A study of the earthworm populations of young mineral soils, with particular reference to colliery spoil

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A STUDY OF THE EARTHWORM POPULATIONS OF YOUNG MINERAL SOILS, WITH PARTICULAR REFERENCE TO COLLIERY SPOIL.

by

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being

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1. INTRODUCTION

Durham is rich in sites of mineral extraction which, after working was finished, were left derelict and have subsequently become totally or partly revegetated. These sites are of two basic kinds : those in which surface extraction has left local superficial strata exposed and those in which an assortment of subterranean strata are dumped as spoil heaps. Artificial substrata such as brick rubble and ash are often associated with such sites. The opportunity was taken to look at the development of invertebrate faunas on these very young mineral soils. In order to bring the project within reasonable limits two decisions were taken. Firstly, attention was concentrated on the earthworm populations. It was felt that problems of identification would otherwise be acute and that the earthworms are probably the most significant group in relation to the development of soil structure and fertility (Guild, 1955 ; Kubiena, 1955). Secondly, from all the wide range of sites available (sand and clay pits; magnesium limestone and sandstone quarries; gravel workings; colliery spoil; lead and copper mining spoil) it was decided to concentrate on colliery spoil with sand and clay pit sites and one or two artificial substrates for comparison. Copper and lead mining spoil was excluded because of its toxicity; gravel workings because of the high water table making this type of site quite distinct from the others; magnesium limestone and sandstone quarries because of the very shallow soils. Moreover, colliery spoil has the additional advantage that there is usually good vehicular access to the site and ownership is in the hands of a small number of organisations, of which Durham County Council and the National Coal Board are the biggest, making the negotiation of rights of access relatively straightforward.

Since many of these sites are being or have been reclaimed or restored some consideration of the results and implications of reclamation techniques and subsequent management is also included.

11 METHODS

i. Site selection

When selecting sites four problems had to be borne in mind:

a. The need for a range representing different substrata, stages of succession or management operations.

b. The need to gain access.

c. The further need for vehicular access to transport water and equipment to the sampling area.

d. The need to keep travelling costs down to a reasonable level.

e. The need for level areas for sampling.

Preliminary searches for sites on foot in the immediate vicinity of Durham revealed Flass Vale (V) and Durham Brickworks (X), sand and clay sites respectively, which were chosen as representative of immature 'natural' mineral soils. A number of small spoil heap sites were also located but only the Shincliffe (111) and Houghall (V1) sites were subsequently used.

The most productive approaches were by letter to the N.C.B. H.Q. in Team Valley and to the County Land Agent and Valuer, Durham County Council. Both were very helpful and suggested the sites on which the bulk of this dissertation is based.

A number of sites were very diverse (particularly Watergate 2) and were therefore subdivided. The principal characteristics of each site and its subsites are tabulated in tables 1. and 11.

ii. Design of Sample

a. Number of sample units. Phillipson et. al. (1976), in their beechwood study used twenty two replicates or sample units, each 25 cm. x 25 cm. Miles (unpublished) used three sample units of 1 $m.^2$.

Table 1.

Site data.

Grid ref:	Site No.	Owner or agent	Substratum	No. of subsites	Name	Date of start of colonisation
319507	1	N.C.B.	Shale	1	Lady Anne.	1900 Abandoned
226061	11	N.C.B.	Shale.	4	Watergate 2	1964 Abandoned
			Shale and dumped Materials.	3		
299404	111	Dean and Chapter	Ash and shale.	2	Shincliffe	c.1920 Abandoned
			Brick rubble.	1		
254597	1V	N.C.B.	Shale.	2	Waldridge Fell	1963 Abandoned
264428	V	Durham City Council	Sand.	1	Flass Vale	1975 Restored
282407	V1	Durham County Council	Shale.	1	Houghall	c1935 Restored
143531	V11	N.C.B.	Shale with brick rubble.	2	South Medomsley	c1969 Restored
			shale with soil	1		1973-4 Restored
297375	V111	Durham County Council	Shale.	1	Bowburn	1973 Restored
			soil on shale.	1	"	"
160365	1X	Durham County Council	Colliery tailings.	2	Roddymoor	1969 Restored
			Shale	1	"	"
277437	X	J.G. Usher and son.	Clay	1	Durham Brickworks	c1950 Abandoned
			Total Subsites	24		

Note; All grid references are quoted from the Ordnance Survey 1 : 50,000 maps nos. 88 and 93.

Table 11

Subsite details

Type of site	Type of vegetation	Site no.	Subsite no.	Mode of Restoration	Approx age (yrs).	Sampling date
Sand quarry	Grass/herb with young trees	V	1	Sown & planted	3	7/8
Clay quarry	Grass/herb	X	1	nil	28	11/5
Naturally revegetating	Grass/herb	1	1	nil	78	8/6
shale	Betula scrub	11	1	nil	14	9/6 and 10/3
	Developing Betula scrub	11	2	nil	14	9/6
	Betula on grass heath	11	3	nil	14	9/6
	Mixed woodland	11	6	nil	14	23/6
	Ulex thicket	1V	1	nil	15	22/6
	Betula on Calluna heath	1V	2	nil	15	23/6
Naturally revegetating	Betula scrub	111	1	nil	58	18/6
ash and shale	Calluna heath	111	2	nil	58	19/6
Naturally revegetating brick rubble	Grass/herb	111	3	Demolition and levelling only	58	19/5 and 19/6
Naturally revegetating	Grass/herb	11	4	nil	14	15/6
soil or rubble dumped	Grass/herb	11	5	nil	14	21/6
on shale	Grass/herb	11	7	nil	14	10/8
Planted brick rubble	Grass/herb with developing	V11	1	Levelled	9	10/8
on shale	scrub. Planted pines	V11	2	Levelled	9	13/8
Planted, soiled shale	Developing grass/herb. Planted pines	V11	3	Levelled soiled and ridged	4	13/8
Planted colliery tailings	Grass/herb. Planted mixed woodland	1X	1	Levelled and drained	9	13/8
Planted shale	Sown Festuca/Trifolium sward. Planted mixed woodland	V111	1	Levelled, drained and fertilised	5	11/8
	Planted pines in mixed woodland	V1	1	Nil	43	7/8
Grass sward on colliery tailings	Agricultural grassland	1X	2	Levelled, drained and fertilised	9	13/8
Grass sward on shale	Agricultural grassland	1X	3	Levelled, drained and fertilised	9	13/8
Grass sward. Soil on shale	Agricultural grassland	V111	2	Levelled, drained, soiled & fertilised	5	11/8

Nordstrom and Rundgren (1974) used thirty two and twelve sample units of 0 • 5 m.^{2}. Satchell (1970) reports that to secure a 5% sampling error of the mean thirty two 0 • 5 m.^{2} sample units were required at Merlewood and one hundred and three 1 ft.^{2} sample units at Rothamstead. Allen (1974) recommends a minimum of five to ten replicates.

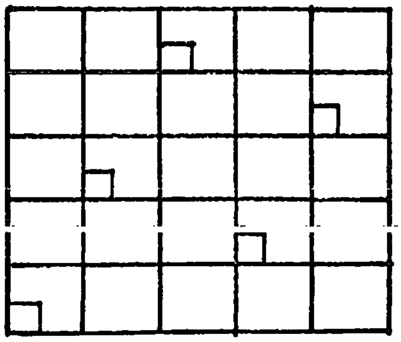
Complete sampling of a subsite, taking five sample units and using earthworm sampling techniques described below requires forty litres of water which can just be carried over about fifty yeards by hand. The smaller number (five) of sample units was therefore chosen.

b. Size of sample unit. Philipson et. al. (1976), and others have used a 25 cm. x 25 cm. sample, partly because of the difficulties of hand sorting anything larger. Miles (unpublished) used 1 m.^{2} sample units but this raised, for me, acute problems of water transport. Finally a 0 • 2 m^2. sample was chosen as handsorting was not envisaged. The total sample size in any subsite therefore becomes 1 m.^{2}, which makes comparison with other workers' results easy.

c. Sampling procedure. Allen (1974) suggests that two viable approaches to sampling a particular area can be employed: the use of random numbers in relation to a fixed co-ordinate grid reference drawn up for the site, and sampling at regular intervals along a similar grid network. No statistical analysis requiring random sampling was envisaged so that regular sampling was favoured. Subsite characteristics varied greatly, however, for example:

1. Subsite 11 1. An even, closed canopy of young birch scrub on level ground.
2. Subsite 11 2. An open-canopy birch scrub.
3. Subsite 11 3. Small islands of vegetation c. 5' in diameter.
4. Subsite 1 1. An undulating, elevated surface on which the 'humps' could not be sampled due to surface run-off of formalin.

Allen (1974) accepts that in an exploratory study of this kind subjective decisions on where to collect samples are sometimes valid. In this study a balance of subjective and more statistically derived sampling procedures was therefore adopted. For example, in subsite 11 1. a baseline five paces long was established and the five sample units positioned, again by pacing, in the pattern shown. When a tree trunk or a large lump of shale intervened the sample unit was placed just to one side.



Similarly, in subsite 1 1., sample units were placed in those hollows nearest to selected points on the above kind of grid.

iii. Earthworm sampling techniques.

Earthworms play a vital role in soil ecology and their study has always promised to be most productive of new insights. However, severe problems exist of efficient and consistant sampling of these animals. Many techniques have been used: chemical methods using potassium permanganate or formaldehyde solution, carried out in situ; handsorting, washing and flotation methods carried out on soil cores or samples of various sizes. Heat extraction and electrical processes have also been employed.

Raw (1959) looked at the permanganate, formalin and hand-sorting methods. He found permanganate ineffective; the deep-burrowing species were most effectively sampled by the formalin method; surface species, living in the root mat or litter, were best estimated by hand sorting. Raw again (1960) compared a hand-sorting with a washing technique.

He found that in a soil with a dense turf only half (by numbers) of the worms were found by hand-sorting. It was, however, the smaller worms which were missed so that the error was much less marked when wet worm biomass was determined. Soils without much turf were effectively sampled by hand sorting. Satchell (1970) also reviewed techniques available. Some of the newer techniques, e.g. by heat extraction, have specialist uses, such as for sampling litter, but are not generally applicable.

Recent workers have tended to develop combinations of techniques suiting the particular habitat in which they are working. Thus Phillipson et. al. (1976) removed a soil core for hand-sorting, extracted the deeper burrowing forms from the hole using formalin and collected samples of litter for processing by infra-red extractor.

In this study the time requirement for handsorting, up to two hours per sample unit, was a critical factor and the formalin technique was used. Miles (unpublished) used 0·225% and 0·55% solutions, with a fifteen minute interval between applications. Phillipson et. al. (1976) used a 4% solution. I used a 0·25% solution which was within the limits used by the others. It was made up in the field by mixing pre-measured quantities of 50 ml. of 40% formalin with water in an 8 litre watering can. The following procedure was adopted:

a. Surface vegetation and litter were removed to aid formalin penetration. This material was transferred to labelled bags.

b. Approximately 2·7 litres of dilute formalin were watered on using a rose.

c. A close watch was kept and all worms appearing were transferred to a labelled jar.

d. After 10 minutes, or when all the solution had sunk into the soil, whichever came later, a second similar application was made.

e. After a similar interval a third application was made. This time the lower stems of the vegetation were thoroughly explored using the fingers.

f. The position of any worms withdrawing was noted and these were collected by means of a spade.

Note Where soils were waterlogged or penetration limited, the full 8 litres was not applied.

Where litter accumulation was large this was later hand-sorted.

In addition four selected sample units were hand-sorted as a check on the formalin technique. The technique used involved removing a sample 43 cm. x 43 cm. x 15 cm. and removing it to the laboratory in two plastic sacks for sorting.

