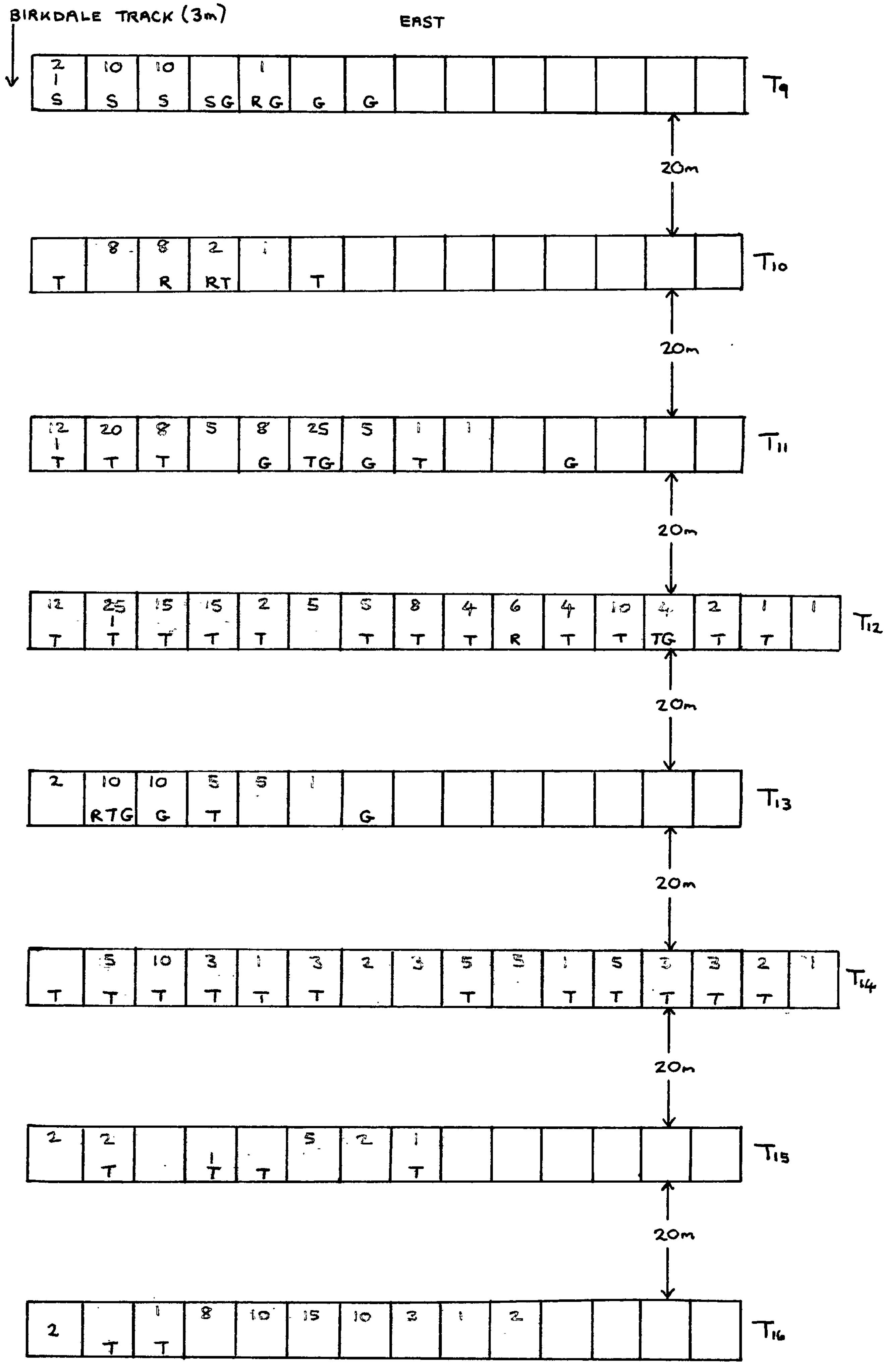
WEST

BIRKDALE TRACK (3m)

T_9												G		5
T_{10}													12 S	2 5 CS
T_{11}													2 S	1 RS
T_{12}									2	2 C	3 C	10 T	15 CRT	7 1 ST
T_{13}	2 G	10	15	3 G	5 G	5 R	8	8	10	3 T	5 T	5 T	1 RT	2
T_{14}								T	1 X	6 TX	12 T	20 T	12 T	T
T_{15}											1 C	2 CT		
T_{16}							G	1 G	4	4	2	1 T	T	C

20m (spacing between each transect)

FIGURE 5: TRANSECTS ALONG SECTION A OF THE BIRKDALE TRACK



WEST

BIRKDALE TRACK (3m)

T_{17}										1	3 T	2	3	3
20m														
T_{18}													T	C
20m														
T_{19}	T	2 T	7 T	5 T	10	15 T	15	12 T	20 RT	5 RT	10 R	5 T		S
20m														
T_{20}													T	1 T
20m														
T_{21}					4	2	4	2	2 T		T	1	1 R	1 5
20m														
T_{22}												1	2	
20m														
T_{23}														
20m														
T_{24}														

FIGURE 6: TRANSECTS ALONG SECTION A OF THE BIRKDALE TRACK

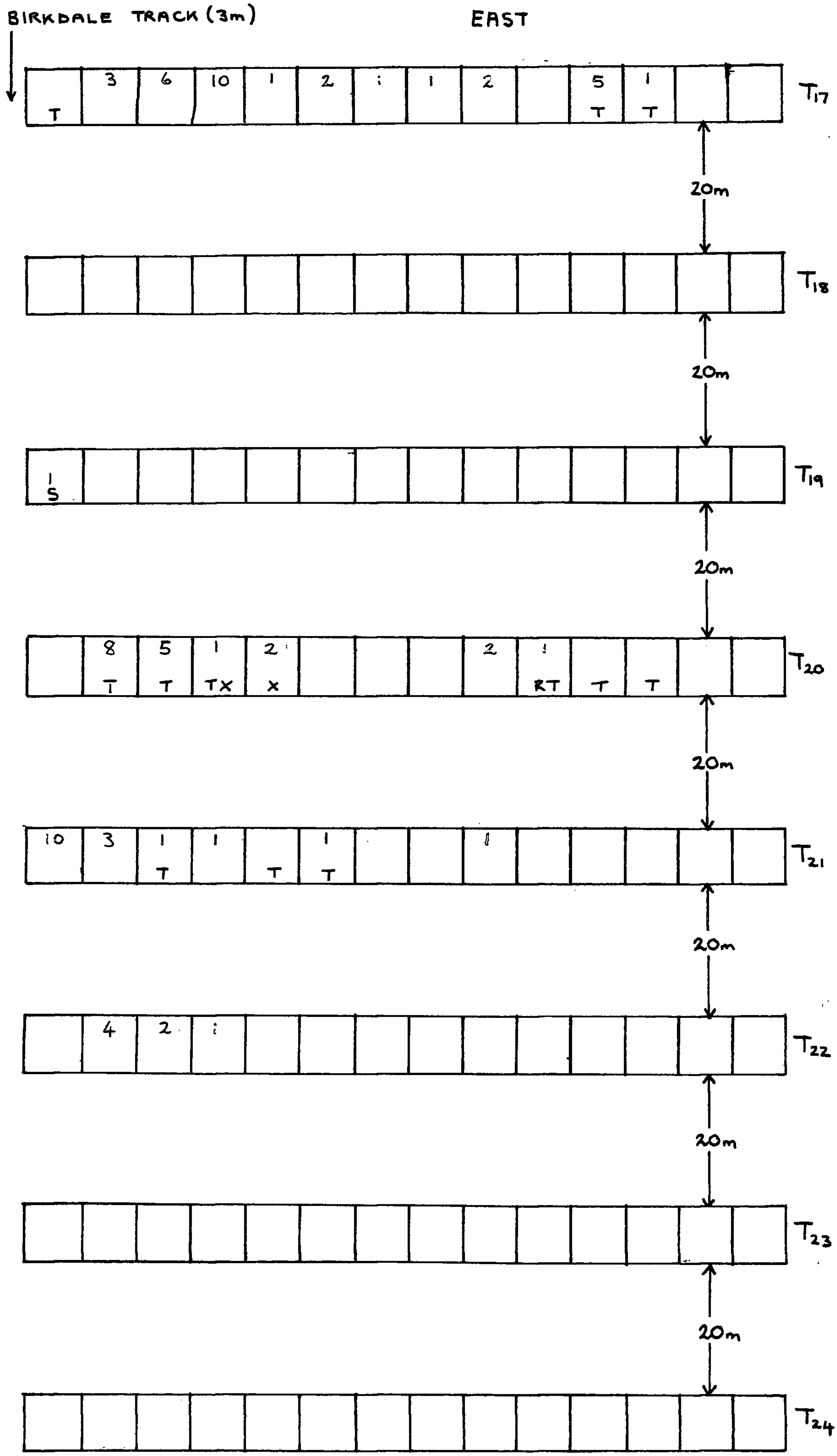


Plate 7 : Section A of the Birkdale Track with an uneven distribution of weeds along the verge