The top 5 cm. was sorted first. The roots were carefully teased apart with the fingers so that the fine material sprinkled down onto an enamel tray. Specimens were located by touch, since the soft bodies were easily recogniseable, and by sight : a close watch was kept on the surface of the accumulating material in the tray. Anything which wriggled, failed to bounce, fell more slowly or was dissimilar in any way from a soil crumb or small stone were closely examined. Worms were placed immediately into a labelled jar of 10% formalin. The remainder of the sample was then similarly treated.

Where the sample to be hand-sorted was wet and waterlogged a somewhat different technique had to be used. The soil was broken apart into particles 1·5 cm. in diameter or less. The soil mass tended to fragment along a burrow, through an aestivation chamber or along a decaying root thus exposing burrowing worms. The plant roots, rhizomes and stolons were also teased apart to locate surface-living forms.

iv. Data collection

a. The earthworms All specimens disturbed by the formalin solution were carefully searched for and collected. Those from each sample unit were collected separately. Initially it was intended to keep the specimens alive in damp moss for about twenty four hours to empty the gut and to ensure accurate biomass determinations. This resulted in some deaths and it was found preferable to kill and preserve the worms in 10% formalin as they were caught. Subsequently the worms were identified. Some difficulty was experienced in efficiently distinguishing between immatures of _L. castaneus_ and _L. rubellus_ which were therefore lumped together when counting. Small, very immature specimens of _L. terrestris, L. festivus,_ and _L. friendi_ (only one mature specimen of this species was found) may have been included in the above group, but their numbers were much smaller and any consequent error was not thought likely to be significant. Similarly, immatures of _A. rosea_ and _A. caliginosa_ were lumped together. After a minimum of five days the preserved worms from each sample unit were dried of superficial moisture and weighed to determine wet biomass.

b. Soil samples for analysis. The time involved in carrying out a full soil analysis programme for every sample unit (over 100 of them) promised to be prohibitive. Tomlinson et. al. (1977) quote 20 days for a full analysis of 100 samples by an expert. To limit the analytical programme to an acceptable length the following sampling procedure was adopted. Two 5 cm. x 6 cm. deep cores were taken immediately adjacent to each sample unit. These topsoil samples were bulked to provide two parallel samples, each with a core from all five sample units.

A similar pair of samples were built up from cores taken from 7 cm. to 14 cm. below the soil surface. Some sites had impenetrable rubble or lumps of shale just below the surface. Only the upper samples could be obtained for these sites.

c. Turf depth. A vertical cut was made in the turf which was then carefully torn free of the underlying subsoil. The thickness of this turf mat was measured with a pair of calipers, care being taken to avoid crushing the turf.

d. Soil temperature. A thermometer was inserted at depths of 5 cm and 10 cm respectively. It was allowed to stabilise each time and the readings recorded. Unfortunately the vagaries of the weather produced very erratic topsoil temperature readings due to periodic intense insolation. These readings were discontinued after the end of June.

e. Vegetation. For each sample unit a list was made of the higher plants found within it. The general type of vegetation of the subsite was also noted. e.g. grass/herb, *Betula* scrub etc (see Table 11).

Bearing in mind the importance of litter as a source of food for earthworms and of the standing vegetation in insulating the ground surface from extremes of heat these two elements of the vegetation were collected separately. First the standing biomass within the sample unit was clipped off at ground level. Then the litter was lightly raked out and the samples were separately bagged and returned to the laboratory for drying and weighing. Normally, for comparative purposes, oven-dry weights are determined. In this case air-dry weights were found and a correction factor determined for conversion to oven-dry weight. (See Appendix 2). Air-dry weight was determined by placing each sample in a shallow tray in the laboratory, leaving for a minimum of five days, turning daily, and then weighing.

The % ground cover was also estimated for each sample unit and for the whole subsite.

f. Other enviromental influences on earthworm numbers.(See Appendix 1)

1. It was assumed that the nature of the substratum would have an effect on earthworm numbers. Eight distinct substratum ("soil") types were distinguished.

Thus:

1. Shale
2. Shale topped by dumped rubble
3. Shale topped by soil
4. Ash
5. Colliery tailings
6. Brick rubble
7. Sand
8. Clay

2. Vegetation tends to develop naturally on tips in three types of situation : close to the natural contours of the surrounding land; at the bottom of slopes; in hollows on the tip surface. This was assumed to reflect the accumulation of moisture at the points and it was further assumed that earthworms were likely to be similarly affected. The "moisture factor" of each subsite was therefore estimated on the following scale:

1. Close to natural contours
2. The bottoms of hollows on a raised tip surface
3. A raised level, or gently undulating surface
4. A hump on a raised tip surface

3. Shade gives protection both from insolation and heat loss and is very important, if difficult to determine precisely. A four point scale was finally divised:

1. Continuous canopy present
2. Interrupted or incomplete canopy
3. Young, well-grown trees but with no close canopy
4. No trees or very young ones only

4. The weather during the period of data collecting showed a very marked pattern (see Appendix 1) Dates of sampling were therefore grouped as below to fit in with the weather pattern:

1.	Prior to		8/6
2.	8/6	to	14/6
3.	15/6	to	20/6
4.	21/6	to	29/6
5.	7/8	to	13/8

5. Not all subsites were homogeneous in terms of environmental variables. To summarise the information about homogeneity/heterogeneity those sites with a reasonable number of earthworms were classified on a four point scale.

1.	Site homogeneous
2.	Site heterogeneous but similar points selected for the sample units giving apparent homogeneity
3.	Site heterogeneous in terms of biotic variables
4.	Site heterogeneous in terms of physical variables

V. Soil analysis procedures.

Allen (1974) and Tomlinson et. al. (1977) were consulted to draw up a suitable soil analysis programme. The techniques used are outlined in table 111 They were kept simple, concentrating on those physical variables which seemed most likely to affect earthworm populations. These were:

a. pH This seemed likely to be critical. Satchell (1955) demonstrated that at a pH of 4·4 earthworms died. This pH is well within the range found on colliery spoil. The amount of exchangeable calcium is also widely believed to be important for earthworms but since Satchell's work suggests that the two variables are impossible to distinguish in their effect only pH was determined.

b. Fresh moisture. Earthworms are vulnerable both to a shortage and an excess of water. It was hoped that the weather during the period of study would avoid extremes so that determinations at any one time would reflect the general characteristics of a site. In fact the weather was extreme and changeable : drought in June and deluge in July and early August. % loss of weight on air drying of the soil samples was used as a measure of available fresh moisture, but the determinations were discontinued in August when the soils were often waterlogged.

c. Organic matter. Since many of the sites have a substratum of colliery spoil difficulties were anticipated. Determination by ignition removes the fossil hydrocarbons in the shale as well as the humus and dead organic material, so leading to inaccuracy. Workers on shale at York University (Chadwick, personal communication) are using a flotation technique to determine organic content and a similar technique was used here.

d. Humus/fossil hydrocarbons. Since earthworms seem to be encountered so infrequently in colliery spoil it seemed possible that fossil hydrocarbons might actually inhibit colonisation by earthworms. The mineral residue after separation of dead organic matter was therefore ignited to determine loss by ignition as a measure of the levels of fossil hydrocarbons. Any completely humified material in the samples was expected to distort the result somewhat.

Table 111

Soil analysis programme

Analyse fresh	Sub-sample 1.	**p.H. determination**
		1. Check meter against two buffer solutions, one on either side of the expected p.H. range.
		2. Half fill 50 ml. beaker with fresh soil and add just sufficient distilled water (approx. 2:1 by volume water : soil) to allow immersion of the electrode.
		3. Stir frequently for a few minutes; allow to stand for further 15 minutes.
		4. Immerse electrode in slurry and wait for needle drift to cease. Record p.H. to 1 decimal place.
	Sub-sample 2.	**Fresh moisture**
		1. Accurately weigh c. 100 gm fresh soil (W_1) and transfer to a shallow drying tray.
		2. Allow to dry for a minimum of 5 days on the laboratory bench, stirring daily.
		3. Reweigh (W_2).
		4. Calculate fresh moisture as a % of fresh weight : $\frac{(W_1 - W_2)}{W_1} \times 100$
Store in deep freeze for a minimum of 48 hrs.	Sub-sample 3.	**Non-humified organic matter**
		1. Place approximately 20 gm. in a weighed evaporating basin.
		2. Dry in oven at 105°C overnight.
		3. Cool in desiccator (further break up any persisting lumps).
		4. Weigh accurately (W_1).
On removal from the freezer thaw for 8 hrs. Run off free water. Carefully break up any lumps.		5. Add to water in large receptacle and stir thoroughly. Allow to settle. Carefully remove organic fragments and transfer to a clean weighed evaporating basin.
		6. Dry again in oven, cool in desiccator and weigh accurately. (W_2).
		7. Calculate organic matter as % of oven-dry weight $\frac{(W_1 - W_2)}{W_1} \times 100$
		Humus/fossil hydrocarbons.
		8. Take the settled, mineral faction (5. above). Filter carefully. Transfer to weighed evaporating basin.
		9. Dry in oven at 105 C. Cool in desiccator.
		10. Transfer c. 1g into a weighed, dry crucible. Weigh accurately (W_1)
		11. Place in muffle furnace and allow the temperature to rise slowly to 450 C.
		12. Allow to remain at that temperature for four hours.
		13. Allow to cool and transfer to desiccator. Cool to room temperature and weigh accurately (W_2).
		14. Calculate % loss on ignition $\frac{(W_1 - W_2)}{W_1} \times 100$

3. RESULTS AND DISCUSSION

i. Assessment of methods used.

Three decisions - relating to extraction method; number of sites; size and number of sample units - were made in selecting methods of study : these clearly have a bearing on the usefulness of the results for analysis and the validity of any conclusions. An attempt is made here to evaluate the impact of these decisions.

a. The effectiveness of the earthworm sampling technique. The simple formalin extraction technique used might be expected to be quite good at extracting the deeper burrowing forms, but less good at extracting those species living in turf mat and litter. The results from two grassland sites, 11 7. and V111 2, from each of which an additional sample unit (43 cm. x 43 cm.) was taken for hand sorting, were used for this assessment. Table IV gives sample unit data for these sites.

Site 11 7. is a grass/herb site on soiled shale. Total numbers and wet biomass of the worms in the handsorted sample unit were within the range found in the formalin - extracted sample units. A. longa and A. terrestris were not found in the handsorted sample whereas a single specimen of O. lacteum, not found by formalin extraction, was present.

Site V111 2. is a pasture site, also on shale, with a very heavy, clay topsoil. Here only a few deep-burrowing specimens were found (all A. longa). One such specimen occurred in the hand-sorted sample unit where it was removed from the top 5 cm. of the soil. The lower 10 cm. of the soil revealed neither worms nor evidence of burrows. The inference is that A. longa may not have been a deep burrower on this site.

The rather low wet biomass of the handsorted sample unit of 11 7., and the absence of A. longa and L. terrestris both tend to confirm the superiority of formalin extraction over handsorting for deep burrowers.

The occurrence of a single specimen of Octolasion in the handsorted sample unit of 11 7, and the slightly above average number of A. chlorotica in the handsorted sample unit of V111 2, do not provide evidence that handsorting is significantly better than formalin extraction in extracting horizontal burrowers and litter-living forms.

Table 1V

Sub-sample counts : Site 11 7.

Sample unit:	1	2	3	4	5	Total (m^{-2})	Mean	S.error	Handsorting
Species:									
A. chlorotica		1				1	0·2	0·12	0
A. longa		2	1	1	3	7	1·4	0·51	0
A. rosea	1	4	3		3	11	2·2	0·73	3
L. rubellus				1		1	0·2	0·12	1
L. terrestris		1			1	2	0·4	0·25	0
O. lacteum						0	0·0	0·0	1
Total	1	8	4	2	7	22	4·4	1·36	5
Biomass(g.)	0·05	1·67	0·45	0·25	8·17	10·59	2·12	0·95	1·37

Site V111 2

Sample unit:	1	2	3	4	5	Total (m^{-2})	Mean	S.error	Handsorting
Species:									
A. chlorotica	2	6	3	3	8	22	4·4	1·12	6
A. longa		3			1	4	0·8	0·58	1
A. rosea		2				2	0·4	0·25	0
Total	2	11	3	3	9	28	5·6	1·83	7
Biomass(g)	0·15	6·34	1·40	0·38	2·57	10·84	2·17	1·13	4·77

b. The study sites as representatives of other revegetating sites.

Limitations of time meant that not many sites could be sampled. The question therefore arises of whether the results of this study would be repeatable, given a different selection of sites. A computer search of the literature failed to reveal any published work on comparable sites with which the earthworm data could be compared. As a result this evaluation is limited to the vegetation of the sites, with the assumption that vegetation similarities are associated with similarities in general ecology.

Firstly, the data collected on the higher plant species found in the sample units was processed to arrive at a % occurrence figure for each species. No data was collected for the sites under agricultural management (V11 2; 1X 2.and 1X 3) and site X, leaving twenty subsites with a total of one hundred possible occurrences. Sixty four species in all were identified. This is not a comprehensive list of species occurring on the sites since specimens growing outside the 0·2 $m.^2$ sample units were not recorded and some closely related species, both of which occurred but were not consistantly distinguished between, were recorded simply under the generic name. The low % occurrence figures are a result of the small sample size. The most commonly occurring grasses were Festuca sp. (47%), Dactylis glomerata (31%), Arrhenatherum elatius (18%), Holcus sp. (24%), Deschampsia flexuosa (19%) and Agrostis sp. are inflated because more than one species is involved. The most commonly occurring herb species were Trifolium repens (20%), Chamaenerion angustifolium (14%) Plantago lanceolata (38%) Achillea millefolium (16%) and Hieracium vulgatum (29%).

Richardson, et. al. (1971) found eighty five species, including planted trees which my method excluded. The five commonest grasses, in their results, were the same species as in this study, though not in the same order of abundance and at much higher % levels since individual sites were sampled exhaustively. The main herbs found by Richardson et. al. were

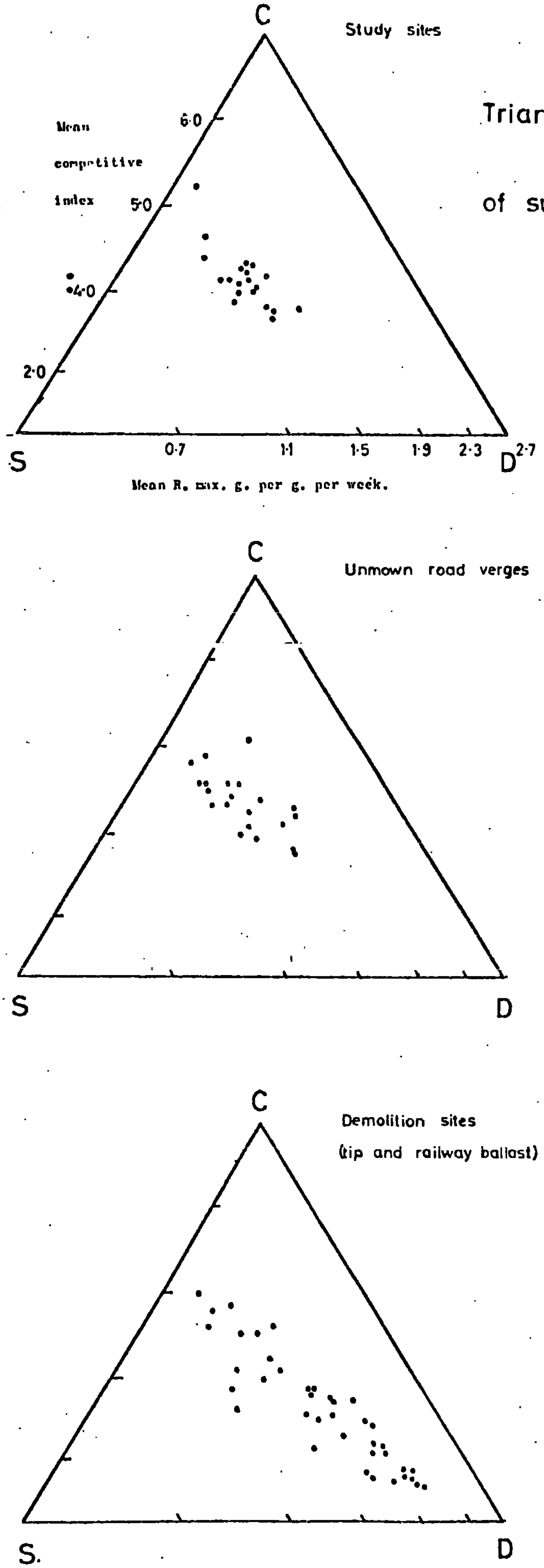
Centaurea nigra, Chamaenerion angustifolium, Hieracium sp., Plantago lanceolata and Tussilago farfara. The similarity with the results of this study is less close than for the grasses but the high incidence of Achillea millefolium and the near absence of Tussilago farfara probably reflects the relative maturity of the sward in many of my sampled sites. The high incidence of Trifolium repens similarly reflects the use of a grass - legume mixture as a spoil - stabilising aid on a number of the reclaimed sites. Richardson et. al. looked at two hundred and thirty seven pit heap areas. The data from the twenty subsites used in this study show a sufficiently close similarity to Richardson's results to support the argument that the sites are representative.

Secondly, it is helpful to look at the work of Grime (1974). Grime made an attempt to classify sites by the strategies of their flora in response to stress, competition and disturbance, with a view to developing a system for use by non-specialists (see Appendix 4). He illustrated, in his triangular ordination model, the characteristics of many common herbaceous habitats of which two are included in Fig. 1. for reference. Fig. 1. also shows the ordination of the subsites (apart from X 1.) used in this study. It is noteworthy that the subsites, apart from the two heather - dominated heathland sites, form a close and distinctive group similar to that given by Grime for infrequently mown roadside verges but slightly offset towards the stress apex. The similarity with the group for tip and railway ballast is also close, but without the long 'tail' of disturbed sites with predominantly ruderal plants. It is suggested that the close grouping of the sites in this ordination model, at least comparable to that for sites classified by Grime, tends to confirm that they are representative of a distinct kind of habitat.

c. The adequacy of sample unit size and number per subsite. The original decision to use five 0·2 m^2 sample units per subsite was based to a large

Fig. 1

Triangular ordination of subsite vegetation



degree on logistic considerations and the quantitative data must be interpreted with caution. Nordstrom and Rundgren (1973) comment that a complete list of species can be obtained by using a relatively small number of samples. Since in all thirteen species were found (Phillipson et. al. 1976) found ten in an exhaustively sampled beechwood) with seven of the subsites having five or more species and seven species occurring in five or more subsites it seems likely that reasonable reliance can be placed on the presence / absence data. It must be remembered, also, that many of these subsites are highly stressed habitats not particularly favourable to earthworms. Further, in the most favourable sites (Table V) earthworm populations reached numbers $m.^{-2}$ comparable with other workers, quoted elsewhere.* The standard error of the sample units was also comparable. Thus overall population levels, whether recorded in numbers or biomass seem likely to be reliable.

TABLE V

Subsite data of favourable sites

Sample Units	1	2	3	4	5	Total (m^{-2})	Mean	s.e.
Subsite	11 1.							
Total biomass	18·8	5·8	10·6	9·9	9·0	47·0	9·42	1·01
Total number	25	28	36	42	38	169	33·8	3·17
Subsite	11 1.	R.						
Total biomass	4·5	11·1	7·9	5·4	7·9	36·8	7·36	1·15
Total number	22	48	44	19	55	188	37·6	7·21
Subsite	11.	6.						
Total biomass	1·8	10·0	4·6	13·3	18·4	48·0	9·62	2·98
Total numbers	8	21	23	9	17	77	15·6	3·06

* e.g. Nordström and Rundgren (1973) found biomass totals (gm. $m.^{-2}$) of 20·81 gm. (s.e. 5·65) in alder/birch wood, 59·35 gm. (s.e. 3·88) in permanent pasture and 6·85 (s.e. 1·06) in abandoned grassland.

d. The project was planned to allow the use of a multiple regression technique in the analysis of the results. Of the variables measured in this study only the p H data yielded results which seemed sufficiently consistent for use in complex analysis.

Similarly, the grading of sites for moisture, shade and homogeneity, whilst producing results which were useful in the discernment of trends in the development of earthworm populations, was not considered sufficiently definitive for use in such a complex technique.

It is considered that the original scheme, modified in the light of the experience gained in this study, and with a more extensive data collecting programme throughout the whole season might produce, through the use of a multiple regression technique, more conclusive evidence of the factors governing the distribution and abundance of earthworm species, but for the present study the data obtained were subjected to a number of simpler analyses only.

ii Species found with notes on their life history.

a. Species List

Species		Total occurrences
Allolobophora rosea (Savigny)	)	29
Allolobophora caliginosa (Savigny)	)	
Allolobophora chlorotica (Savigny)		9
Allolobophora longa Ude		17
Bimastos eiseni (Levinsen)		1
Dendrobaena rubida (Savigny)		7
Lumbricus castaneus (Savigny)	)	65
Lumbricus rubellus Hoffmeister	)	
Lumbricus terrestris Linnaeus		23
Lumbricus festivus (Savigny)		5
Lumbricus friendi Cognetti		1
Octolasion cyaneum (Savigny)		0
Octolasion lacteum(Oerley)		0

Note: Octolasion cyaneum occurred only in the clay soil of site X 1 for which sample unit data are not available. O. lacteum only occurred as a single specimen in a handsorted sample unit of subsite 11 7.

b. Lifestyle categories. Phillipson et. al. (1976), quoting Bouche, ascribe their ten species to one of three lifestyle categories. Nordström and Rundgren (1973)also studied the vertical distribution of the worm populations of their sites. The three categories are:

Epigées (litter dwellers) : L. castaneus and D. rubida were placed in this category by Phillipson et. al. In this study L. rubellus must also be included. Nordström and Rundgren found that it was predominantly found in the litter. Phillipson et. al. did not find it at all.

Anécique (deep burrowers) : A. longa and L. terrestris belong to this category, though in one subsite (V11 2) A. longa seemed to have formed much more superficial burrows comparable with those of the Endogees.

Endogées (horizontal burrowers):A. caliginosa, A. rosea and O. cyaneum were ascribed to this category by Phillipson et. al. who also stated that A. chlorotica was intermediate in type. Nordstrom and Rundgren, on the other hand, found all these species (except O. cyaneum on which they give no results) at depths essentially comparable with those of A. longa and L. terrestris. In this study quite marked behavioural differences between the species were apparent which clearly endorsed Phillipson et. al.'s distinction between the three categories.

The epigees, when formalin was applied, quickly emerged and moved briskly over the surface, often crawling up into the vegetation. The anecique were much slower to appear. They withdrew slowly from the burrow and then they also moved away over the soil surface, but with a much greater tendency to move through the basal stems of the vegetation. Finally the endogees moved very reluctantly from their burrows, often not emerging completely at all, and tended not to crawl any distance but to insinuate themselves between stems of vegetation at ground level and simply lie there. Great care in searching through the basal stems of the vegetation was essential to locate them all. They were often moribund when picked up. The deaths of collected worms, early in the study (see section 11 iv a.), were almost always of species in this category.

c. Seasonal change in abundance and activity. For a small number of sites repeat sampling was carried out after an interval of time. For two sites this was done by a complete re-sampling whilst for two further sites a sixth sample-unit for handsorting was collected some time after the initial sampling by formalin extraction. The results are tabulated below: table V1 and and V11

Table V1

Seasonal change in abundance : full resampling

Site 11 1.