FIGURE 7: TRANSECTS ALONG SECTION B OF THE BIRKDALE TRACK

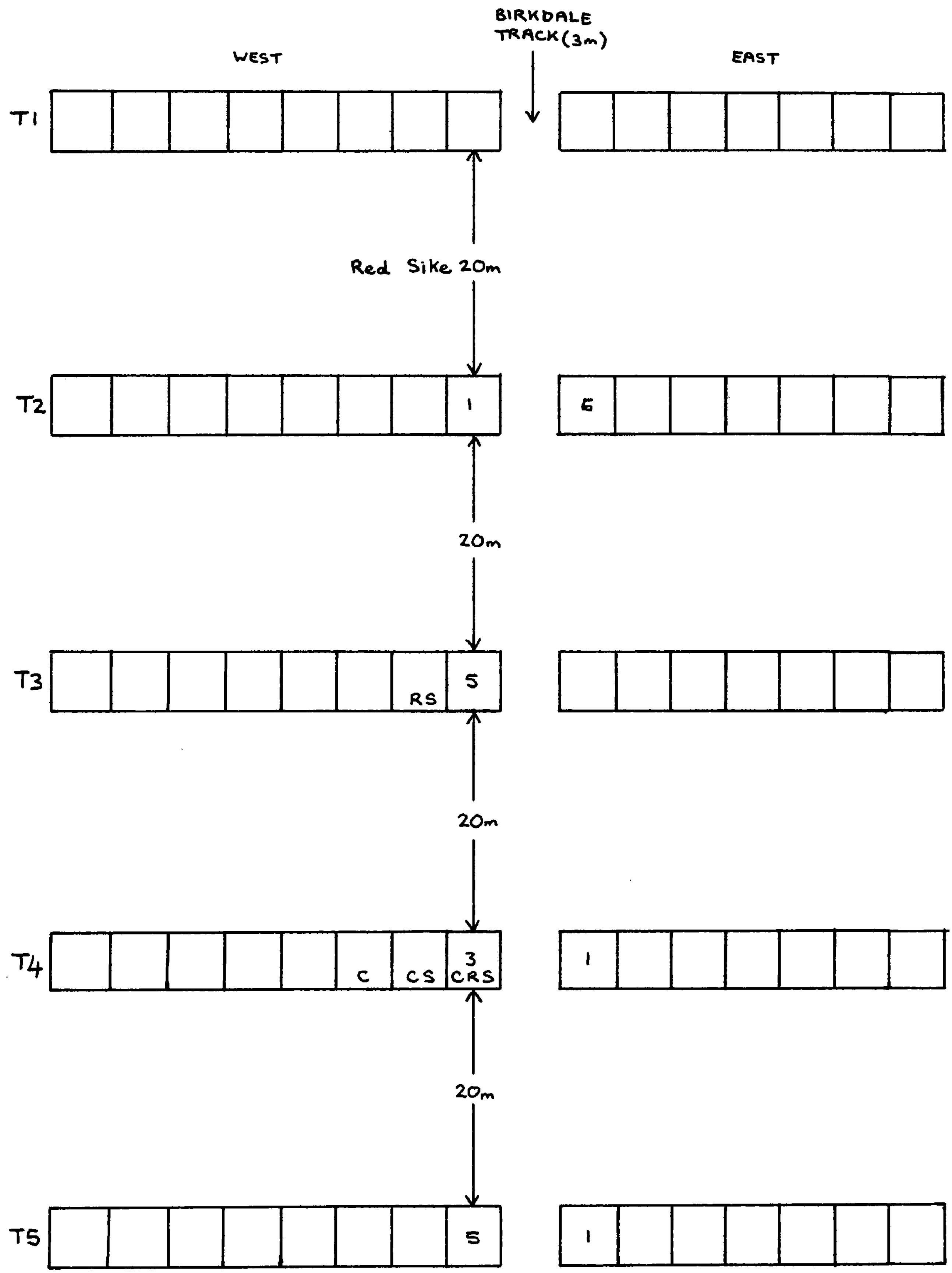
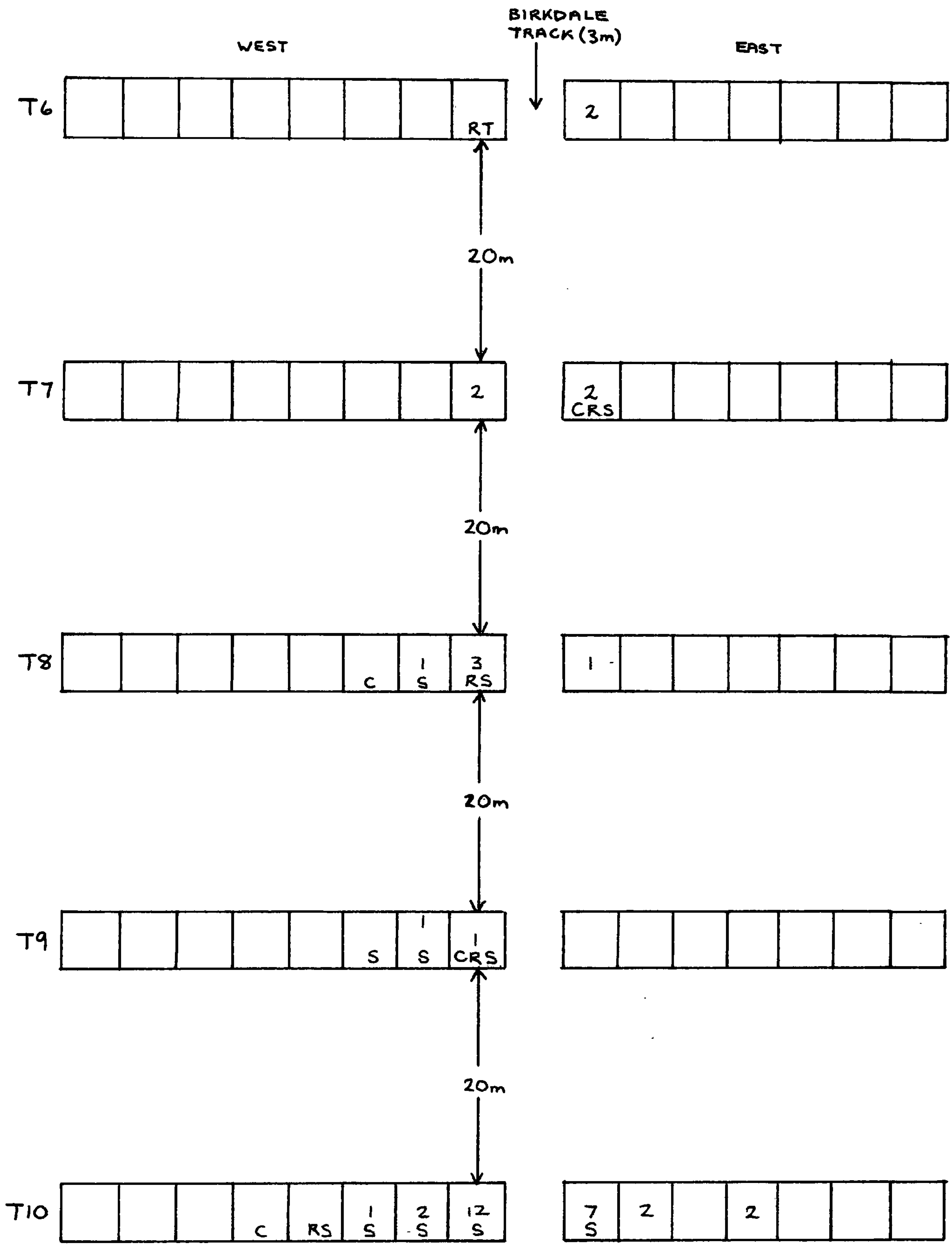


FIGURE 8: TRANSECTS ALONG SECTION B OF THE BIRKDALE TRACK



The southern section of the Birkdale Track is the first 200m of the new road. Although it is much more recent than the previous section and also further from the car park the weed distribution is very similar (Figures 9 and 10). Again *Bellis perennis* is only recorded once and *Poa annua* predominates. *Sagina procumbens* is the other major weed in the area. The distribution and spread of these two weeds is comparable to that on the old section of track. In most cases the weeds are confined to a 2m strip of land between the road and a ditch. This may act as a barrier to further spread together with the dense heathland on the far side of the ditch. The amount of disturbance and the percentage bare ground is much greater along this section of the track than elsewhere. This reflects the construction work carried on here in association with the reservoir. It must enhance weed invasion compared with other sections of the Birkdale Track where trampling by visitors is the main disturbance.

FIGURE 9: TRANSECTS ALONG SECTION C OF THE BIRKDALE TRACK

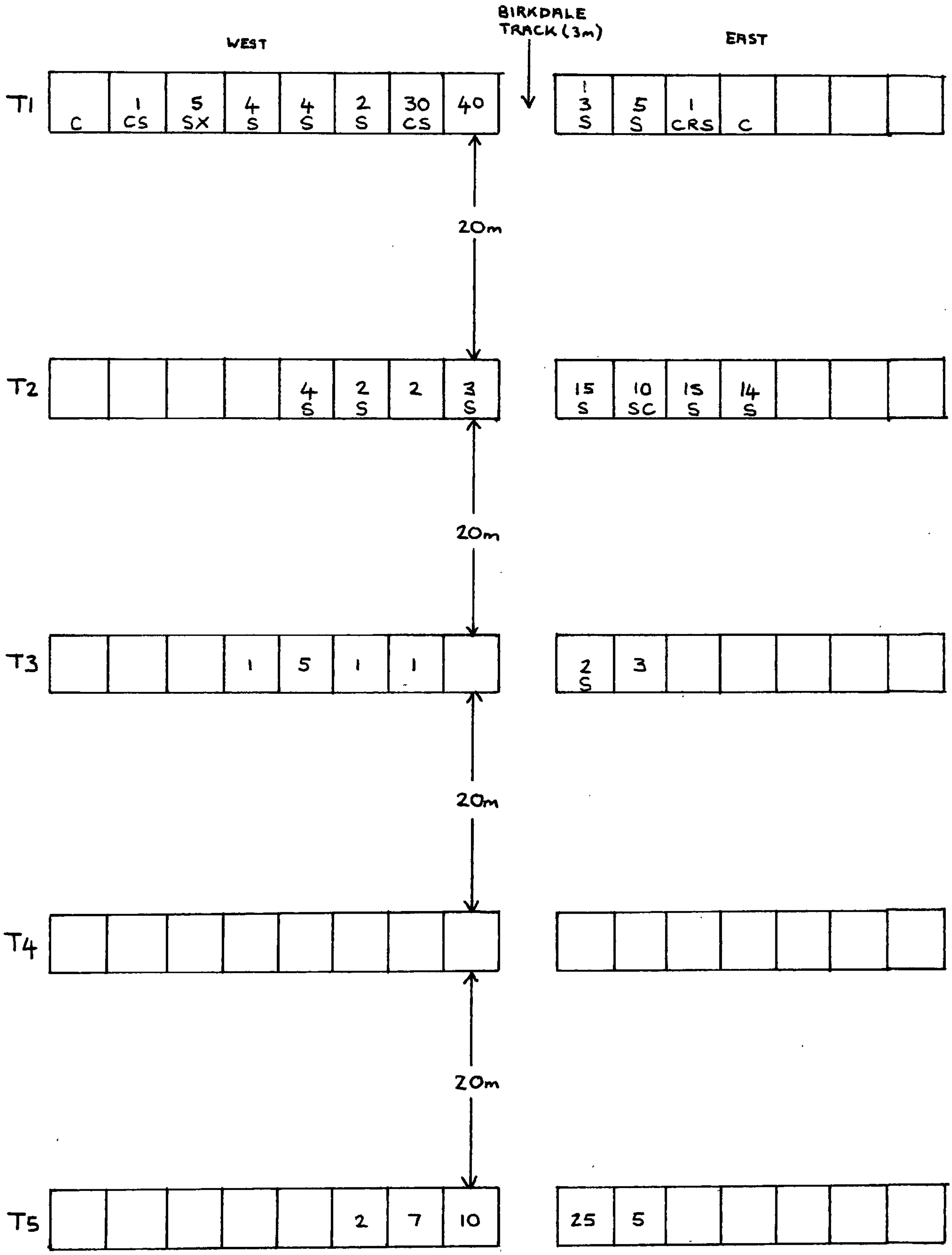


FIGURE 10: TRANSECTS ALONG SECTION C ON THE BIRKDALE TRACK

WEST | BIRKDALE TRACK (3m) | EAST

T6					2	1		1	5						
								20m							
T7							1	1	1						
								20m							
T8				1	2 S	5 S	10 S	5	S	4					
								20m							
T9						S	4	10	1						
								20m							
T10						3			3	6					

This description of the distribution of weeds has been used to construct two hypotheses. Together they could explain the location and spread of weeds and the differences between species. The two suggestions are:-

1. The location and spread of weeds can be explained by their dispersal mechanisms. The distrubtion of weeds on the sheep tracks is dependant on dispersal by sheep and wind. Migration of weeds off the tracks is subject to the same dispersal mechanisms together with vegetative spread. The distribution of weeds on the Birkdale Track is dependant on dispersal by man and wind and also possibly by sheep. Migration of weeds away from the road may be a result of vegetative spread as well.
2. The distribution of weeds on the tracks is dependant on the soil characteristics. The location of individual weed species may be a response to inherent soil conditions. The overall location and spread of weeds on the sheep tracks is dependant on sheep trampling and fertilisation of the soil. On the Birkdale Track weed distributions are related to human trampling and possibly fertilisation by litter disposal or sheep droppings.

Both explanations are based partly on physical conditions in the area and partly on the inherent characteristics of the weeds.

CHAPTER 2 - DISPERSAL AND MIGRATION OF WEEDS

This section of the fieldwork aimed to relate the distribution of weeds to their dispersal mechanisms. On the sheep tracks the majority of weed dispersal must be performed by wind and sheep. People are not permitted to leave the Birkdale Track and in practice very few wander far from the road. Wind dispersal is assessed according to the type of seeds produced by each species. Dispersal by sheep was examined as a possible dispersal mechanism by studying sheep movements in the field. Human movements were also considered in the case of the Birkdale Track.