Date	9th June								10th August							
Sample units	1	2	3	4	5	Total	Mean	S. error	1	2	3	4	5	Total	Mean	S. er[illegible]
Species																
A. rosea/ caliginosa				2	2	4	0·8	0 49	7	26	22	8	34	97	19·4	5·25
L. castaneus/ rubellus	24	28	34	40	36	162	32·4	2 86	15	22	22	11	21	91	18·2	2·22
L. terrestris	1					1	0·2	0 12								
Total	25	28	34	42	38	167	33·4	3 12	22	48	44	19	55	188	37·6	7·22
Biomass(g)	11·5	5·76	10·56	9·87	9·0	46·69	9·34	0 98	4·53	11·10	7·85	5·43	7·91	36·82	7·36	1·1[illegible]

SITE 111 3.

Date	19th May								19th June							
Sample units	1	2	3	4	5	Total	Mean	S. error	1	2	3	4	5	Total	Mean	S. err
Species																
A. rosea			1		1	2	0·4	0 25	1					1	0·2	0·12
L. castaneus/ rubellus	3	2	1	2	6	14	2·8	0 86	2	2		3	1	8	1·6	
L. terrestris		2	4	3	3	12	2·4	0 68				1	1	2	0·4	0·25
Total	3	4	6	5	10	28	5·6	1 21	3	2	0	4	2	11	2·2	0·66
Biomass	0·38	8·18	10·69	9·32	9·31	37·88	7·58	3 39	0·77	0·26	0	3·61	1·51	6·15	1·23	0·65

Table V11

Season change in abundance : resampling by handsorting

Site 11 6.

Date	23rd June								20th July
Sample units	1	2	3	4	5	Total	Mean	S. error	Handsorted
Species									
A. rosea									1
A. longa			1			1	0 2	0 • 12	
L. castaneus/rubellus	8	18	14	5	10	55	11 • 0	2 • 28	10
L. terrestris		3	8	4	7	22	4 • 4	1 • 44	1
Total	8	21	23	9	17	78	15 • 6	3 • 06	12
Biomass	1•76	10•04	4•56	13•25	18•43	48•04	9•61	2 • 99	2•60

Site 1 1.

Date	8th June								20th July
Sample units	1	2	3	4	5	Total	Mean	S. error	Handsorted
Species									
A. rosea					1	1	0•2	0 •12	1
L. rubellus	3		3	1	7	14	2•8	1 • 2	
L. terrestris	3	2		2	4	11	2•2	0 • 73	
Total	6	2	3	3	12	26	5•2	1 • 83	1
Biomass	13•81	9•42	0•30	2•76	2•02	28•31	5•66	2 • 56	0 35

These results seem clearly to indicate :

1. Under the drought conditions found in late May and June marked reductions in numbers of worms extracted occurred. In exposed extreme situations the litter-dwelling L. rubellus/L. castaneus crash in numbers (Site 1 1.). In more sheltered, woodland conditions (Site 11 6.) these species maintained their numbers rather better though the drop was still marked in site 11 1. (birch scrub) between the 9th June and 10th August. Phillipson et. al. (1976) found a reduction in numbers of L. castaneus over this period. The deep-burrowing species, L. terrestris occurs in all the later samples with a markedly reduced frequency. Numbers per sample unit (0•2 $m.^2$) drop from a mean of 2•4 to 0•4 (site 111 3) 2•2 to 0•0 (Site 1 1.) and 4•4 to 1•0 (site 11 6.). The old grass/herb site (1 1.) is clearly a very critical one for worms. The only specimen found in the later handsorted sample was a single aestivating immature A. rosea.

2. Quite marked changes in species composition can occur. Site 11 1.was remarkable for the tremendous increase in A. rosea/A. caliginosa (equal numbers of adults of the two species were found) following the wet weather of July and early August. Looking at the data for all the sites for this pair of species, it emerges that prior to the end of June only nine specimens were found in thirteen subsites from which worms were collected. In early August, however, one hundred and fifty eight specimens were found in eleven sites. Comparable figures for A. longa were one and forty three.

Evans & Guild (1948) show that A. caliginosa in pasture declines in numbers drastically after 25th April, effectively disappearing from the soil. It increases rapidly in numbers between 15th and 22nd August as the worms emerge from the cells in which they have spent several months in diapause. They state that the decline in numbers after 25th April is due to a decrease in soil moisture. Allolobophora nocturna, a close relative of A. longa. showed a similar pattern. A. longa was present only in very small numbers but the results above suggest that it behaves similarly. Standen (personal communication) has found a similar startling increase in A. caliginosa in August and the phenomenon appears general.

It is noteworthy that the response of A. caliginosa / A. rosea to the onset of summer drought is sudden whereas that of L. castaneus /L. rubellus is gradual. It may be that the former, like A. longa go into obligate diapause whereas the latter enter a facultative diapause though Edwards and Lofty (1972) say that A. caliginosa and A. rosea have a facultative diapause. An alternative explanation may be that the Allolobophora species are less tolerant of draught and enter diapause more quickly.

It is more difficult to interpret population changes in terms of the reproductive cycle. Evans & Guild (1948) showed A. nocturna and A. caliginosa to be hatching rapidly in October but his further analysis was dependent on his distinction between immature, juvenile and adult members of individual species. An attempt was made to gain some insight into growth and reproductive cycles by looking at immature : mature ratios for the common species. Because of difficulties in identifying the immatures A. rosea and A. caliginosa are again considered together, as are L. castaneus and L. rubellus. The other species regularly present in any numbers is L. terrestris. The results were not very productive. In L. terrestris the immature : adult ratio stays very close to unity for single subsites through the period of study, i.e. : 19th May 6 : 6 ; 8th June 6 : 5 ; 21st June 3 : 2 ; 23rd June 13 : 9 ; 10th August 1 : 1 . In A. rosea/ A. caliginosa significant numbers were only present on and after the 10th August and in a period of 4 days, on different subsites, the ratios changed from 83 : 14 to 16 : 5, to 10 : 1, to 13 : 8. It is not possible to draw conclusions from those results. Finally, in L. castaneus / L. rubellus, where differences between subsites are again pronounced (e.g. 106 : 60 and 11 : 0 on 9th June and 52 : 3 on 23rd June) a single valid comparison exists for site 11 1. between the 9th June and 10th August : 106 : 60 and 63 : 28 respectively. This can no more than suggest either a slightly greater mortality of adults than of juveniles over the summer period or the beginnings of a hatch from cocoons in the wet weather of late July. Since Edwards and Lofty (1972) give the length of the period from laying to hatching as sixteen weeks for L. rubellus and fourteen weeks for L. castaneus, and since the peak of cocoon production is given as mid July to end September for L. rubellus and June/July for L. castaneus the last explanation seems unlikely, unless cocoon production began in April at a significant level.

iii. Factors affecting the distribution and abundance of earthworm species

~~The distribution and abundance of an earthworm species is largely~~ dependent on its physiological needs. The importance of soil pH, temperature and water content is well known. Clearly one must also consider available food. The importance of these variables, as illustrated by this study is discussed below.

a. p. H.

Doubleday (1971) gave a range of pH, using data from 44 colliery spoil sites, from 2·0 to 9·0 with the mode at pH 4 - 5. My own results give a range from pH 3·0 to pH 6·8. Table V111 gives the distribution of pH for the sites used. Where the 'topsoil' and 'subsoil' values differed by more than pH 0·5 the values of the topsoil was taken on the assumption that this was the more critical for a range of species. The data, as is shown by examination of the earthworm population data - appendix 1., is strongly influenced by the diapause induced by the dry weather of June and July. Table V111 shows the maximum population density of the four common species at each step in the pH range.

Table V111

pH and species abundance

pH	3·0	3·5	4·0	4·5	5·0	5·5	6·0	6·5
no. of samples	1	1	2	4	4	2	7	4
Maximum population density (no. m $^{-2}$)								
of : A.rosea/caliginosa				1	2	11	97	21
A. longa					2	7	4	25
L.rubellus/castaneus	10		17	12	55	1	166	14
L.terrestris	1		1	11	22	2	1	12

If one assumes that there is no distinct threshold in pH for the occurrence of a particular species, and that pH exerts a limiting effect on population size then the data shows the three Allolobophora species to be intolerant of acid conditions, A. longa being the most extreme, whilst the Lumbricus species are much more tolerant though good populations are only found above pH 5·0. This agrees with Satchell (1955). Nordström and Rundgren(1974) found, in contrast, that of these species only L. rubellus was indifferent to pH and that all the other species were acidophobic. The low numbers of L. terrestris below pH 4·5 may be compatible with the latter findings.

b. Soil temperature

Edwards and Lofty (1972) reviewing the effect of temperature on earthworms stressed that at soil temperatures above 10° C the numbers extracted from soil tend to be inhibited. Under laboratory conditions the thermal death point of L. terrestris is given as 28° C, though in combination with sustained soil aridity lower temperatures are likely to be lethal in the field.

Initially, from the 8th June onwards, temperatures were taken at 5 cm. and at 10 cm. depths. On the sites studied up to the 15th June both readings were the same and varied from 13.5°C to 15°C. From the 15th to the 19th June temperatures up to 21°C were recorded at 5 cm. depth and gradients from 21°C at 5 cm. depth to 14.5°C at 10 cm. depth were noted. After the 21st June periodic rain brought the soil temperatures down again and the readings were discontinued. Clearly some of the sites being studied are intensely vulnerable to high levels of insolation during the summer and, as Rhee (1967) has pointed out, it is dry summers which check the development of populations. Soil temperatures can not reflect these seasonal stresses unless recorded over long periods of time. A clearer indication of the vulnerability of a site to periodic and lethal high soil temperatures is given by an assessment of the amount of shade insulating the soil surface from intense insolation. This is discussed in section 3.

c. Soil moisture

Earthworms are vulnerable to prolonged drought though they are very tolerant of short term aridity, being able to tolerate a loss of 18% of body weight through desiccation without loss of function and a loss of 70 - 75% without dying, (Edwards & Lofty, 1972). Low soil humidity provokes the onset of diapause in some species e.g. *A. longa.* Wet areas, on the other hand are avoided by *L. terrestris* whereas *A. caliginosa* will tolerate water - logging, as will *A. chlorotica* and *A. longa.* (Laverack 1963). The effects of soil moisture on populations of worms, like those of soil temperature, are difficult to evaluate in a short - term study of this kind. Determinations of % water loss on air drying proved, predictably, to be largely dependent on the rainfall (if any) of the previous twenty four hours. They were discontinued when the heavy rainfall of August led to general water - logging. Evidence of the effect of soil moisture on the real populations of single species, independent of diapause, is limited and anecdotal but probably real. Thus B. eiseni, a litter-dwelling species, was only found in one sample unit of subsite V1 1., planted shale at Houghall. The sample unit in which the two specimens were found was the only one located in a slight hollow and had 415 gm. of litter as compared with litter weights for the other sample units of 493 gm. 815 gm. 682 gm. and 979 gm. The slightly moister litter, in this hollow, was apparently just tolerable to this species and was possibly being decomposed a little faster than that in the other sample units.

Further, A. chlorotica was only found in any numbers at two subsites, X (clay) and V111 2 (heavy, clayey topsoil on shale). The water - holding capacity of this material might be expected to be better than that of shale. A high figure of 30% weight loss on air-drying was recorded for the latter site, though this was after rain. Clays may, of course, be qualitatively distinct from sands and shales in other ways of importance to earthworms.

d. Available food

Organic matter is vital to earthworms. Soils low in organic matter, for example mineral soils at early stages of colonisation by plants, contain very few worms. Where the vegetation is productive but worms are absent organic matter accumulates in a thick mat on the soil surface. Weights of litter obtained from the samples by a light raking of the surface represent only a part of the food available to earthworms. Amounts varied in the samples taken from 82 gm. $m.^{-2}$ on subsite 11 4, a very arid grass/herb habitat to 3383 gm. $m.^{-2}$ on subsite V1 1., a very mature woodland habitat. The % dead organic matter in the top 6 cm of the soil varied from 5% on subsite 11 3., 11 5. and 1V 1. to 28% on site 1 1.. These figures suggest that in the relatively heavily vegetated sites of this study the quantity of food available is not limiting. On the other hand the large amounts of litter on many sites (five with more than 500 gm. $m.^{-2}$) suggests that other factors are inhibiting the build - up of earthworm numbers and leading to the accumulation of litter.

It is known (Wallwork 1976) that the palatability of litter for earthworms depends on the low C : N ratio. In grassland this is low. Woodland litter has a higher C : N ratio, which varies with species. Sycamore and birch both have quite high palatability (Satchell & Lowe 1967). Satchell (1967) clearly stated that assorted herbs and grasses (including Agrostis sp. which occurred abundantly in many sites) were more palatable than tree litter. These preferences seem to apply to a number of species.

Normally earthworm populations are higher in productive land than any other type of habitat. Edwards & Lofty (1972) quote 37 - 50 gm. $m.^{-2}$ for mixed woodland and 51 - 152 gm. $m.^{-2}$ for pasture. In this study, however, the highest earthworm biomass (47 gm. and 48 gm) were recorded for woodland sites (11 1, and 11 6) though grassland sites early in the season had good populations too. (38 gm. - site 111 3, and 28 gm. - site 1 1). The implication is that limiting factors, other than food, operate more strongly on grassland than woodland sites.

Effects of specific types of litter can be discerned in one or two instances. Firstly the only specimens of B. eiseni found were in a dense mat of Deschampsia flexuosa litter (subsite V1 1) - a common habitat for the species. Secondly, subsite 111 2, a Calluna heath had no worms at all, suggesting very low palatability. There was no grazing on this heath and therefore no dung, with which earthworms are often associated on Calluna moors (Svendsen 1957). On the other hand, site 1V 2. Calluna with Betula scrub had populations of worms - possibly due to the much greater palatability of Betula litter.

Site 1V 1 a Ulex thicket, whose litter might be expected to be unpalatable had an earthworm biomass of 11·3 gm. Grass and herb species were present only in very small amounts on this site and the earthworms must have fed on the Ulex litter. Presumably, at least after weathering, its palatability is quite high.

iv. Factors affecting the development of earthworm population size.

The best indicator of total earthworm population is taken to be the wet biomass for each subsite. The effect of a range of environmental factors is discussed:

a. pH

The influence of pH on populations of single species has been examined in section iii a. Fig. 2 shows the relationship between total earthworm biomass and soil pH There is a tendency towards higher biomass at higher pH. The older grassland swards (1 1. and 111 3) and the younger, closed canopy woodlands (11 1, and 11 6) are again notable in that the earthworm biomass is almost of a different order from that of the other sites.

b. Moisture and shade

Fig. 3 shows the relationship between wet biomass and soil moisture (% weight loss on air drying). The resultant scatter diagram is very difficult to interpret. No clear correlation exists. For example, the very high biomass figures at about 12% moisture content and the very low biomass at 36% moisture content seem out of place or inconsistant. These may be explained by the effect of a closed woodland canopy on moist soils producing a stable moisture regime even though soil moisture was quite low at the time of sampling and, possibly, the effect of diapause reducing earthworm numbers in drier soils (sites V111 2. and V1 1). Leaving these cases aside there is, at the time of sampling, a relationship between high numbers and soil moisture. There can be no question that soil moisture is crucial for earthworms and, since spot checks on soil moisture were expected to give a poor correlation with earthworm biomass two alternative approaches to the problem of the effect of soil moisture on earthworm biomass were prepared. The sites were all ranked, in the field, in terms of a "moisture factor" and a "shade factor" as described in section 2 iv f. The "moisture factor" was

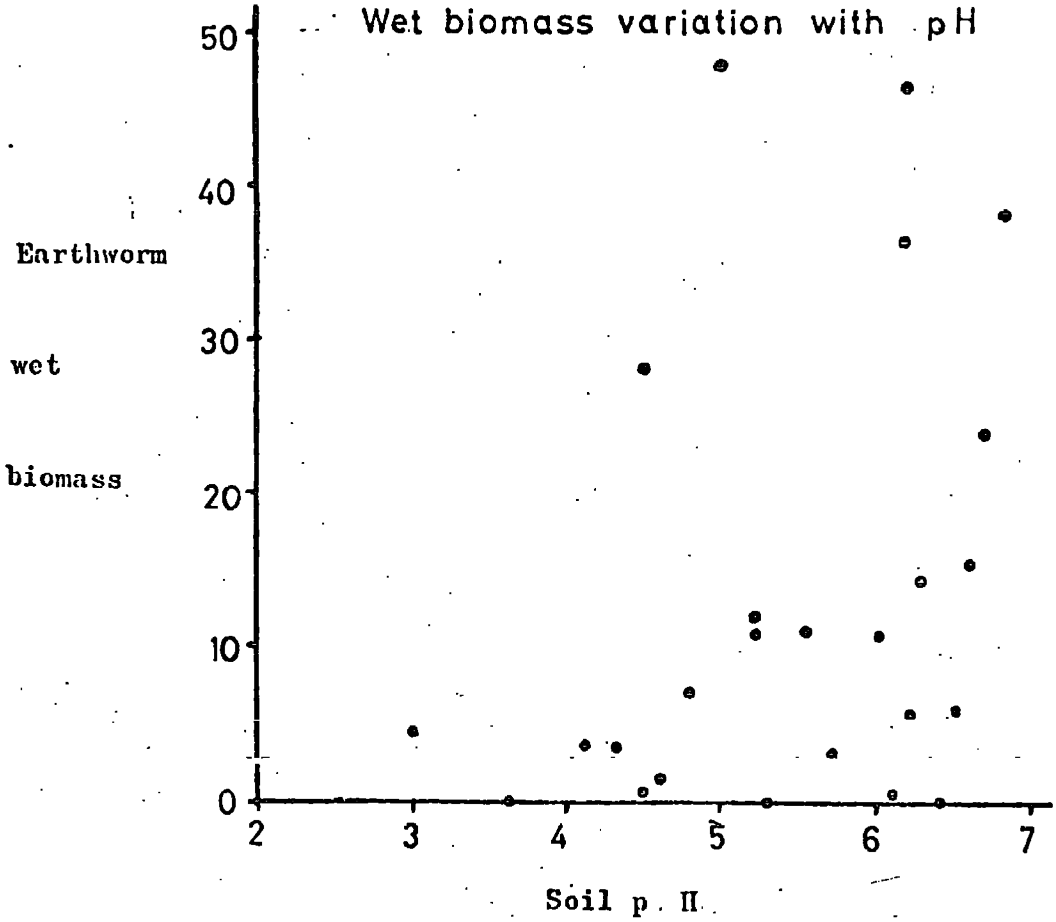


Fig. 2

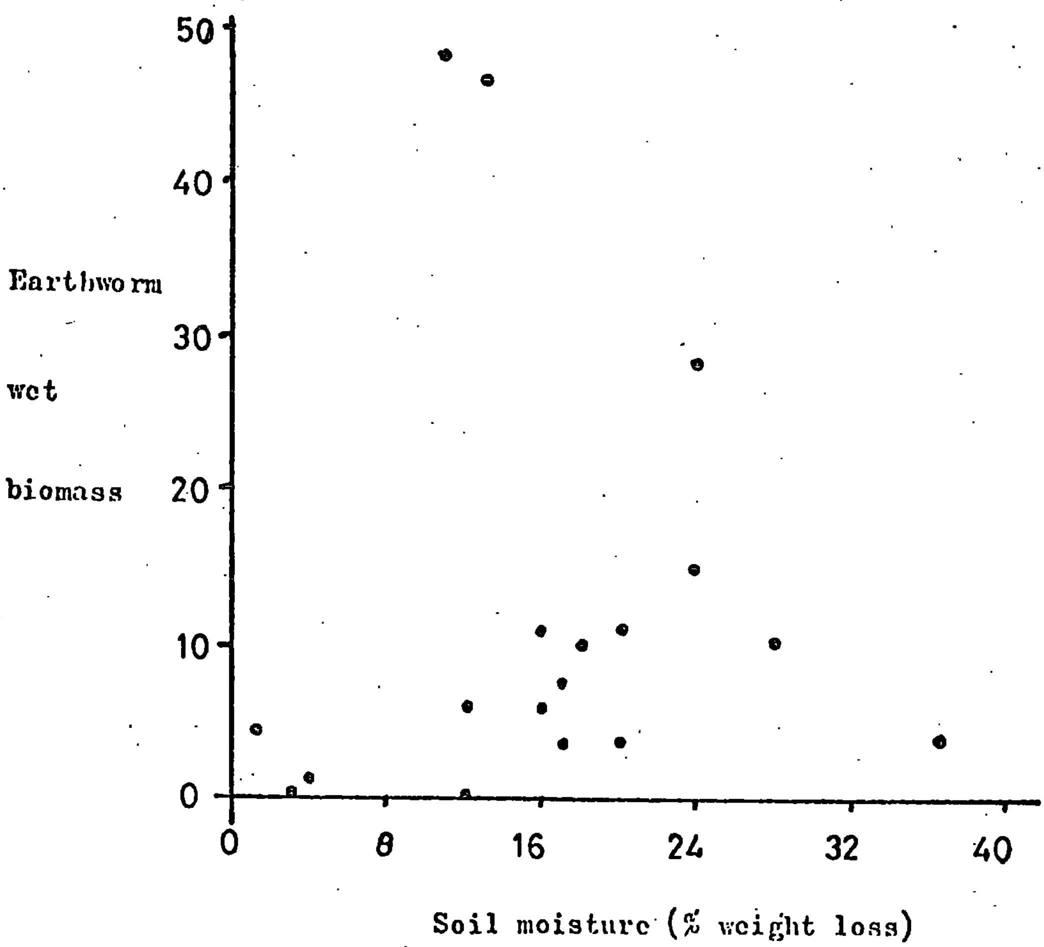


Fig. 3

Wet biomass variation with soil moisture seen as a subjective assessment of the availability of ground water and the "shade factor" as an estimate of the amount of protection from insolation, reducing loss of water from the soil and ground vegetation. Earthworm biomass was plotted against "moisture factor" (fig. 4) and against "shade factor" (fig. 5). Fig. 4 shows the drop in maximum biomass at higher "moisture factors", i.e. under drier conditions.

Taking fig. 5 on the other hand, it was expected that increased shade would promote a more stable water regime and support higher populations. However, only sites 11 1. and 11 6., with a completely closed canopy show a high biomass. Any break in the canopy, it seems, allows drying out of the soil and inhibits the development of a high earthworm biomass. The relatively high biomass of sites X 1., 111 3. and 1 1., open mature grassland sites, may reflect the more vigorous dense growth of grasses and herbs in full sunlight leading both to the increased availability of highly palatable litter and to the buffering of temperature and moisture conditions at the ground surface enabling good populations to develop. A thick turf mat at site 1 1. may indicate that the population is not optimum. Site 1V 1., with a very low biomass under woodland shade conditions, also looks anomalous. This site, the Houghall tip, is a steeply-sided one with a high canopy and no shrub layer. It has a very heavy build up of litter (over 3000 gm. $m.^{-2}$) and seems to be very vulnerable to drought.