Various methods were adopted to assess the importance of weed dispersal by sheep. It was necessary to determine the relative amount of use received by the four sheep tracks. Firstly, the frequency of fresh droppings along the tracks was recorded. This is a quantitative measure of the relative amount of trampling and grazing along each track. Direct observation of sheep behaviour, position and movement was a qualitative supplement to this information. This was carried out by sitting on a high point where most of the study area could be viewed at once. The sheep were observed with binoculars. Thus their movements were not determined or affected by human presence. This system was used at various times between 8 a.m. to 8 p.m. As much as possible of the diurnal rhythm of the sheep was recorded so that any regular movements were not missed. The direct observation of sheep is very important in indicating possible directions of weed spread as well as actual amounts of trampling and use of the tracks. The Birkdale Track is regarded as the main source of weeds. Their distribution on the sheep tracks is assessed in relation to this supply. However, if any reliable facts about migration of weeds are to be obtained it will be necessary to repeat the mapwork in 5-10 years' time. This will indicate whether weeds are still spreading or whether the picture is static and there is no increasing danger of weed invasion. Conditions will also change with an increase in human interference or an increase in sheep stocking on the fell. These factors should also be monitored over the same time period.

On the Birkdale Track migration of weeds was assessed by repeating a survey carried out in 1968 and 1970. Two 140m sections and one 100m section of track were studied by taking five random 20m quadrats in every 7m stretch of ground. The area under study was a 1.5m wide strip of land either side of the track. This survey gave some measure of temporal changes in weed distributions. Visitors and local farmers arriving from outside the immediate area are regarded as the main source of weeds for the Birkdale Track.

The statistical results from this section are given in Appendix B.

RESULTS AND DISCUSSION

The dispersal mechanisms of the six weed species in the study were assessed. It is hoped that this survey will help to explain the contrasting distributions of these weeds and their overall location on Widdybank Fell. Firstly, the possibility of wind dispersal will be considered. Secondly, animal dispersal, particularly by sheep, is discussed. The species are ranked in order of their ability to spread by these mechanisms.

Taraxacum officinale has the smallest seeds. They are also equipped with pappus to aid wind dispersal. Poa annua has very small seeds but no additional dispersal mechanisms. Bellis perennis has small achenes but again no dispersal aids. Both Sagina procumbens and Cerastium holosteoides have larger seeds which are fired from valves on the plant. They possess no adaptations to assist wind dispersal. Ranunculus repens has by far the largest seeds and wind dispersal is probably very ineffective. Vegetative spread may well predominate in this case because the species is able to produce new plants even after grazing (Harper 1977). The order of dispersal ability involving animals is probably the same as that for wind dispersal. Therefore it is impossible to determine which mechanism is the more important. All that can be given is an idea of the extent to which dispersal (of some sort) can explain weed distributions. The only weed under study which is definitely adapted for external transport by sheep is Taraxacum officinale. This species has pappus attached to the seeds which can become caught in animal fur. All the weeds are very low-lying plants at this altitude so that their seeds are unlikely to be carried by sheep except on their feet. However, some may be eaten and carried internally. This is most probable in the case of Poa annua which is still capable of germination after being eaten and then excreted (Hill 1977). The seeds are resistant to digestion and are still viable when they are deposited in droppings. Poa annua, being a grass, is also the weed species most susceptible to sheep grazing.

This order of dispersal ability corresponds fairly well with the relative distributions of the six species. Taraxacum officinale, Bellis perennis and Poa annua can be found along the whole 1200m length of the Top Track. They show no decline in abundance from the source area of weeds along the Birkdale Track. This implies that they must be efficiently dispersed even though the Top Track has been used for many years. The mechanisms of dispersal described above support this view There were also unexpected discoveries of Poa annua on the extreme northern end of the Summit Track and on part of the sheep track leading from the Borehole construction path. Both Bellis perennis and Poa annua were found on the most southerly part of the Lowest Track. They also grew abundantly on a short section of sheep track connecting two gullies above the Lowest Track in an area where weeds were very sparse. In all cases the nearest source of weeds (either a sheep track or a shake hole where sheep congregate) was some distance away. This situation implies that dispersal is not a major influence on the distribution of these weed species. The other three weeds all have more local distributions which may be partly a result of their relatively inefficient dispersal mechanisms. This is particularly true in the case of Ranunculus repens. It has a very limited distribution: mainly confined to a few hollows near the Birkdale Track. Finally, it should be noted that the weeds with the best dispersal mechanisms are also the most abundant. Taraxacum officinale is an exception to this rule. Nevertheless, the relative ability of weeds to spread may be able to account for their abundance as well as their actual location.

The dispersal hypothesis is certainly unsatisfactory as a complete explanation for weed distributions. This is shown by several characteristics of weed locations which it cannot explain. For instance, both wind and sheep dispersal could account for the decline in weed abundance and spread from the Top to the Lowest Track. Winds are less strong on the lower slopes where the ground is sheltered by the higher land to the north and east. Most dispersal probably occurs southwards from the Birkdale Track so shelter could be important on the Lowest Track. Altermatively, dung counts and sheep observations show that the Top Track is much more frequently used than the Lowest Track (Tables 4 and 5; Plates 8 and 9). Therefore sheep are unlikely to carry many weeds along the lower paths. However, if these trends are extended to include the Summit Track they predict that weeds should reach their highest abundance here. In practice this is not true although winds are very strong and dung counts imply that this track is used more than the Top Track. This suggests that dispersal is not an important explanation for the overall distribution of weeds on Widdybank Fell. The physical characteristics of the area may be an alternative explanation for the relative abundance of weeds on the four tracks. In particular, it was noted that the Summit Track does not have a high percentage bare ground to match its intensive use (Table 6). This may be a result of thick vegetation mat consisting primarily of Juncus squarrosus, Festuca spp. and Eriophorum vaginatum which is resistant to trampling. In contrast the areas of Calluna vulgaris with many

TABLE 4 : DUNG COUNTS ALONG THE FOUR SHEEP TRACKS

	Sheep Tracks (dung count/10m)			
	Lowest	Middle	Top	Summit
N				
Grassland	2.8	2.0	2.7	2.0
Heathland	2.3	2.7	3.6	2.3
Grassland	2.4	1.0	1.8	3.6
Heathland	0.9		4.2	3.0
Grassland	1.6		7.1	5.0
Heathland			2.8	3.0
S				

TABLE 5 : OBSERVATIONS ON SHEEP MOVEMENTS ALONG THE FOUR SHEEP TRACKS

	Sheep tracks (mean number of sheep/1000m)			
	Lowest	Middle	Top	Summit
Grassland	2.2	4.8	4.6	2.9
Heathland	0.6	3.1	4.0	1.1
Moving North	1.4	3.2	3.7	2.7
Moving South	1.4	4.7	4.9	1.3

TABLE 6 : DISTRIBUTION OF BARE GROUND ALONG THE FOUR SHEEP TRACKS

	Sheep tracks (number of quadrats recording bare ground)			
% bare	Lowest	Middle	Top	Summit
0	12	9	33	39
1-10	33	19	72	36
11-20	14	15	44	18
21-30	6	9	32	3
> 30	35	24	61	4

Plate 8 : Sheep using the Top Sheep Track - a well-worn path

Plate 9 : Sheep walking along the Middle Sheep Track

Sphagnum species are susceptible to erosion. Bayfield (1970) working in the Cairngorms confirms the fact that these species are much more severely affected by trampling than Eriophorum spp. Whatever, the cause, the absence of bare ground is likely to reduce the success of weed colonisation.

Other evidence tends to support the view that dispersal cannot provide a complete explanation for weed distributions. For instance, there is very little spread of weeds away from the sheep tracks. It is inconceivable that dispersal is a barrier to weed migration on such a small scale. Vegetative spread alone should allow weeds to spread some distance away from the tracks if physical conditions are suitable. Similarly, the sharp division of weed species between areas of grassland and heathland cannot be due to restrictions on dispersal. The reasons for this pattern must lie in the environmental conditions which prevent either colonisation or survival of weeds. It seems probable that sheep exert most of their influence on weed distributions through their effects on the ground rather than through seed dispersal.

The sheep did not show any tendancy to walk in a set direction along the different tracks. Therefore there is no need to argue that weed migration occurs in different directions rather than from the main source on the Birkdale Track. This is confirmed by some of the weed patterns which show declines in abundance away from the road. However, weeds have probably been in the area for a long time because the fell has been used as pastureland for many centuries. Migration must also occur from other centres which have developed high concentrations of weeds such as the shake hollows. The central section of the Summit Track is one such area. Weed abundance declines away from this zone where sheep congregate. The dung counts along these sections of track indicate that they are well used and direct observation confirms this fact. Unlike the other three tracks, the low concentration of weeds on the Summit Track does not reflect the amount of use the path receives. It is suggested that weed colonisation is limited by some environmental factor and not by wind or animal dispersal.

Dispersal does not seem to be the factor limiting further weed spread on the upper tracks. It is assumed that there is no comparable limit to dispersal on the Lowest Track. The seeds of weeds are present for colonisation in the areas of rare plants. For instance, Bellis perennis, Ranunculus repens, Sagina procumbens and even Poa annua have colonised wet hollows bordering Red Sike only a few metres to the west of the Lowest Track where no weeds are found. These zones are also less than 500m from the vast weed source on the Birkdale Track.

On the Top Track weeds are abundant more than 1200m from the road. Furthermore there is no significant decline in the abundance of Poa annua and Bellis perennis along the section of the Lowest Track on which weeds are found. There is a fairly abrupt change from an environment in which weeds are found to one in which they do not grow. Therefore the idea that dispersal mechanisms control and limit weed distributions in the areas of Teesdale rarities is rejected.

On the Birkdale Track dispersal cannot account for many of the weed distributions observed. This is illustrated by the similar weed concentrations on the old and new sections of the track. Indeed Poa annua has spread further from the road in the new section. This is probably due to the greater disturbance here. Once again this implies that bare ground rather than limitations on weed migration control the extent of weed colonisation. Bare ground in turn is a reflection of trampling and disturbance by man and his animals. The only weed which does not follow this pattern is Ranunculus repens. This species has a significantly greater concentration on the old section of the track. In this case poor dispersal ability probably explains the situation. It has been stressed several times that Ranunculus repens has by far the most inefficient dispersal mechanism of the six species under study. The environment along the two sections of track is very similar and cannot provide an explanation for the contrasting amounts of Ranunculus repens found these. Therefore this is an example of dispersal rather than soil limitations controlling the location of weeds.

The survey along the Birkdale Track comparing the vegetation with 1968 records suggest that changes are certainly occuring (Table 7). There has been an increase in the percentage of many weedy species such as Bellis perennis; Taraxacum spp.; Plantago major and Trifolium repens. Other weeds which were previously absent in the area or first noted in 1970 were also recorded. These include Poa annua; Sagina procumbens and Cerastium holosteoides. They were not very abundant and were confined to the immediate edge of the track. Cirsium arvense and Senecio jacobea were classified as new species in 1970. However, they were not recorded in 1978. Therefore the threat to the natural vegetation seems to be coming mainly from long established weeds rather than new species. It is these species which are capable of migrating into vegetation communities growing along the sides of the Birkdale Track. The control survey in 1968 showed that these weeds, particularly Bellis perennis, are members of the natural vegetation away from the road but they become much more abundant where there is disturbance.

Among other members of the vegetation Plantago maritima; Minuartia verna; Prumella vulgaris and Linum catharticum have all increased in abundance in the verge. This suggests that these are species which can tolerate trampling. The 1968 control survey away from the track confirms that three of these plants are more abundant near the road where the ground is disturbed. The exception is Linum catharticum but there is no obvious reason why this species should give contradictory results. Plantago lanceolata showed only slight increases in the study area since 1968 and Polygonum viviparum decreased in abundance. In 1970 both species had decreased. Although some error may have been involved it is surprising that there was no increase during the 10 year period. Both species were much more abundant in the verge than the control strip in 1968 so they obviously like a disturbed environment. Excessive trampling may now be controlling the abundance of these two species.