The influence of shade is thus a very complex one for which my simple ordination is inadequate. Where close woodland shade does protect the ground surface from desiccation good populations develop. An interrupted tree canopy on the other hand is certainly no more productive than a mature, uncut grassland sward in terms of earthworm biomass.

c. <u>Age of site</u>

No clear relationship between age of site and earthworm biomass was expected or found. The physical conditions of a particular site closely

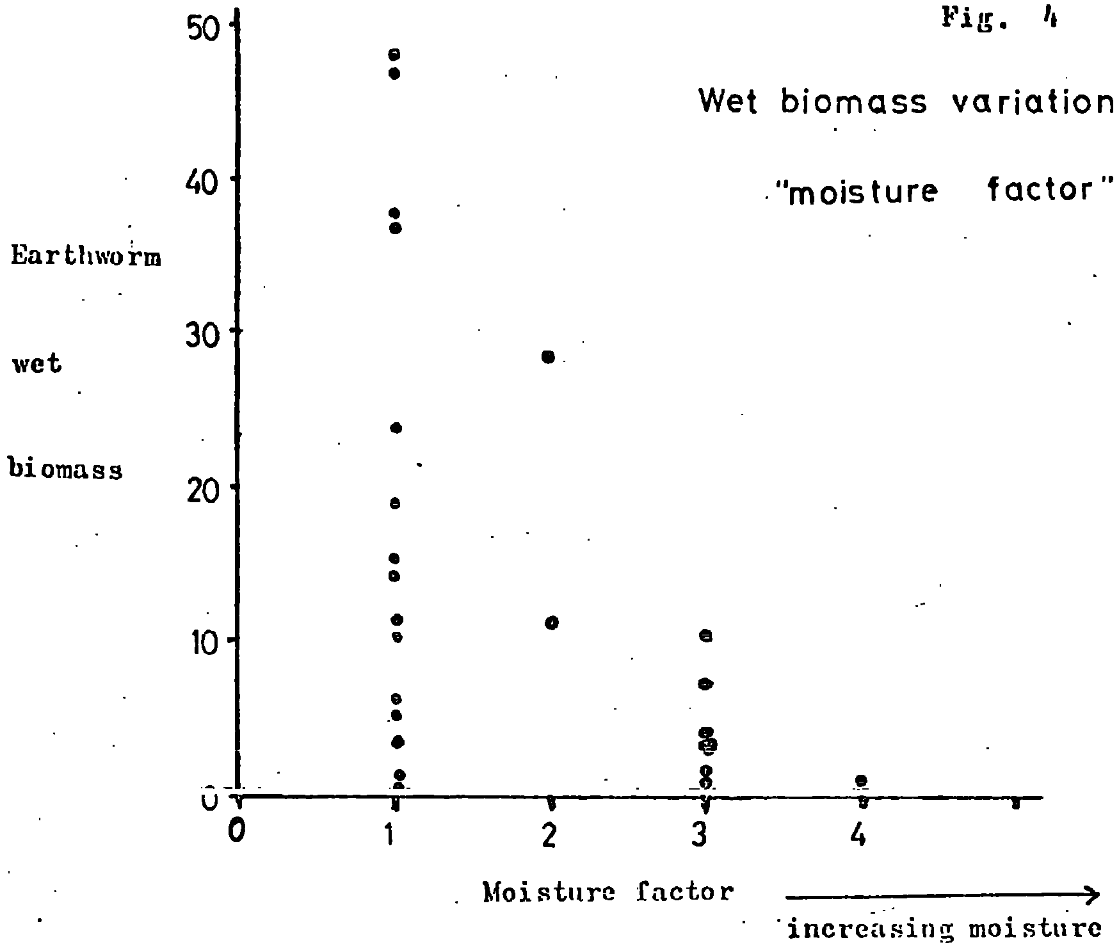


Fig. 4

Wet biomass variation with "moisture factor"

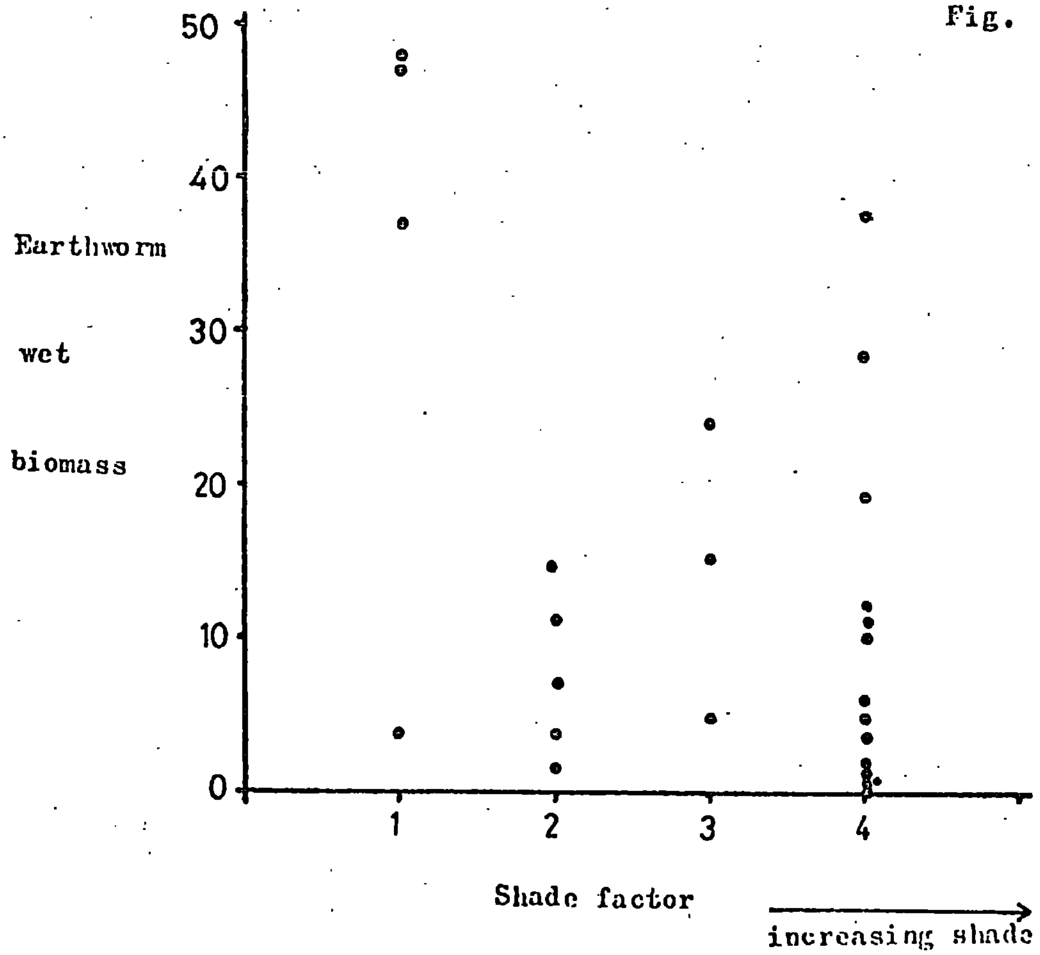


Fig. 5

Wet biomass variation with "shade factor" dictate the rate of colonisation by vegetation and hence the development of invertebrate populations generally. There is some evidence, however, that the build - up of earthworm populations in grassland sites is slower than in woodland sites. If a closed canopy develops quickly then a large biomass of earthworms (approaching 50 $m.^{-2}$) is possible in sites no more than fifteen years old (e.g. 11 1). Biomass may drop on older sites as root competition increases and as a raised canopy allows air circulation and a greater desiccation of the soil surface. On the grassland sites only two (111 3. and 1 1.) had an earthworm biomass in excess of 25 gm. Both are over 50 years old.

d. <u>The type of substratum</u>

The relative unimportance of type of substratum as an influence on earthworm population size is indicated when comparisons are made between carefully matched sites. Thus sites V111 1. and V 1. are both recently planted sites with a sown ground vegetation of <u>Festuca/Trifolium</u> mixture. The number of worms (3) is the same in each case. The earthworm biomass is similar (5·9 gm. and 3·4 gm.). The substrata are shale and sand respectively.

Also sites 1X 1. and 1X 2. are on the the same substratum (colliery tailings), of the same age (9 years), but the one planted with mixed trees (1X 1) has an earthworm biomass of 14·7 gm. whereas the other (1X 2) (ley or pasture) has no worms.

In short, factors other than substrate type influence the build up of earthworm biomass though there is evidence that substrate can influence species composition, through pH for example

e. <u>Other variables</u>.

Preliminary analysis of the relationship between the weight of litter collected at each subsite and earthworm biomass present failed to reveal any significant relationship. The amount of litter, in fact, represents both the quantity of food available for worms and the end result of worm-aided decomposition of organic matter.

% loss on ignition was determined up to the end of June. This was intended to reveal the % of fossil hydrocarbons in the soils with a view to investigating any possible inhibiting effect this might have on earthworm population development. It quickly became apparent that high % loss on ignition was not even associated with the shales containing fossil hydrocarbons. The highest figures were for old sites on ash and brick rubble respectively. Both sites had a well-established vegetation so that loss on ignition was more likely to be due to the build-up of humus Examination of the basic data in appendix 1 reveals that shales in no way inhibit the development of earthworm populations. Sites 11 1.and 11 6. are both on shale, as is 1 1. These are amongst the sites with the very highest earthworm biomass. This conclusion became apparent by the end of June and thereafter this determination was discontinued.

The other environmental variable measured was root mat depth. Fig. 6 shows the relationship with biomass. The scatter diagram seems to show a very weak negative correlation between earthworm biomass and root mat depth implying that root mat depth builds up when worm populations, and hence rates of decomposition of organic matter, are low. The young closed-canopy woodlands and older grassland sites seem to show a similar trend whilst being of a different order of biomass.

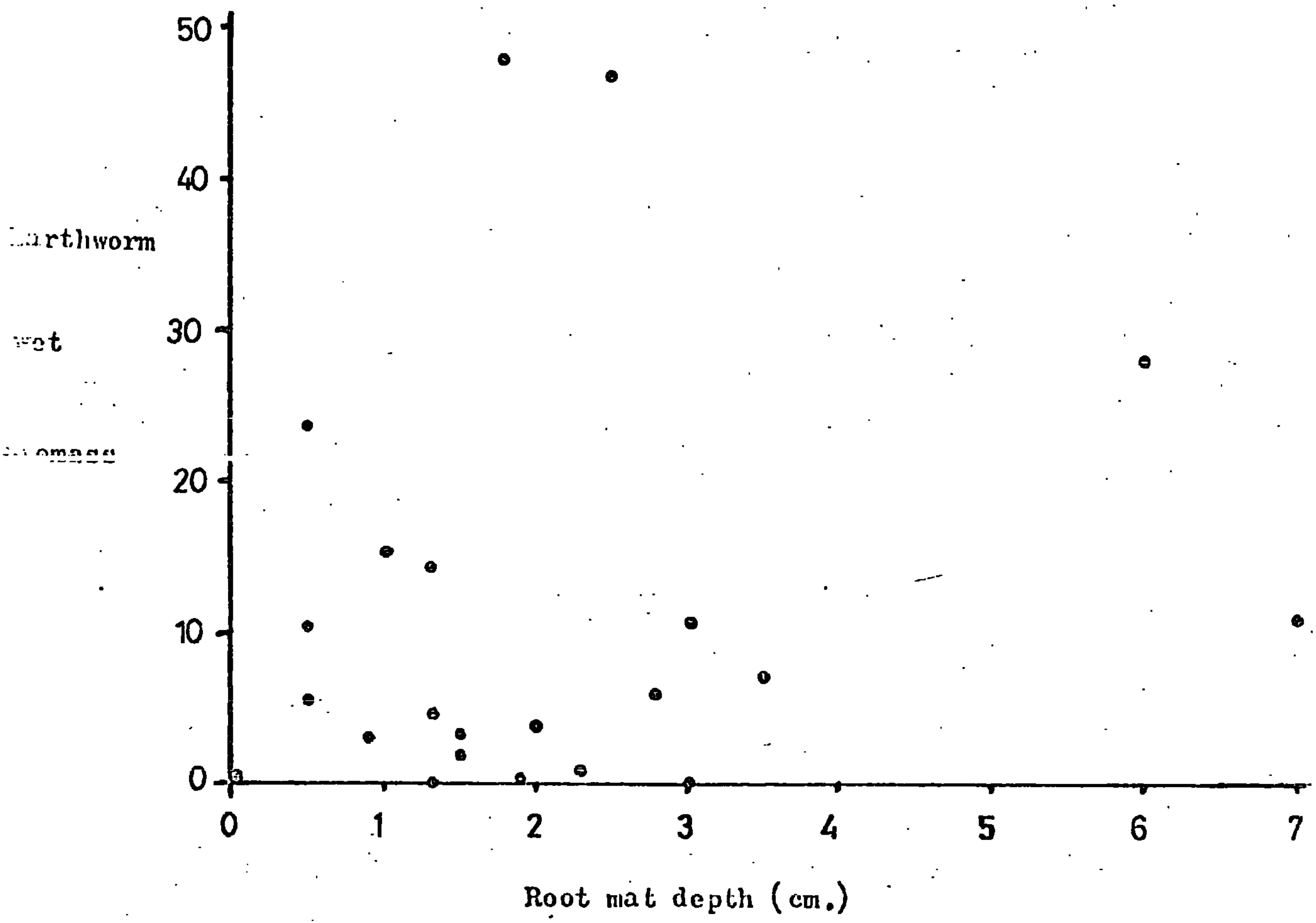
The subjectively assessed "homogeneity factor" did not stand up to rigorous analysis and was not used.

v. Colonisation and succession by earthworms

The commonly occurring species all form part of a characteristic mixed woodland association on mull soils (Edwards & Lofty 1972). Association analysis by Nordstrom and Rundgren (1973) and by Phillipson et. al. (1976) revealed detailed variations in associations in different

Fig. 6

Wet biomass variation with root mat depth



habitats but the present study lacks the data to make comparable analyses. The species occurring in any site seem to vary with the particular conditions of pH and aridity found there. From the data available one possible mode of succession by earthworms is as follows. Once vegetation has developed and litter for food and shelter has been produced then individuals of L. rubellus migrate in. These worms are highly active, crawling freely over the soil surface in wet weather. They can probably migrate at rates greater than the 10 m. year given in Edwards & Lofty (1972) for A. caliginosa. As the vegetation develops further L. terrestris is likely to colonise where moderate acidity and a tendency to aridity in summer are characteristic of the substratum. Where the soils approach neutrality and seasonal desiccation is less marked A. caliginosa A. rosea and A. longa are likely to occur. B. eiseni and D. rubida are dependent on the build up of litter under moist conditions.

vi Implications for the reclamation and development of derelict land

Over the past thirty years a great deal of work has been carried out on problems of restoring derelict areas. Major research (University of Newcastle-upon-Tyne 1971, 1972) and development projects (Hilton 1967) have been undertaken. Symposia have been held (Hutnik & Davis 1973) and a sub-committee of the British Ecological Society has reported on various aspects of restoration (Ranwell 1967, Goodman 1967). The assumption has often been made that derelict sites are basically inhospitable to plant and animal life. The necessity of aiding soil formation and mineral turnover has been generally accepted (Ranwell 1967) but the larger soil animals have tended to be seen as environmental indicators rather than as primary agents in the build up of soil fertility (Goodman 1967). This study suggests that non-toxic spoil and derelict sites generally can be revegetated and soil fertility built up by the agency of natural recolonisation and succession.

The sites examined in this study are of this type.

It is clear that undulations in the spoil surface provide far better conditions for the development of earthworm populations that flat, carefully graded surfaces. Riley, in Hutnik & Davis(1973), described the advantages of furrow regrading of spoils. Byrnes & Miller (in Hutnik and Davis, 1973) similarly showed how natural communities were established quite quickly in the troughs of a ridge - trough topography. They suggest ten years as the time needed for a prominent tree layer to become established. This is comparable to the stage of development of subsite 11 1. Where the substratum tends to dry out rapidly, and most spoils do when in the form of tips, the problem is not one of controlling run - off but of husbanding any rainwater. A hummocky or ridge and furrow surface can achieve this.

Byrnes & Miller see such reclaimed habitats as being very important, not for timber but as wildlife reservoirs. In British terms one sees them as low - pressure amenity sites or nature reserves.

Whilst, if scrub was not allowed to develop, a ridge - furrow topography would support good grassland communities, the creation of flat amenity grasslands, such as playing fields, and agricultural grassland is fraught with difficulties. Thus surface water becomes a problem, with waterlogging and erosive run - off as described by Downing (University of Newcastle-upon-Tyne 1972). Earthworm populations are unlikely to develop. In this study two silage/pasture fields (Subsites 1X 2. and 1X 3.) had 0 m.$^{-2}$ and 1 m.$^{-2}$ worms respectively. Hutson (University of Newcastle-upon-Tyne 1972) found very few on the same site three years after reclamation and the situation had not changed six years later. Thatch development and failure of mineral cycling are likely, in the absence of worms (Randell et. al. 1972), to require expensive management. The basic problem in this context would seem to be one of close mowing which deprives the soil surface of its insulating layer of vegetation leading to extremes of temperature inimical to worms.

Topsoiling presents one approach to the problem of surface soil desiccation, as at subsite V111 2, but despite moderate earthworm populations being present (28 m. $^{-2}$) 10·8 gm. biomass) deep burrowing species were absent and activity seemed to be limited to the top 5 cm. with very little evidence of crumb structure development. Topsoiling without the quick establishment of vegetation cover seems a waste of time since site V11 3, with 4 year old pines planted and no ground cover had no worms after the four years despite being covered with a good layer of soil.

Another solution for pasture on spoil might be the application of a dilute slurry. Pain (1974) found that a slurry of 2% dry matter resulted in a doubling of earthworm numbers in pasture though L. terrestris declined. This result seems directly comparable with the situation found on site V111 2.(mentioned above) in this study. This site was heavily grazed and dung was much in evidence in the area sampled, within 50 m. of the access road.

It is not possible to comment further on problems of agricultural production on spoil soils, but even in this kind of intensive use some undulation, if not ridge and furrow, of the ground surface seems desirable to make the best use of available water.

This study does suggest, however that, given some remodelling of the surface of tips and derelict sites, rich and diverse habitats with a wide range of species and closely similar to woodland, hedgerow, roadside verge and heathland habitats can develop naturally. Such sites would become a major visual and informal recreational amenity. One of the sites (No. 111, Shincliffe) already has this status and much local enthusiasm has been generated for its protection recently.

It is arguable that reseeding and planting is always desirable in the reclamation of mineral spoil in the interests of timesaving. Current practice seems to favour the planting of Alnus, Robinia and Populus sp., all producing litter with good palatability for worms. The very low palatability of Pinus sp. and the other conifers suggests that they are undesirable elements of a developing community on mineral spoil and derelict sites, from the point of view of developing a stable earthworm fauna and building up soil structure and fertility. No pure stand of conifers was looked at in this study but subsite V1 1.(Houghall) had a high proportion of pines. This might be an additional factor causing the very low earthworm populations of this close-canopy woodland site.

My results like those of Neumann (in Hutnik & Davis 1973) suggest, finally, that if the soil is to develop a good earthworm population and to build up fertility quickly, a close-canopy woodland should be created as soon as possible. It would be prohibitively expensive to plant three year old trees at, say, 2' 6" spacing. The broadcasting of Betula seed or the planting of Alnus slips are cheaper alternatives.

APPENDIX 1.

Table 1X : Earthworm numbers

Subsite	X 1		111 3		1 1		11 1		11 2		11 3		11 4		111 1		111 2	
Date of collection	11/5		19/5		8/6		9/6		9/6		9/6		15/6		18/6		19/6	
mature/ immature	m	i	m	i	m	i	m	i	m	i	m	i	m	i	m	i	m	i
A. rosea)			1															
A. caliginosa)				1		1		2										
A. chlorotica	2	10																
A. longa	5	15																
B. eiseni																		
D. rubida																		
L. castaneus)	1		1				4								2			
L. rubellus)	2		2	11		14	56	106		11	2	7		2	2	8		
L. terrestris			6	6	5	6	1					1				1		
L. festivus	3	3													3			
L. friendi																		
O. cyaneum	0	6																

Subsite	111 3 R		11 5		1V 1		11 6		1V 2		V 1		V1 1		1 1 R	
Date of collection	19/6		21/6		22/6		23/6		29/6		7/8		7/8		10/8	
mature/ immature	m	i	m	i	m	i	m	i	m	i	m	i	m	i	m	i
A. rosea)															7	
A. caliginosa)		1		1		2									7	83
A. chlorotica																
A. longa					1	1					2	1				
B. eiseni													2			
D. rubida																
L. castaneus)	1												2		6	
L. rubellus)		7		5	3	7	3	52	1	7			5	10	22	15
L. terrestris			2	3			9	13		1						
L. festivus		2			2				1							
L. friendi					1											
O. cyaneum																

Subsite	V11 1		11 7		V111 1		V111 2		V11 2		V11 3		1X 1		1X 2		1X 3		Total		Grand Total
Date of collection	10/8		10/8		11/8		11/8		13/8		13/8		13/8		13/8		13/8				
mature/ immature	m	i	m	i	m	i	m	i	m	i	m	i	m	i	m	i	m	i	m	i	
A. rosea)			1						8										17		
A. caliginosa)	5	16		10	1			2		13				4				1	13	137	167
A. chlorotica			1				16	6		3									19	19	38
A. longa	1	1	1	6			2	2	6	19				1					18	46	64
B. eiseni																			2	0	2
D. rubida	1	2											11	6					12	8	20
L. castaneus)	3												2						22		}
L. rubellus)	3	14		1	1					7			21	17					123	363	} 503
L. terrestris	1		1	1	1					1									26	33	59
L. festivus																			9	5	14
L. friendi																			1	0	1
O. cyaneum																			0	6	6

Subsite	X 1	111 3	1 1	11 1	11 2	11 3	11 4	111 1	111 2	111 3 R	11 5	1V 1	11 6	1V 2	V 1	V1 1	1 1 R	V11 1	11 7	V111 1	V111 2	V11 2	V11 3	1X 1	1X 2	1X 3	Total	Grand Total
Totals	13 55	10 18	5 21	61 108	0 11	2 8	0 2	7 9	0 0	1 10	2 9	7 10	12 65	2 8	2 1	9 10	4[illegible] 146	14 33	4 18	3 0	18 10	14 43	0 0	34 28	0 0	0 1		
Grand total	68	28	26	169	11	10	2	16	0	11	11	17	7	10	3	19	18[illegible]	47	22	3	28	57	0	62	0	1		879
Biomass	18·8g	37·9g	28·3g	47·0g	1·4g	4·8g	0·8g	7·3g	0·0g	6·2g	11·0g	11·3g	48·0g	3·6g	3·4g	3·8g	3[illegible]·8g	15·2g	10·6g	5·9g	10·8g	24·0g	0·0g	14·7g	0·0g	0·8g		
Ratio	0·28	1·35	1·09	0·28	0·13	0·48	0·4	0·46		0·56	1·0	0·66	0·62	0·36	1·13	0·2	0 2	0·32	0·48	1·97	0·59	0·42		0·24		0·8		
No. of species	6	5	3	4	1	2	1	4	0	4	3	5	2	3	1	3	1	6	6	3	3	6	0	5	0	1		