Finally, many of the rare plants recorded had declined in abundance since 1968. Viola riviniana has been eliminated except in Area 1. Kobresia simpliciuscula, Seloginella, Carex capillaris and Primula farinosa were very uncommon. Only Gentiana verna seems to be able to maintain its population size. Even this species is far less abundant than in the control strip of 1968. Nevertheless gentians are fairly resistant to trampling and there should be need for much less concern here than in the case of many other Teesdale rarities. The best sites for these plants do not border the Birkdale Track so that the overall threat to the rare species is not as severe as the survey would suggest.

TABLE 7 : CHANGES IN THE DISTRIBUTION OF WEEDS ALONG THE BIRKDALE TRACK

Species	Percentage Frequency								
	Area I			Area II			Area III		
	1968	1978	Change	1968	1978	Change	1968	1978	Change
Bellis perennis	43	51	+8	75	92	+17	51	69	+18
Carex capillaris	3	4	+1	1	8	+ 7	21	17	- 4
Cerastium holosteoides	0	7	+7	0	2	+ 2	0	9	+ 9
Cirsium arvense	0	0	0	0	0	0	0	0	0
Gentiana verna	0	0	0	6	6	0	6	8	+ 2
Kobresia simpliciuscula	28	26	-2	8	0	- 8	4	2	- 2
Linum catharticum	5	10	+5	0	6	+ 6	7	14	+ 7
Minuartia verna	8	7	-1	6	7	+ 1	3	26	+23
Plantago lanceolata	28	29	+1	71	79	+ 8	63	57	- 6
Plantago major	0	13	+13	3	44	+41	4	25	+21
Plantago maritima	52	67	+15	15	21	+ 6	13	32	+19
Poa annua	0	13	+13	0	0	0	0	6	+ 6
Polygonum viviparum	20	11	- 9	52	39	-13	45	52	+ 7
Primula farinosa	3	4	+ 1	0	1	+ 1	0	0	0
Prunella vulgaris	30	30	0	34	30	- 4	13	18	+ 5
Sagina procumbens	0	18	+18	0	4	+ 4	0	6	+ 6
Selaginella selaginoides	6	10	+ 4	3	2	- 1	1	2	+ 1
Senecio jacobaea	0	0	0	0	0	0	0	0	0
Taraxacum officinale	20	26	+ 6	32	49	+17	24	31	+ 7
Trifolium repens	3	9	+ 6	49	52	+ 3	26	44	+18

TABLE 7 (contd.)

Species	Area I 1968	Area I 1978	Area I Change	Area II 1968	Area II 1978	Area II Change	Area III 1968	Area III 1978	Area III Change
Viola riviniana	2	2	0	1	0	-1	0	0	0

Percentage Frequency

In conclusion, the repeat of the 1968 survey has been very useful in indicating that changes are occuring in the roadside vegetation. The situation is not static. Most species have not reached a balance in numbers - weeds are still on the increase and several plants are on the verge of being eliminated from these areas. Weed dispersal and colonisation is a slow process and there is likely to be an increasing weed problem in future years.

CHAPTER 3 - SOIL ANALYSIS

This section of the fieldwork aimed to relate the distribution of weeds to some environmental characteristics. The soils of the study area were analysed in detail but vegetation associations were also considered.

Soil analysis was carried out in the permanent quadrats used earlier for the study of weed migration. Two 10cm. deep cores were taken randomly in each of the permanent quadrats. The soil auger used had a 3cm. diameter. This was the smallest bore size which gave a large enough soil volume to carry out the range of tests required. Only two replicas were taken within each quadrat because the quadrats were small and it was important to keep damage in the area to a minimum. The top 10cm. of soil was the rooting zone and therefore represented the environment in which the weed species grow. Soil depth was also measured in the field using a length of thin wire. The wire was inserted into each quadrat five times and the mean depth to which it penetrated was then calculated. The values were probably underestimates because small stones prevented the wire from recording the complete depth of soil. In the laboratory the soil samples were subjected to a series of tests. The methods adopted are described below (after Allen 1966).

Firstly, the fresh soil was weighed and its volume calculated from the core size. These mass and volume readings were used to calculate soil density. The results have been taken as a surrogate for soil compaction which is very difficult to measure directly. Density will obviously vary with the nature of the material forming the soil. Nevertheless it was considered that trampling and compression would be the major forces altering soil density within this small area.

Secondly, a small sample of fresh soil (10–20g) was oven-dried at 105^{o}C. for 48 hours. The loss in weight was used to calculate the moisture content of the soil.

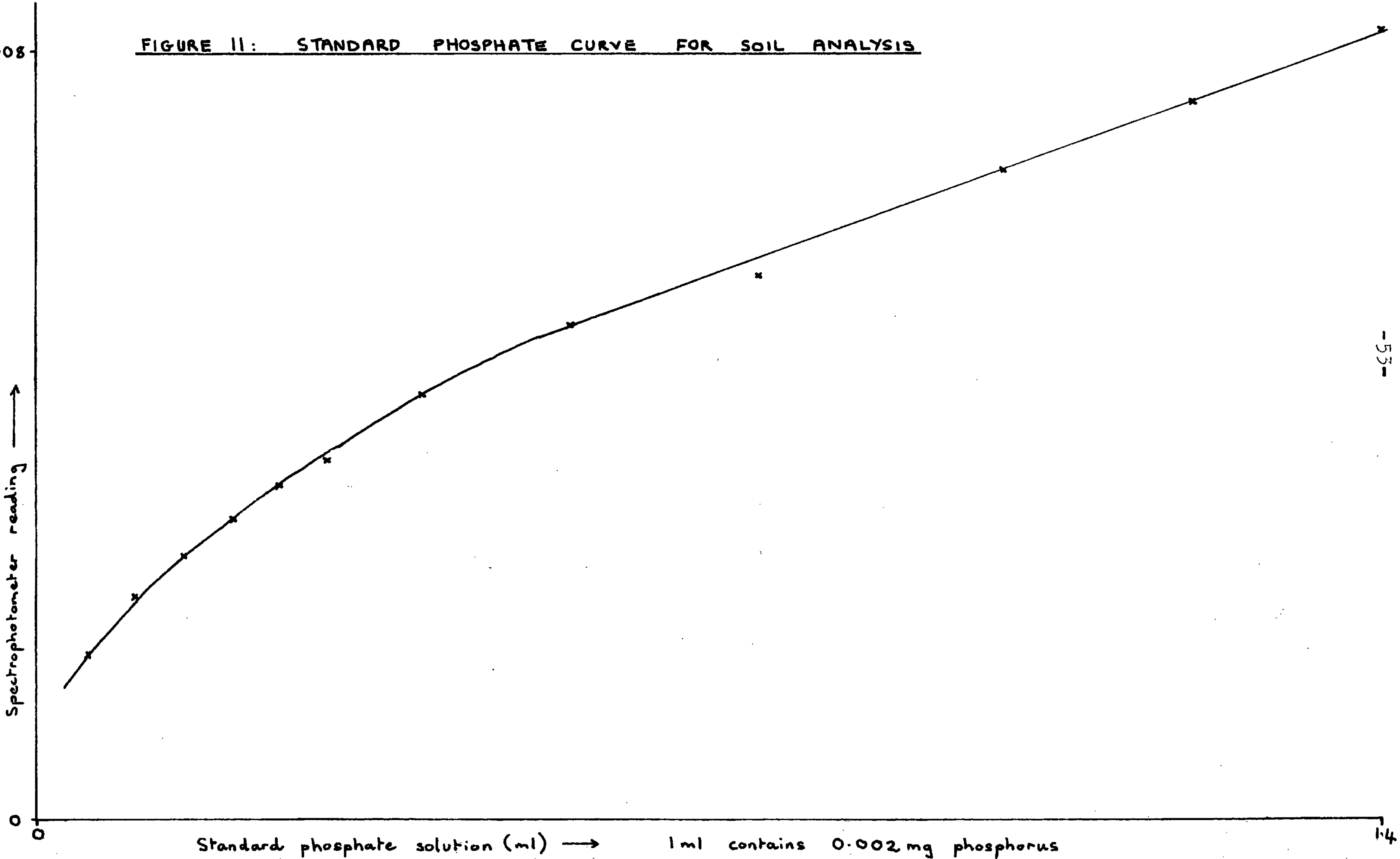
Thirdly, approximately 10g of soil were mixed with 30cm^3 of distilled water and the pH measured on a buffered pH meter.

Fourthly, 1g of oven-dried soil was placed in a muffle furnace at 450^{o}C for 4 hours. The loss in weight was used to calculate the organic content of the soil.

For the remaining tests it was first necessary to air-dry the soil by exposing it to the atmosphere for four days. A section of the core was kept intact for the field capacity experiment. The core was saturated with a known volume of water. It was then allowed to drain freely. The volume of soil and volume of water lost were used to calculate the soil field capacity.

Finally, the phosphate content of a ground and sieved portion of air-dried soil was measured. 2.5g of soil were shaken with 100cm^3 of Truog's reagent (200cm^3 of 0.05M sulphuric acid were diluted to 10 L and buffered at pH3 with 30g of ammonium sulphate) on a rotary shaker for 1 hour. The mixture was then filtered using No.44 paper. 50cm^3 of filtrate were placed in a flask together with 2cm^3 of ammonium molybdate reagent and 2cm^3 of stannous chloride reagent. The solution was shaken and left for 30 minutes. The molybdenum blue colour was measured in an "Uvispek" spectrophotometer. A standard phosphate curve was constructed which enabled the soil readings to be converted to actual values of extractable phosphate (Figure 11). This test was chosen because it is known to be suitable and reliable for all but the most calcareous soils (pH78). The results of the soil analysis are presented in Tables 8 to 30. The calculation methods are given in Appendix C.

FIGURE 11: STANDARD PHOSPHATE CURVE FOR SOIL ANALYSIS



RESULTS AND DISCUSSION

The soil survey of the sheep tracks on Widdybank Fell had two main aims. Firstly, the heathland soils were compared with the areas of open grassland. It was hoped that this experiment would help to explain the contrasting distributions of Poa annua and Bellis perennis. Secondly, track soils were compared with those on either side in areas both with and without weeds. From this work it was planned to assess whether the soil was limiting weed migration and whether sheep significantly modify the soil along the trackways.

Along the Top Track the soils in the five permanent sites which only support Poa annua are significantly different in several respects from those which only contain Bellis perennis (Tables 8 to 14). The soil in the zone where both weeds are found has intermediate characteristics. It was demonstrated by greenhouse experiment with controls that the weeds caused no significant alteration of soil characteristics (Table 15). Furthermore there is no significant difference in the amount of sheep dung along this section of the track. Therefore the soil contrasts must be regarded as inherent.

The Chi-squared test shows that the pH is significantly higher and organic matter and moisture content lower in areas of Bellis perennis. The percentage organic matter is a measure of the humus content of the soil. The difference must reflect varying amounts of decaying vegetation matter if the amounts of sheep droppings are fairly constant along this part of the Top Track. Soil depth is also significantly less in areas of Bellis perennis. The type of vegetation which surrounds the sheep track presumably reflects soil conditions as well. Therefore the correlation between vegetation association and weed type is a result of common soil requirements. Laboratory experiments were used to confirm the fact that soil conditions are important in limiting the distribution of both weeds. Bellis perennis was planted in pots with soil from site 3 where only Poa annua grows. Similarly Poa annua was planted in pots with soil from site 2 where only Bellis perennis grows. All the weeds survived but flowering was inhibited and many of the leaves became yellow and wilted. The soil obviously inhibited the growth of these two weeds. It would probably have an even greater effect on young seedlings or germinating seeds as this is the most sensitive period in the life of a plant.

Interspecific competition cannot account for contrasting distributions of the two weeds in the field. They grow together in close proximity without any apparent ill-effects. This is well

TABLE 8 : SOIL pH VALUES MEASURED FROM THE TOP SHEEP TRACK

	Q_0	Q_{1W}	Q_{2W}	Q_{3W}	Q_{4W}	Q_{5W}	Q_{1E}	Q_{2E}	Q_{3E}
Site 1									
T1	6.3	6.3	5.8	5.9			5.2	4.2	
T2	6.9	6.7	7.2	6.5			6.6	6.5	
T3	5.5	5.0	4.9				4.8		
T4	6.4	6.8	6.4				6.7		
T5	5.4	4.8					4.8		
Site 2									
T1	7.4	7.5					7.4		
T2	6.6	5.7	5.5	5.2			6.2	5.6	5.3
T3	5.2	5.2					5.2		
T4	5.8	5.8	5.8	5.8	5.8	5.6	5.8	5.6	
T5	7.3	7.5					7.5	7.3	7.4
Site 3									
T1	5.5	4.5					5.2	5.1	
T2	5.3	3.7					5.6	5.5	
T3	4.7	3.6	3.5				4.0	4.2	
T4	5.3	5.2	5.2				5.1	4.6	
T5	4.6	4.5					4.4	4.0	

X^2 test to determine whether there is a significant difference between the pH of soils where Bellis perennis grows and those where Poa annua grows on the Top Track:

$X^2 = 10.12$ Significant at 0.01 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the pH of soils on and off the Top Track in areas where Bellis perennis grows:

U = 75 Not significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the pH of soils on and off the Top Track in areas where Poa annua grows:

U = 57 Significant at 0.05 probability level (1-tailed test)

TABLE 9 : SOIL MOISTURE % MEASURED FROM THE TOP SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{2W}	Q_{3W}	Q_{4W}	Q_{5W}	Q_{1E}	Q_{2E}	Q_{3E}
T1	37	31	30	35			24	21	
T2	35	35	34	29			31	32	
T3	28	26	22				18		
T4	25	26	21				29		
T5	26	31					31		
Site 2									
T1	16	16					19		
T2	27	24	28	26			25	26	25
T3	36	26					31		
T4	22	29	21	26	26	23	20	22	
T5	24	23					19	30	25
Site 3									
T1	28	29					29	33	
T2	17	32					28	21	
T3	31	32	42				23	29	
T4	26	24	28				25	26	
T5	24	25					27	28	

X^2 test to determine whether there is a significant difference between the moisture % of soils where Bellis perennis grows and those where Poa annua grows on the Top Track:

$X^2 = 3.90$ Significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the moisture % of soils on and off the Top Track in areas where Bellis perennis grows:

U = 79 Not significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the moisture % of soils on and off the Top Track in areas where Poa annua grows:

U = 97 Not significant at 0.05 probability level.

TABLE 10 : . SOIL ORGANIC % MEASURED FROM THE TOP SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{2W}	Q_{3W}	Q_{4W}	Q_{5W}	Q_{1E}	Q_{2E}	Q_{3E}
T1	21	17	14	21			20	16	
T2	38	31	27	20			21	21	
T3	28	20	18				19		
T4	26	18	22				18		
T5	17	18					28		
Site 2									
T1	13	13					17		
T2	37	16	17	13			21	18	15
T3	16	16					14		
T4	28	33	37	34	32	29	31	28	
T5	19	13					12	18	12
Site 3									
T1	21	22					23	21	
T2	41	14					30	10	
T3	28	27	25				25	22	
T4	32	19	22				24	24	
T5	20	25					24	20	

X^2 test to determine whether there is a significant difference between the organic % of soils where Bellis perennis grows and those where Poa annua grows on the Top Track:

$X^2 = 6.74$ Significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the organic % of soils on and off the Top Track in areas where Bellis perennis grows:

U = 57 Significant at 0.05 probability level (1-tailed test)

Mann-Whitney U test to determine whether there is a significant difference between the organic % of soils on and off the Top Track in areas where Poa annua grows:

U = 43 Significant at 0.01 probability level (1-tailed test)

TABLE 11 : SOIL DENSITY (g/cm^3) MEASURED FROM THE TOP SHEEP TRACK

	Q_0	Q_{1W}	Q_{2W}	Q_{3W}	Q_{4W}	Q_{5W}	Q_{1E}	Q_{2E}	Q_{3E}
Site 1									
T1	0.27	0.27	0.26	0.25			0.23	0.23	
T2	0.22	0.19	0.22	0.22			0.26	0.23	
T3	0.26	0.24	0.22				0.26		
T4	0.23	0.28	0.22				0.24		
T5	0.24	0.28					0.19		
Site 2									
T1	0.29	0.22					0.28		
T2	0.27	0.26	0.26	0.22			0.26	0.21	0.24
T3	0.32	0.25					0.25		
T4	0.27	0.30	0.26	0.29	0.25	0.26	0.24	0.19	
T5	0.31	0.29					0.28	0.23	0.28
Site 3									
T1	0.26	0.27					0.24	0.28	
T2	0.29	0.10					0.16	0.24	
T3	0.31	0.17	0.15				0.25	0.22	
T4	0.28	0.24	0.21				0.18	0.18	
T5	0.23	0.23					0.22	0.26	

X^2 test to determine whether there is a significant difference between the density (compaction) of soils where *Bellis perennis* grows and those where *Poa annua* grows on the Top Track:
$X^2 = 3.74$ Not significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the density (compaction) of soils on and off the Top Track in areas where *Bellis perennis* grows:
U = 53 Significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the density (compaction) of soils on and off the Top Track in areas where *Poa annua* grows:
U = 41 Significant at 0.01 probability level (1-tailed test)

TABLE 12 : SOIL FIELD CAPACITY (cm^3 of water/100cm^3 of soil) MEASURED FROM THE TOP SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{2W}	Q_{3W}	Q_{4W}	Q_{5W}	Q_{1E}	Q_{2E}	Q_{3E}
T1	6.9	5.5	5.2	1.4			7.2	1.3	
T2	15.0	7.5	6.7	3.1			11.1	2.3	
T3	3.6	6.2	3.0				2.4		
T4	2.1	4.5	4.3				5.9		
T5	9.7	4.5					7.3		
Site 2									
T1	9.5	3.7					6.4		
T2	7.8	8.1	6.5	3.2			2.9	3.5	8.8
T3	11.3	10.9					6.6		
T4	10.4	12.5	13.0	6.9	5.7	6.0	13.9	10.0	
T5	5.2	13.2					5.2	12.5	9.0
Site 3									
T1	7.0	3.1					2.1	1.3	
T2	1.7	4.3					5.2	2.3	
T3	15.6	4.9	2.9				4.3	1.1	
T4	3.3	5.5	5.2				3.5	1.5	
T5	5.5	4.1					4.9	5.1	

X^2 test to determine whether there is a significant difference between the field capacity of soils where Bellis perennis grows and those where Poa annua grows on the Top Track:

$X^2 = 3.17$ Not significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the field capacity of soils on and off the Top Track in areas where Bellis perennis grows:

U = 72 Not significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the field capacity of soils on and off the Top Track in areas where Poa annua grows:

U = 54 Significant at 0.05 probability level.

TABLE 13 : SOIL PHOSPHATE CONTENT (mg/g dry wt. of soil) MEASURED FROM THE TOP SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{2W}	Q_{3W}	Q_{4W}	Q_{5W}	Q_{1E}	Q_{2E}	Q_{3E}
T1	.043	.024	.025	.008			.033	.005	
T2	.008	.001	.001	.001			.005	.001	
T3	.012	.010	.002				.011		
T4	.016	.005	.002				.006		
T5	.003	.001					.001		
Site 2									
T1	.026	.004					.025		
T2	.100	.018	.011	.009			.011	.011	.015
T3	.004	.001					.004		
T4	.006	.005	.003	.003	.001	.001	.003	.003	
T5	.029	.018					.019	.012	.014
Site 3									
T1	.027	.025					.034	.020	
T2	.020	.028					.016	.011	
T3	.008	.007	.003				.010	.005	
T4	.135	.015	.016				.007	.006	
T5	.073	.010					.025	.001	

X^2 test to determine whether there is a significant difference between the phosphate content of soils where *Bellis perennis* grows and those where *Poa annua* grows on the Top Track:

$X^2 = 1.04$ Not significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the phosphate content of soils on and off the Top Track in areas where *Bellis perennis* grows:

U = 45 Significant at 0.01 probability level (1-tailed test)

Mann-Whitney U test to determine whether there is a significant difference between the phosphate content of soils on and off the Top Track in areas where *Poa annua* grows:

U = 41 Significant at 0.01 probability level (1-tailed test)

TABLE 14 : SOIL DEPTH (cm) MEASURED FROM THE TOP SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{2W}	Q_{3W}	Q_{4W}	Q_{5W}	Q_{1E}	Q_{2E}	Q_{3E}
T1	8	8	15	13			8	11	
T2	6	8	12	16			7	17	
T3	14	15	16				25		
T4	10	10	14				11		
T5	11	13					11		
Site 2									
T1	9	11					13		
T2	12	13	13	16			15	20	22
T3	14	18					17		
T4	17	24	24	21	28	20	23	21	
T5	7	9					8	8	10
Site 3									
T1	19	23					21	20	
T2	5	9					7	7	
T3	13	13	15				9	9	
T4	9	10	11				10	13	
T5	25	20					30	30	

X^2 test to determine whether there is a significant difference between the soil depth of soils where <u>Bellis perennis</u> grows and those where <u>Poa annua</u> grows on the Top Track:

$X^2 = 140$ Not significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the depth of soils on and off the Top Track in areas where <u>Bellis perennis</u> grows:

U = 50 Significant at 0.05 probability level.

Mann-Whitney U test to determine whether there is a significant difference between the depth of soils on and off the Top Track in areas where <u>Poa annua</u> grows:

U = 57 Significant at 0.05 probability level (1-tailed test)

TABLE 15 : RESULTS OF THE LABORATORY SOIL EXPERIMENTS:

	Control	*Bellis perennis*	*Poa annua*	Both Weeds
Mean pH	6.3	6.3	6.4	6.6

TABLE 16 : RESULTS OF THE SOIL ANALYSIS FROM THE TWO SHEEP HOLLOWS

Soil Characteristics	Grassland Hollow		Heathland Hollow		Droppings (mean values)
pH	6.6	6.5	5.4	5.6	7.7
moisture %	26	35	24	28	
organic %	24	33	38	27	
density (g/cm^3)	0.17	0.19	0.27	0.26	
field capacity (cm^3 of water/$100cm^3$ of soil)	9.5	8.8	7.0	5.9	
phosphate content (mg/g dry wt. of soil)	.125	.080	.094	.095	0.360
depth (cm)	5	7	6	8	

illustrated in the case of site 1. Limitations on dispersal are also no restriction on weed growth in the three sites because the change in weed species is very abrupt between grassland and heathland zones.

The other soil characteristics which were studied (namely depth, compaction, field capacity and phosphate content) do not vary significantly from areas of Bellis perennis to those of Poa annua. Therefore, the major edaphic controls on the distribution of Poa annua and Bellis perennis seem to be pH, moisture and organic content. Poa annua prefers damper and more humus-rich soils. Its very abrupt changes in abundance along the sheep tracks suggest that the presence of a particular nutrient may also be important for its survival. The presence of Poa annua is correlated with a high percentage bare ground. This is not so true for the other weeds but may be an additional requirement for the successful establishment of Poa annua. Bellis perennis is tolerant of the high pH and low organic content of the dry calcareous rendzina soils formed in areas where limestone is at or near the surface. However, Bellis perennis will also grow in some of the heathland zones to which Poa annua is confined. These soils are very variable in character, particularly in pH, because some exposed limestone areas will support a vegetation complex dominated by Calluna vulgaris (Mapping Unit 4 Jones 1975). Therefore Bellis perennis probably does not grow in a greater range of soil conditions than Poa annua.