APPENDIX 1 continued

Table X :- Environmental variables

Subsite	X 1	111 3	1 1	11 1	11 2	11 3	11 4	111 1	111 2	111 3 R	11 5	IV 1	11 6	IV 2	V 1	V1 1	11 1 R	V11 1	11 7	V111 1	V111 2	V11 1	V11 2	IX 1	IX 2	IX 3
Date of sampling	1	1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	5
Weather pattern																										
a. Standing plant biomass(gm)	-	-	170	121	76	192	187	174	-	217	339	-	178	594	177	116	-	234	173	193	-	325	-	324	-	-
b. litter (gm)	-	-	100	137	175	135	82	352	1258	147	109	881g	170	583	215	3383	-	352	448	136	-	129	-	507	-	-
Total plant biomass(gm)	-	121	270	258	251	327	269	526	-	364	448	-	348	1171	392	3499	-	586	621	329	-	454	185	621	-	-
ratio b/a	-	-	0·59	1·13	2·30	0·7	0·44	2·02	-	0·68	0·32	-	0·96	0·91	1·21	29·16	-	1·50	2·59	0·70	-	0·40		1·56	-	-
Weighted R. max	-	-	1·34	1·34	1·35	1·38	1·36	1·25	0·58	1·48	1·22	1·42	1·36	0·61	1·37	1·15	-	1·33	1·35	1·24	1·33	1·33	1·54	1·26	1·20	1·29
Weighted C.I.	-	-	3·51	4·48	6·32	3·98	4·34	5·13	3·86	4·25	4·16	4·54	4·44	4·01	3·43	4·55	-	4·28	3·95	4·08	4·46	3·22	3·62	3·87	3·64	4·06
Shade factor	4	4	4	1	2	3	4	2	4	4	4	2	1	1	4	1	1	3	4	4	4	3	4	2	4	4
% ground cover	100	100	100	100	50	90	100	100	100	100	100	100	100	91	100	80	-	90	80	100	90	75	40	100	100	100
No. of species of higher plants	-	-	15	13	7	13	17	12	3	15	18	10	21	5	8	10	-	19	8	4	4	18	11	14	5	3
"soil" type	8	6	1	1	1	1	2	4	4	6	2	1	1		7	1	1	2	3	1	3	2	3	5	5	1
'moisture factor'	1	1	2	1	3	3	4	3	3	1	2	1	1	3	1	3	1	1	3	1	1	1	3	1	1	1
root mat depth(cm)	-	-	6·0	2·5	1·5	1·3	2·3	3·5	3·0	2·8	7·0	-	1·8	1·[illegible]	0·8	2·0	-	1·0	3·0	0·5	0·5	0·5	0.0	1·3	1·3	1·8
Homogeneity factor	-	3	2	1	4	4	-	4	-	3	2	3	1	4	-	4	1	3	1	-	1	3	-	3	-	-

APPENDIX 1 continued

Table X1 : Soil Analyses

Subsite	X 1	111 3	1 1	11 1	11 2	11 3	11 4	111 1	111 2
subsoil/topsoil	s.-t.	s t	s t	s t	s t	s t	s t	s t	s t
mean p.H.		6·0 6·8	4·5 4·5	6·2 6·2	5·9 4·6	3·1 3·0	4·6 4·5	3·8 4·7	3·7 3·6
% soil water loss	-	-	4 24	4 13	4 4	3 1	4 3	12 17	7 12
% dead organic matter	-	-	1 28	1 6	1 6	0 5	2 8	2 26	3 25
% loss on ignition	-	-	4 11	7 12	3 5	4 4	7 6	14 17	12 13

Subsite	111 3R	11 5	1V 1	11 6	1V 2	V 1	V1 1	11 1 8	V11 1
subsoil/topsoil	s t	s t	s t	s t	s t	s t	s t	s t	s t
mean p.H.	6·5 6·5	- 5·2	6·6 5·2	4·2 5·0	4·5 4·1	5·9 5.7	4·3 4·3	-	- 6·6
% soil water loss	4 12	- 16	5 20	5 11	12 17	18 20	14 36	-	- 24
% dead organic matter	3 14	11 5	0 5	3 6	1 11	-	-	-	-
% loss on ignition	12 14	8 9	6 9	6 14	7 9	-	-	-	-

Subsite	11 7	V111 1	V111 2	V11 2	V11 3	1X 1	1X 2	1X 3
Subsoil/topsoil	s t	s t	s t	s t	s t	s t	s t	s t
mean p.H.	6·1 5·6	3·9 6·2	- 6·0	6·8 6·7	5·2 5·3	- 6·3	- 6·4	- 6·1
% soil water loss	12 18		- 30	-	-	-	-	-
% dead organic matter	-	-	-	-	-	-	-	-
% loss on ignition	-	-	-	-	-	-	-	-

APPENDIX 2

Conversion of air-dry weights to oven-dry weights

Throughout the study the determination of standing plant biomass and litter weights was as air-dry weight. Normally, for comparative purposes, oven-dry weights would be determined. The bulk of the samples and the small capacity of the available oven-space made the determination of oven-dry weights difficult. Moreover, over the length of time that the field data was being collected (particularly in late May and early June) the vegetation was actively growing and thus similar samples collected, say, two weeks apart could be expected to differ substantially in dry weight.

For comparative purposes a correction factor was devised to convert air-dry to oven-dry weights. Eight samples were the basis for this correction factor. For each sample air-dry weight was determined as described in Chapter 2. Each was then transferred to a 105°C drying oven for twenty four hours and reweighed. A second reweighing after a further twenty four hours resulted in no further loss of weight.

Results :	Sample	Air-dry weight (gm)	Oven-dry weight (gm)	loss (gm)	% loss
	1	28·0	25·0	3·0	10·7
Biomass	2	24·0	21·5	2·5	10·4
	3	17·7	16·0	1·7	9·6
	4	15·5	14·0	1·5	9·7
	5	35·2	31·7	3·5	9·9
Litter	6	31·7	27·2	4·5	14·2
	7	29·0	25·8	4·8	16·5
	8	24·3	21·0	3·3	13·6

Correction factors : Standing plant biomass - 10%

plant litter - 14%

Table X11

Conversion from air dry to oven dry weight

APPENDIX 3

Occurrence of higher plants on mineral spoil or rubble

Species	Occurrence(%)	Species	Occurrence(%)
Equisetum arvense.	4	Quercus sp.	4
Pteridium aquilinum.	3	Salix sp.	0
Ranunculus repens.	3	Calluna vulgaris.	10
Cerastium vulgatum.	12	Linaria vulgaris.	3
Arenaria serpyllifolia.	4	Prunella vulgaris.	1
Acer pseudoplatanus.	15	Plantago lanceolata.	38
Ulex europaeus.	5	Galium verum.	1
Medicago lupulina	7	Galium saxatile.	2
Trifolium repens.	20	Galium aparine.	1
Trifolium pratense.	4	Sambucus nigra.	1
Lotus corniculatus.	10	Lonicera periclymenum.	1
Vicia cracca.	12	Senecio jacobaea.	1
Lathyrus pratensis.	9	Tussilago farfara.	7
Rubus idaeus.	1	Achillea millefolium.	16
Rubus fruticosus.	12	Cirsium sp.	7
Potentilla erecta.	1	Centaurea nigra.	8
Fragaria vesca.	1	Hypochoeris radicata.	8
Alchemilla vulgaris.	2	Leontodon Lispidus.	2
Rosa sp.	1	Hieracium pilosella.	6
Crataegus monogyna.	10	Hieracium vulgatum.	29
Chamaenerion angustifolium.	14	Taraxacum officinale.	3
Aegopodium podagraria.	2	Luzula campestris.	1
Heracleum sphondylium.	10	Carex sp.	1
Rumex acetosella.	1	Molinia caerulea.	1
Rumex acetosa.	2	Festuca sp.	47
Rumex obtusifolius.	1	Lolium perenne.	5
Betula sp.	0	Poa pratensis.	9

Species	Occurrence (%)
Dactylis glomerata.	31
Cynosurus cristatus.	1
Arrhenatherum elatius.	18
Holcus sp.	24
Deschampsia caespitosa.	7
Deschampsia flexuosa.	19
Agrostis sp.	60
Phleum pratense.	3
Alopecurus pratensis.	2
Anthoxanthum odoratum.	1

Note:

Since the sample units only recorded the ground flora the occurrences of tree species listed reflect only the number of seedlings. It is noteworthy, if odd, that Betula and Salix which occur as scrub on a number of sites had no seedling occurrences whereas Quercus, Acer and Crataegus, much less common as scrub, do occur as seedlings.

Species are listed in taxonomic order after:

Clapham, A.R., T.G. Tutin and E.F. Warburg : Excursion Flora of the British Isles : Cambridge 1959.

APPENDIX 4.

Classification of sites by reference to plant strategies.

Grime (1974) sought to develop a method of vegetation classification to include recent or unstable vegetation, to avoid unnecessary abstraction and provide data intellegible to non-specialists. These considerations seem highly relevant to studies of influences on the fauna of young, recently colonised mineral spoil.

His method is based on the assertion that there are three basic determinants of herbaceous vegetation - competition, stress and disturbance - and that each has invoked a distinct strategy on the part of the flowering plant. His triangular ordination model consists of an equilateral triangle in the corners of which the three determinants reach their respective maxima. Each species is placed within the triangular model in relation to two axes. One axis in the ordination (the Competitive Index) was a numerical index based upon estimates of the maximum height of canopy, lateral spread of canopy and litter accumulation. The maximum score for height of canopy was twice that allowed for the other two elements. The second axis (R. max.) was the maximum relative growth rate (gms per gm. per week) determined in a standardised productive environment 2 - 5 weeks after germination.

In classifying the vegetation of specific habitats the values for individual species were weighted according to the relative frequency of the species in the 1 $m.^2$ sample. In this study that is the frequency of occurrence (1 - 5) in the five 0·2 m^2 sample units. The R. max. and Competitive Index data for individual species were obtained from Dr. K. Thompson, Botany dept., Durham University. Data for woody species were not available, since the system is one for classifying herbaceous vegetation, so that ordination of scrub sites was based only on ground flora. A number of other species had not had their R. max. determined but their exclusion in calculating the weighted R. max. for each site did not appear to have a significant effect.

Calculated, weighted values of R. max. and Competitive index are given in table X11 1

Table X111 eighted R. max. and Competitive Index data

Site	1 1.	11 1.	11 2.	11 3.	11 4.	11 5.	11 6.	11 7.	111 1.	111 2.	111 3.
Weighted R. max.	1·34	1·34	1·35	1·38	1·36	1·22	1·36	1·35	1·25	0·58	1·48
Weighted C. I.	3·51	4·48	6·32	3·98	4·34	4·16	4·44	3·93	5·13	3·86	4·25
Total occurrences	35	29	21	31	38	45	38	28	22	11	40
Occurrences with known C.I.	34	20	17	29	38	45	33	28	20	11	40
Occurrences with known R. max.	26	12	12	19	32	30	24	24	15	10	29

Site	1V 1	1V 2	V 1	V1 1	V11 1	V11 2	V11 3	V111 1	V111 2	1X 1	1X 2	1X 3
Weighted R. max.	1·42	0·69	1·37	1·15	1·33	1·33	1·54	1·24	1·33	1·26	1·20	1·29
Weighted C. I.	4·45	4·04	3·45	4·55	4·28	3·22	3·62	4·08	4·46	3·87	3·64	4·06
Total occurrences	18	13	21	18	33	43	21	12	12	31	11	9
Occurrences with known C. I.	13	13	20	15	30	43	21	12	12	31	11	9
Occurrences with known R. max.	9	12	19	11	27	30	17	12	12	27	10	9

5. SUMMARY

A study was made of the earthworm populations of a range of sites with a young mineral substratum derived from sand and clay extraction or the dumping of colliery spoil.

Natural recolonisation of these sites, under favourable conditions, produced a varied vegetational cover resembling that of hedgerow or roadside verge in floristic composition. Thirteen earthworm species typical of mull woodland soils were found, though species composition of individual sites varied with soil p.H. and moisture. L. rubellus (possibly with L. castaneus) proved to be the pioneer earthworm species with good tolerance of low p.H. A. rosea, A. caliginosa and A. longa, on the other hand, were found in less acid and moister sites. Sampling of all species changed in efficiency during the drought in the early part of the study period due mainly to diapause.

The moisture regime of the site proved to be critical for earthworm populations. An arbitrary scaling of sites according to topography seemed to reflect the moisture regime and to correlate with earthworm biomass for the most productive sites at each point on the "moisture factor" scale. Where the water regime was favourable highest earthworm biomass developed in young close-canopy woodland and in much older, mature grassland. Biomass (gm. $m.^{-2}$) was closely similar to published data for similar habitats.

The particular substratum had a less marked effect on earthworm populations than water regime and management.

It is concluded that such sites,after the development of natural communities,have considerable potential as visual and informal recreational resources or as nature reserves. Where a return to more intensive use is obligatory greater problems of management arise.

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