Ranunculus repens and Sagina procumbens are usually located in the areas with Bellis perennis and are presumably tolerant of the same soil conditions. Cerastium holosteoides and Taraxacum officinale are equally abundant in heathland and grassland zones which suggests a wide range of soil tolerence. However, in the case of Ranunculus repens and Cerastium holosteoides the most important soil requirements are probably fertile, organic and phosphate rich conditions. This is demonstrated by the very high concentrations of these weeds in the two hollows which were studied in detail (Table 16). The stoloniferous habit of Ranunculus repens also enables the plant to spread quickly over dungpatches even if it does not root in them (Harper 1978). One hollow was surrounded by grassland and had a fairly high pH, the other was in a heathland zone with lower pH. However, both hollows recorded very high values for phosphate and humus content. These are probably the major controls on the distribution of the two weeds. The very high percentage cover of Ranunculus repens and Cerastium holosteoides in these fertile hollows must limit the presence of other weeds - notably Bellis perennis and Poa annua. These grow along most sections of the track where the extra-fertile conditions which enhance the growth of Cerastium holosteoides and Ranunculus repens are not found.

Hoveland, Buchanan and Harris (1976) confirm the importance of high phosphorus levels to the growth of Cerastium holosteoides (measured as dry herbage yield). Phosphorus deficiency was revealed by stunting and red-purple coloration. They also suggest that weeds are more sensitive to phosphorus than potassium and other cations. Weeds were also more tolerant of acid than very alkaline conditions. Their failure to survive on the sugar limestone soils of the Lowest Track supports this view. There was a wide variation in weed response to the pH range 4.7 to 6.3. Cerastium holosteoides and Taraxacum officiale were severely reduced in soils with the lowest pH. However, this is not applicable to the heathland soils of the Top Track where pH readings are generally greater than 5.0. The lower values on site 3 do correspond with a zone where Taraxacum officiale and Cerastium holosteoides are not recorded.

At the permanent sites on the Top Track soil conditions are significantly different on the path from those off the track. In most cases there is a gradation of conditions associated with a decline in weed abundance away from the track. This discovery applies irrespective of the weed species involved. In both grassland and heathland areas the percentage organic matter, phosphate content and soil density are all higher on the track itself and the soil depth is lower. These micro-edaphic contrasts are assumed to be the result of sheep modification of the soil on the paths. The sheep create the tracks and they are the only major variable which has contrasting effects on and off the tracks. Vegetation differences cannot account for the situation because all species with the exception of Calluna vulgaris and the weeds themselves are equally abundant in both localities. Laboratory experiments mentioned earlier have proved that neither Bellis perennis nor Poa annua significantly alter the soil conditions. Calluna vulgaris does lower soil pH and cause shading of other plants so this may be an additional explanation for the soil differences and weed distributions in heathland sections of the track. However, this factor cannot account for the gradation of soil charactertistics. In contrast, sheep interference declines away from the track and could explain the trend in soil conditions.

On the path itself sheep trampling and erosion can explain increased soil compactionwhich is also the cause of shallower soils. Droppings can account for the increase in organic matter and phosphate. Dung is almost entirely confined to the tracks and immediately either side. Some samples of sheeps' droppings were analysed in the same way as the soil (Table 16). Extremely high percentage organic matter and phosphate content were recorded. These will fertilise the soil as the droppings decay. Indeed, it is surprising that the phosphate content of soils along the track, and particularly in hollows where dung concentrations are very high, is not much greater. The low values cannot be accounted for by the extraction technique which is known to be efficient. Some phosphate may be locked in the soil in an unavailable form but it is likely that most is lost by leaching. This idea was confirmed by the last set of soil samples which were collected after a period of heavy rain. They came from a variety of sites but all gave lower phosphate values than had been recorded previously. A study by Crisp (1966) at Moorhouse gives a quantitative measure of the movements of phosphorus within the ecosystem. He stresses that the main losses from the system are via peat erosion and in solution in stream water. Widdybank Fell is a very similar environment and the same conditions probably hold true. The higher pH on track soils supporting Poa annua compared with the surrounding soils can also be explained by the presence of sheeps' dung. This gave pH values of 7.0 - 8.0 when analysed in the laboratory. The values are very similar to the pH recorded in the grassland soils. Therefore it is understandable that there is no pH contrast between track and other sites in these sections. The other soil measurements did not vary significantly on and off the path. These factors were moisture content and field capacity. They are not greatly modified by sheep trampling or fertilisation and therefore cannot be a major control on weed distributions.

The importance of soil characteristics in determining weed colonisation and survival is confirmed by greenhouse experiments. Both Bellis perennis and Poa annua failed to survive using soil samples collected away from the track. It is inconceivable that barriers to dispersal limit weed distributions on such a small scale. Furthermore, the sheep paths and the Birkdale Track have been in existence throughout this century and the Top Track was also used by miners to cross the fell during the nineteenth century. Therefore weeds have probably been present for a long while particularly on the Top Track. Migration off this track under present conditions, it is suggested, is complete. However, spread to other tracks which are less well used may still be occuring.

In conclusion, organic and phosphate enrichment of track soils may have encouraged weed growth. Increased pH is also important in areas of acidic heathland. Soil compaction is correlated with the presence of weeds. It is probably important because compaction is a measure of the amount of trampling, erosion and sheep fertilisation on the track. Sheep also bare the ground along the paths which enables weeds to colonise relatively free from competition. However, there is a significant decline in the percentage bare ground away from the track. This implies that the availability of sites for colonisation as well as soil characteristics may limit weed migration. If this is true then an increase in sheep pressure or even continued use of the land at the same stocking intensity could result in further erosion. This in turn could enhance weed spread. _Cerastium holosteoides_ seems to be an exception to this rule. It has spread further from the sheep tracks than any other weed and is also recorded for 200m along the path to the gas borehole where other weeds are absent. Both these sites are notable for their lack of bare ground. The absence of bare ground on Sections 2 and 3 of the Summit Track is probably an important reason for the lack of weeds here. The soil conditions are not significantly different from those in Section 1 where weeds are abundant and the ground is eroded (Tables 17-23).

Work by Sjogren (1970) on the Baltic island of Oland confirms this view. The original stocking intensity on this limestone heathland was less than 0.1 ewe/ha . The vegetation had reached a balance with this grazing intensity so that there was only a slight reduction in species diversity. However in 1960 intensive sheep grazing at 1 ewe/ha was introduced during summer periods. In practice the pressure was much higher than this because the sheep concentrated in the areas of _Avenetum_ type herbacious vegetation. 20 - 50% of the grassland was unpalatable. Damage by grazing and trampling was severe. Species with weak roots were uprooted by the sheep e.g.: _Viola pumila_, _Luzula campestris_, _Veronica spicata_. Orchids were completely destroyed and were extremely slow to recolonise. Furthermore manuring induced competition from anthropocherous species e.g.: _Cirsium arvense_, _Poa annua_, _Stellaria media_, _Urtica dioica_, _Capsella bursa-pastoris_, and _Geranium robertianum_. Trampling destroyed the moss and lichen layer resulting in severe erosion particularly where _Festuca_ tussock vegetation was dominant. 100 years is suggested as the time requirement for complete recolonisation of the bare soil. The recommended ewe pressure is 0.35 ewe + lambs/ha. But a dry summer will enhance erosion and stocking levels need to be reduced by 75%. The situation is not as serious on Widdybank Fell although stocking levels are higher. In the permanent transects no species recorded off the track could not also be found on the track. However, direct observation of sheep and dung counts together with data from Coulson (1978) indicate that local pressure in grassland sections can be very high (5 ewes/ha). This is true on the Lowest Track notably in areas

TABLE 17 : SOIL pH MEASURED FROM THE SUMMIT SHEEP TRACK

	Section 1	Section 2	Section 3
T1	6.4	4.0	4.1
T2	6.3	3.9	4.5
T3	6.1	4.2	4.3
T4	5.9	3.7	4.0
T5	5.3	4.0	3.9

Mann-Whitney U test to determine whether there is a significant difference between the pH of soils in Section 1 where weeds grow and Sections 2 and 3 without weeds:

U = 0 Significant at 0.001 probability level (1-tailed test)

TABLE 18 : SOIL MOISTURE % MEASURED FROM THE SUMMIT SHEEP TRACK

	Section 1	Section 2	Section 3
T1	21	26	24
T2	23	20	19
T3	34	25	28
T4	35	27	26
T5	28	22	26

Mann-Whitney U test to determine whether there is a significant difference between the moisture % of soils in Section 1 where weeds grow and Sections 2 and 3 without weeds:

U = 15 Not significant at 0.05 probability level.

TABLE 19 : SOIL ORGANIC % MEASURED FROM THE SUMMIT SHEEP TRACK

	Section 1	Section 2	Section 3
T1	18	27	28
T2	15	23	26
T3	22	34	26
T4	38	22	22
T5	23	23	25

Mann-Whitney U test to determine whether there is a significant difference in the % organic matter of soils in Section 1 where weeds grow and Sections 2 and 3 without weeds:

U = 30 Not significant at 0.05 probability level.

TABLE 20 : SOIL DENSITY (g/cm^3) measured from the SUMMIT SHEEP TRACK

	Section 1	Section 2	Section 3
T1	0.30	0.19	0.22
T2	0.26	0.18	0.19
T3	0.27	0.18	0.17
T4	0.19	0.20	0.19
T5	0.27	0.18	0.19

Mann-Whitney U test to determine whether there is a significant difference in the density of soils in Section 1 where weeds grow and Sections 2 and 3 without weeds:

U = 2 Significant at 0.01 probability level (1-tailed test)

TABLE 21 : SOIL FIELD CAPACITY (cm^3 of water/100 cm^3 of soil) MEASURED FROM THE SUMMIT SHEEP TRACK.

	Section 1	Section 2	Section 3
T1	5.9	11.1	10.1
T2	4.4	9.3	4.3
T3	9.6	9.7	5.3
T4	3.2	5.5	5.1
T5	3.5	6.4	7.0

Mann-Whitney U test to determine whether there is a significant difference in the field capacity of soils in Section 1 where weeds grow and in Sections 2 and 3 without weeds:

U = 12 Not significant at 0.05 probability level.

TABLE 22 : SOIL PHOSPHATE CONTENT (mg/g dry wt. of soil) MEASURED FROM THE SUMMIT SHEEP TRACK.

	Section 1	Section 2	Section 3
T1	.027	.011	.013
T2	.040	.044	.014
T3	.063	.036	.020
T4	.125	.041	.020
T5	.028	.025	.015

Mann-Whitney U test to determine whether there is a significant difference in the phosphate content of soils in Section 1 where weeds grow and in Sections 2 and 3 without weeds.

U = 8 Significant at 0.05 probability level.

TABLE 23 : SOIL DEPTH (cm) MEASURED FROM THE SUMMIT SHEEP TRACK

	Section 1	Section 2	Section 3
T1	11	8	15
T2	8	13	20
T3	5	15	22
T4	3	15	10
T5	6	10	12

Mann-Whitney U test to determine whether there is a significant difference in soil depth in Section 1 where weeds grow and in Sections 2 and 3 without weeds.

U = 3   Significant at 0.01 probability level (1-tailed test)

of rare plants near Nameless Sike. Weeds are not a great threat here but direct erosion and grazing is a very real danger to the rare plants. These species are very susceptible to damage by grazing. For instance, a 5 year survey of gentians at Moor House, N. Pennines, showed that flowering and fruiting are inhibited by sheep grazing. Therefore reproduction is limited (Rawes 1964).

Soil samples taken from on and off the Lowest Track in areas of rare plants were analysed as above (Tables 24 to 30). They showed no significant differences in edaphic characteristics. The fact that track soils are not greatly modified by the sheep helps to explain the lack of weeds even on the path. Furthermore the soil conditions are significantly different from the grassland areas of the Top Track where Bellis perennis grows. This enforces the view that the soil imposes limitations on weed distributions. The Lowest Track receives less use than the Top Track - it has a low dung count. As a result the sheep have caused no major changes in soil conditions along the path. Indeed they are a vital element in maintaining the ecosystem. Sheep grazing keeps productivity and competition at a low level thus enabling a high species diversity to persist. Bellamy (1969) suggests that sheep rather than climate may be the fundamental factor behind the existence of the rare plant communities. They have caused the contemporary stablisation of boundary complexes thus creating a unique vegetation. However, a study by Shur-Bagdasaryan (1974) in the steppe zone of Armeria shows that the reproductive capacity of plants varies with the degree of overgrazing. As pressure increases seed yield and number of shoots of perennial plants decreases. Seed reproduction then occurs mainly in annual weeds which dominate the habitat. There is obviously a fine balance on Widdybank Fell between necessary grazing and damage by overgrazing.

Although the Lowest Track has not received much use by sheep it has been worn sufficiently to possess a large percentage of bare ground. Compared with the other three tracks there is a large amount of bare ground in proportion to the number of weeds which have colonised. Even low stocking intensities can threaten the vegetation in such sensitive areas on the sugar limestone (Plate 10). However, weeds are not the problem despite the presence of sites available for colonisation and of weeds nearby. The main limit to weed migration onto the Lowest Track and then to the land either side would appear to be unfavourable soil conditions. Organic matter, moisture content and phosphate content are very low and the pH values are the highest recorded in the entire study area. Welch and Rawes (1969) compared the moisture content of the

TABLE 24 : SOIL pH VALUES MEASURED FROM THE LOWEST SHEEP TRACK

	Q_0	Q_{1W}	Q_{1E}
Site 1			
T1	7.3	7.3	7.3
T2	7.5	7.2	7.5
T3	7.5	7.5	7.5
T4	7.0	7.7	7.3
T5	6.6	7.3	7.0
Site 2			
T1	7.2	7.4	7.4
T2	7.3	7.5	7.3
T3	7.6	7.5	7.5
T4	7.6	7.6	7.5
T5	6.7	6.8	6.8

Mann-Whitney U test to determine whether there is a significant difference between the pH on and off the Lowest Track in areas where rare plants grow:

U = 99 Not significant at 0.05 probability level

X^2 test to determine whether there is a significant difference between the pH of soil samples on the Lowest Track and on grassland sections of the Top Track where <u>Bellis perennis</u> grows:

X^2 = 13.07 Significant at 0.001 probability level.

TABLE 25 : SOIL MOISTURE % MEASURED FROM THE LOWEST SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{1E}
T1	40	13	18
T2	19	30	41
T3	26	16	22
T4	28	16	37
T5	20	33	27
Site 2			
T1	16	9	20
T2	20	27	19
T3	10	21	7
T4	21	9	22
T5	35	35	31

Mann-Whitney U test to determine whether there is a significant difference between the moisture % of soils on and off the Lowest Track in areas where rare plants grow:

U = 96 Not significant at 0.05 probability level.

X^2 test to determine whether there is a significant difference between the moisture % of soil samples on the Lowest Track and those on grassland sections of the Top Track where Bellis perennis grows:

X^2 = 5.47 Significant at 0.05 probability level

TABLE 26 : SOIL ORGANIC % MEASURED FROM THE LOWEST SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{1E}
T1	12	11	18
T2	11	12	11
T3	10	15	13
T4	24	8	15
T5	20	19	21
Site 2			
T1	20	7	17
T2	23	16	24
T3	12	18	4
T4	15	6	14
T5	24	23	27

Mann-Whitney U test to determine whether there is a significant difference in the organic % of soils on and off the Lowest Track in areas where rare plants grow:

U = 77 Not significant at 0.05 probability level.

X^2 test to determine whether there is a significant difference between organic % of soil samples on the Lowest Track and those on the grassland sections of the Top Track where <u>Bellis perennis</u> grows:

X^2 = 7.43 Significant at 0.01 probability level.

TABLE 27 : SOIL DENSITY (g/cm^3) MEASURED FROM THE LOWEST SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{1E}
T1	0.31	0.35	0.28
T2	0.34	0.29	0.35
T3	0.31	0.26	0.31
T4	0.29	0.35	0.28
T5	0.29	0.28	0.26
Site 2			
T1	0.24	0.32	0.23
T2	0.34	0.26	0.24
T3	0.36	0.18	0.36
T4	0.22	0.28	0.33
T5	0.25	0.25	0.26

Mann-Whitney U test to determine whether there is a significant difference in the density (compaction) of soils on and off the Lowest Track in areas where rare plants grow:
U = 86 Not significant at 0.05 probability level.

X^2 test to determine whether there is a significant difference in the density (compaction) of soil samples on the Lowest Track and those on the grassland sections of the Top Track where Bellis perennis grows:
X^2 = 3.80 Not significant at 0.05 probability level.

TABLE 28 : SOIL FIELD CAPACITY (cm^3 of water/100cm^3 of soil) MEASURED FROM THE LOWEST SHEEP TRACK

	Q_0	Q_{1W}	Q_{1E}
Site 1			
T1	8.0	7.5	5.2
T2	11.3	11.0	10.8
T3	8.8	8.5	9.6
T4	16.8	8.0	9.4
T5	7.1	13.1	8.7
Site 2			
T1	9.1	8.6	6.3
T2	10.0	9.7	9.5
T3	14.5	6.7	8.1
T4	7.9	7.6	8.7
T5	8.5	10.1	13.5

Mann-Whitney U test to determine whether there is a significant difference between the field capacity of soils on and off the Lowest Track in areas where rare plants grow:
U = 82 Not significant at 0.05 probability level

X^2 test to determine whether there is a significant difference in the field capacity of soils on the Lowest Track and those on the grassland sections of the Top Track where _Bellis perennis_ grows:
$X^2 = 1.82$ Not significant at 0.05 probability level.

TABLE 29 : SOIL PHOSPHATE CONTENT (mg/g dry wt. of soil) MEASURED FROM THE LOWEST SHEEP TRACK

Site 1	Q_0	Q_{1W}	Q_{1E}
T1	.009	.006	.013
T2	.015	.010	.017
T3	.005	.005	.016
T4	.011	.009	.005
T5	.007	.010	.011
Site 2			
T1	.001	.001	.006
T2	.004	.004	.003
T3	.004	.004	.009
T4	.003	.002	.004
T5	.006	.010	.004

Mann-Whitney U test to determine whether there is a significant difference between the phosphate content of soils on and off the Lowest Track in areas where rare plants grow:

U = 97   Not significant at 0.05 probability level.

X^2 test to determine whether there is a significant difference in the phosphate content of soils on the Lowest Sheep Track and those on the grassland sections of the Top Track where Bellis perennis grows:

$X^2 = 6.30$ Significant at 0.05 probability level.

TABLE 30 : SOIL DEPTH (cm) MEASURED FROM THE LOWEST SHEEP TRACK

Site 1	Q_0	Q_1W	Q_1E
T1	9	13	16
T2	9	9	8
T3	15	18	15
T4	6	10	9
T5	14	17	17
Site 2			
T1	2	10	3
T2	4	4	10
T3	6	7	7
T4	11	14	14
T5	10	15	5

Mann-Whitney U test to determine whether there is a significant difference between the depth of soils on and off the Lowest Track in areas where rare plants grow:

U = 61   Significant at 0.05 probability level (1-tailed test)

X^2 test to determine whether there is a significant difference in the depth of soils on the Lowest Track and those on grassland sections of the Top Track where *Bellis perennis* grows:

$X^2 = 5.26$ Significant at 0.05 probability level.

Plate 10 : Hollow eroded by sheep in an area of Sugar Limestone near the Lowest Sheep Track

sugar limestone soils in areas with and without rare plants. The former have values below 20% which restricts the species diversity and enables rare species to survive relatively free from competition. The lack of moisture produces moisture tensions in most plants including weedy species which are greater than the permanent wilting point during summer. The lack of vegetation can in turn account for the low humus content and high pH of the soils which also discourages weed growth. However, where moisture concentrates in hollows just above Red Sike a great variety of weed species have colonised.

Soil samples were not taken from the sides of the Birkdale Track in an effort to keep damage to a minimum especially where people walk. However, the correlation between Bellis perennis in grassland areas and Poa annua on heathland sections found along the sheep tracks is again recorded. This suggests that soil may once more be the common factor linking these variables. Furthermore the peak of Bellis perennis 1-2m from the road in section 1 conforms to the pattern found by Streeter (1970) on chalk downland at Box Hill, Surrey. He tested the nutrient content of the soil at varying distances from the path. Levels on and immediately either side were very low but there were peak concentrations, especially of nitrogen, a short distance away. He argues that the natural vegetation is adapted to the general nutrient poor conditions. Plants have low growth rates and inter-species competition is at a low level so that there is a high species diversity. However, where there is trampling and addition of nutrients species with a high rate of production and reproduction are at an advantage, e.g. Taraxacum officinale and Plantago major. On the path itself pressure is extreme resulting in erosion and loss of nutrients. Here even weed species find it difficult to survive. This pattern probably also exists along the Birkdale Track where human pressure is intense. People tend to walk along the roadside rather than on the track itself. This was particularly true before the road was tarred in 1970 and was composed of coarse gravel.

On the Birkdale Track Sagina procumbens is more abundant in heathland than grassland areas in contrast to its location on the sheep tracks. This confirms the idea that the distribution of this weed and also the other minor species are not so stringently controlled by soil conditions. The ground on either side of the Birkdale Track is well trampled but fertilisation either by sheep or litter deposition does not appear to be important. Therefore soil conditions may fail to provide an explanation for the extent of weed migration as well. In this case, it is suggested that disturbance of the ground may limit weed distributions. There is a significant decline in the percentage bare ground away from the road. It is suggested that a complete vegetation mat inhibits the establishment and survival of weed species. An exception to this idea are the very calcareous sites near the Meteorological Station. Here a section of turf 6 ft. x 3 ft. was removed in 1962. The patch is now well colonised by limestone species but no weeds have taken advantage of this area of bare ground. Barriers to migration are once again rejected as an explanation for the extent of weed colonisation. Vegetative spread alone should allow the weed verge to be widened if the physical conditions are favourable.

The effect of human disturbance is also shown by the track through to Borehole 44 from the Birkdale Track. The percentage bare ground at either end is not very high now but must have been severely eroded in 1966. Weeds are abundant in these areas. However, in the central section where the path divides disturbance was much less severe and weeds are almost completely absent. Furthermore they have not spread into this area from either end.

CHAPTER 4 — CONCLUSIONS

There are a large number of weeds on Widdybank Fell. However, the problem is less serious than their abundance would suggest. The weeds are not limited in their distribution by their inability to disperse. The main control seems to be the physical characteristics of the area, notably soil conditions. The species studied find it extremely difficult to grow in the Sugar Limestone soils which support many of the rare plant communities. This is particularly true of Poa annua which is a recent coloniser on the fells. It is very unlikely that weeds and rare plants will come into competition with one another. However, other communities particularly in the heathland sections may be in danger if the weeds continue to increase in abundance.

A more serious problem at the moment seems to be the damage caused by trampling and erosion of the ground. This situation requires further investigation. However, this initial study shows that the sheep have created areas of bare ground along the track through the Sugar Limestone. Together with grazing, erosion may threaten the populations of species which are not very abundant. Sheep may cause further alteration of rare plant communities by fertilising the ground and thus altering soil conditions. This does not seem to have occured at the moment and may not become a problem if stocking densities remain constant. However, an increase in sheep pressure would certainly be a very serious threat to the vegetation. The Sugar Limestone grasslands are one area which has very good grazing and the sheep tend to congregate here in large numbers. The tracks are not very well defined because the sheep wander about where the ground is open. Nevertheless the overall damage to these areas is greater than in the heathland sections.

On the Birkdale Track weeds are more abundant than along the sheep tracks. Furthermore they are increasing both in numbers and in species variety. Most of the ground by the road does not contain important rare plant communities. However, there is a small area just south of Slapestone Sike where Moonwort is abundant and a stretch by the Meteorological Station in which Gentians are very common. Both an increase in weeds and in the % bare ground must be stopped if these communities are to be preserved. It is ironical that the people who come to see these plants are also destroying them by disturbing the ground. Viola riviniana is already absent from most sections of the verge. Furthermore an increase of weeds along the Birkdale Track may eventually introduce species which will be capable of growing in the same habitats as the rate plants.

It is important to act now while the situation can still be saved. This will involve work both on the part of the local farmers and the Nature Conservancy.

APPENDIX A

Statistical tests on the distribution of weeds:

Only non-parametric tests were used because the assumptions involved in using parametric tests were not valid. The distribution of weeds was studied statistically by calculating the chi-squared statistic.

Procedure for X^2 test:

Formulate H_0 and H_1. Decide upon the rejection level.

Tabulate the observed frequencies (O) and calculate the expected frequencies (E).

Calculate $X^2 = \frac{(O - E)^2}{E}$

Obtain the significance of the result from a X^2 probability table.

H_0 is the null hypothesis that there is no significant difference between the distribution of weed species.

H_1 is the alternative hypothesis that there is a significant difference between the distribution of weed species.

In all cases the rejection level is $\alpha = 0.05$.

Degrees of freedom = (r - 1) (k - 1) where r is number of rows and k is number of columns.

X^2 test to determine whether there is a significant difference in the abundance of weeds along the 4 sheep tracks:

<u>*Poa annua*</u>: $X^2 = 51.02$ (df = 12)
Significant at 0.001 probability level
% cover - Top > Summit > Middle > Lowest Tracks

<u>*Bellis perennis*</u>: $X^2 = 14.53$ (df = 6)
Significant at 0.05 probability level
% cover - Top > Middle > Summit > Lowest Tracks

<u>*Ranunculus repens*</u>: $X^2 = 16.61$ (df = 3)
Significant at 0.001 probability level
Presence - Summit and Lowest > Top and Middle Tracks

<u>*Sagina procumbens*</u>: $X^2 = 6.47$ (df = 3)
Not significant at 0.05 probability level

<u>*Cerastium holosteoides*</u>: $X^2 = 9.25$ (df = 3)
Significant at 0.05 probability level.
Presence - Summit > Top and Middle > Lowest Tracks

<u>*Taraxacum officinale*</u>: $X^2 = 14.89$ (df = 3)
Significant at 0.01 probability level.
Presence - Top > Middle and Summit > Lowest Tracks

X^2 test to determine whether there is a significant difference in the abundance of weeds between grassland and heathland sections of the 4 sheep tracks:

<u>*Poa annua*:</u> $X^2 = 88.48$ (df = 1)
Significant at 0.001 probability level
Presence - Heathland > Grassland

<u>*Bellis perennis*:</u> $X^2 = 58.66$ (df = 1)
Significant at 0.001 probability level.
Presence - Grassland > Heathland

<u>*Ranunculus repens*:</u> $X^2 = 21.99$ (df = 1)
Significant at 0.001 probability level
Presence - Grassland > Heathland

<u>*Sagina procumbens*:</u> $X^2 = 8.91$ (df = 1)
Significant at 0.01 probability level
Presence - Grassland > Heathland

<u>*Cerastium holosteoides*:</u> $X^2 = 0.54$ (df = 1)
Not significant at 0.05 probability level.

<u>*Taraxacum officinale*:</u> $X^2 = 3.16$ (df = 1)
Not significant at 0.05 probability level.

X^2 test to determine whether the presence of <u>*Poa annua*</u> and <u>*Calluna vulgaris*</u> are negatively associated:

$X^2 = 4.01$ (df = 1)
Significant at 0.05 probability level.

X^2 test to determine whether there is a significant decline in the abundance of weeds along the Lowest Sheep Track away from the Birkdale Track:

<u>Poa annua:</u> $X^2 = 1.28$ (df = 3)
Not significant at 0.05 probability test.

<u>Bellis Perennis:</u> $X^2 = 6.00$ (df = 3)
Not significant at 0.05 probability level.

X^2 test to determine whether there is a significant decline in the abundance of weeds along the Middle Sheep Track away from the Birkdale Track:

<u>Poa annua:</u> $X^2 = 1.65$ (df = 2)
Not significant at 0.05 probability level.

<u>Bellis perennis:</u> $X^2 = 1.42$ (df = 3)
Not significant at 0.05 probability level.

X^2 test to determine whether there is a significant decline in the abundance of weeds along the Top Sheep Track away from the Birkdale Track:

<u>Poa annua:</u> $X^2 = 14.10$ (df = 9)
Not significant at 0.05 probability level.

<u>Bellis perennis:</u> $X^2 = 4.01$ (df = 4)
Not significant at 0.05 probability level.

<u>Ranunculus repens:</u> $X^2 = 7.36$ (df = 1)
Significant at 0.01 probability level

<u>Sagina procumbens:</u> $X^2 = 16.6$ (df = 2)
Significant at 0.01 probability level

<u>Cerastium holosteoides:</u> $X^2 = 4.46$ (df = 1)
Significant at 0.05 probability level.

<u>Taraxacum officinale:</u> $X^2 = 8.94$ (df = 3)
Significant at 0.05 probability level
Increases in abundance away from the Birkdale Track

X^2 test to determine whether there is a significant decline in the abundance of weeds along the Summit Sheep Track away from the Birkdale Track:

<u>Poa annua:</u> $X^2 = 1.62$ (df = 3)
Not significant at 0.05 probability level

<u>Bellis perennis:</u> $X^2 = 0.40$ (df = 1)
Not significant at 0.05 probability level

X^2 test to determine whether there is a significant decline in the abundance of weeds away from the open section of the Summit Sheep Track:

<u>Poa annua</u>: Upper path towards north $X^2 = 9.49$ (df = 4)
Significant at 0.05 probability level
Lower path towards north $X^2 = 10.63$ (df = 3)
Significant at 0.05 probability level
Upper path towards south $X^2 = 12.26$ (df =2)
Significant at 0.01 probability level
Middle path towards south $X^2 = 12.26$ (df = 2)
Significant at 0.01 probability level
Lower path towards south $X^2 = 3.86$ (df = 1)
Significant at 0.05 probability level

<u>Bellis perennis</u>: Upper path towards north $X^2 = 10.48$ (df = 3)
Significant at 0.05 probability level
Lower path towards north $X^2 = 11.17$ (df = 3)
Significant at 0.05 probability level.
Upper path towards south $X^2 = 4.00$ (df = 1)
Significant at 0.05 probability level
Middle path towards south $X^2 = 9.30$ (df = 1)
Significant at 0.01 probability level

X^2 test to determine whether there is a significant difference in the abundance of weeds along the old and new sections of the Birkdale Track:

<u>Poa annua</u>:	$X^2 = 2.57$ (df = 2) Not significant at 0.05 probability level
<u>Ranunculus repens</u>:	$X^2 = 12.60$ (df = 1) Significant at 0.001 probability level More abundant along the old section of track
<u>Sagina procumbens</u>:	$X^2 = 1.40$ (df = 1) Not sigificant at 0.05 probability level
<u>Cerastium helosteoides</u>:	$X^2 = 2.38$ (df = 1) Not significant at 0.05 probability level

X^2 test to determine whether there is a significant difference in the abundance of weeds on the 3 sections of the Birkdale Track

$X^2 = 7.98$ (df = 2)

Significant at 0.05 probability level

% cover - Section 1 > Section 3 > Section 2

X^2 test to determine whether there is a significant difference in the spread of weeds from the 3 sections of the Birkdale Track

$X^2 = 13.40$ (df = 2)

Significant at 0.01 probability level

Migration - Section 1 > Section 3 > Section 2

X^2 test to determine whether there is a significant difference in the spread of weeds on the west and east sides of the Birkdale Track (Section 1)

$X^2 = 3.90$ (df = 1)

Significant at 0.05 probability level

X^2 test to determine whether the concentration of <u>Bellis perennis</u> is significantly greater 1m away from the Birkdale Track compared with the immediate roadside (Section 1)

$X^2 = 6.00$ (df = 2)

Significant at 0.05 probability level

APPENDIX B

Statistical tests associated with the migration of weeds

The chi-squared statistic is used to test the significance of the variables. (The method is described in Appendix A).

X^2 test to determine whether there is a significant difference in the amount of dung between grassland and heathland sections of the 4 Sheep Tracks:

Lowest Track: $X^2 = 9.31$ (df = 1)
Significant at 0.01 probability level
Grassland > Heathland

Middle Track: $X^2 = 0.31$ (df = 1)
Not significant at 0.05 probability level

Top Track: $X^2 = 1.23$ (df = 1)
Not significant at 0.05 probability level

Summit Track: $X^2 = 3.67$ (df = 1)
Not significant at 0.05 probability level

X^2 test to determine whether there is a significant difference in the amount of dung on the 4 Sheep Tracks:

$X^2 = 23.99$ (df = 3)
Significant at 0.001 probability level
Dung count - Top and Summit > Middle and Lowest Tracks

X^2 test to determine whether there is a significant difference in the number of sheep between grassland and heathland sections of the 4 Sheep Tracks:

$X^2 = 1.39$ (df = 1)

Not significant at 0.05 probability level.

X^2 test to determine whether there is a significant difference in the number of sheep observed on the 4 Sheep Tracks:

$X^2 = 49.72$ (df = 3) Significant at 0.001 probability level.

Number of sheep - Top and ~~Summit~~ Middle > ~~Middle~~ Summit and Lowest Tracks.

X^2 test to determine whether there is a significant difference in the number of sheep moving north and south along the 4 Sheep Tracks:

$X^2 = 0.07$ (df = 1)

Not significant at 0.05 probability level

X^2 test to determine whether there is a significant difference in the % bare ground on the 4 Sheep Tracks:

$X^2 = 66.87$ (df = 12)

Significant at 0.001 probability level

% bare ground - Top > Middle > Lowest > Summit Tracks

X^2 test to determine whether there is a significant decline in the % bare ground away from the Top Sheep Track:

$X^2 = 56.51$ (df = 6)

Significant at 0.001 probability level

X^2 test to determine whether there is a significant decline in the % bare ground away from the Birkdale Track.

$X^2 = 213.60$ (df = 24)

Significant at 0.001 probability level.

APPENDIX C

Statistical tests on the soil data:

Once again non-parametric tests were used. These were the chi-squared test (see Appendix A for method) and the Mann-Whitney U test.

Procedure for Mann-Whitney U-test:

For sample size $n_1 \leqslant 20$ and $9 \leqslant n_2 \leqslant 20$

Formulate H_0 and H_1. Decide upon the rejection level.

Place all the values in a single rank order, retaining the group identity of each. Let one group be termed A and the other group B.

Allot ranks to each of the values

Sum the ranks of group A

Calculate $U = n_1 n_2 + \frac{1}{2}n_1 (n_1 + 1) - R_1$ (where n_1 is the number in group A; n_2 the number in group B and R_1 the sum of the ranks given to values in n_1)

Determine the significance of the result from a Mann-Whitney U probability table.

H_0 is the null hypothesis that there is no significant difference between the soil samples.

H_1 is the alternative hypothesis that there is a significant difference between the soil samples.

In all cases the rejection level is $\alpha = 0.05$

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