Soil Fauna Colonization of High Elevation Coal Mine Spoils in the Canadian Rockies

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ABSTRACT

The soil arthropods, nematodes and enchytraeids colonizing high elevation coal mine spoils near Sparwood, British Columbia, were extracted from 2, 5, and 9-year-old reclaimed spoils and undisturbed subalpine meadow soil, over a 4-month period during 1982. This information was then interpreted in view of certain biological and physical site features, to facilitate recommendations regarding current reclamation techniques and objectives.

The number of taxa increased with site age, as did the mean density of most soil fauna. Early colonizers were probably opportunistic species exhibiting tolerance to adverse environmental conditions, good dispersal abilities, high reproductive rates, and subsequent rapid density increases in response to fertilization. These initial colonizing fauna were probably plant, bacterial, or unspecialized feeders. Undisturbed subalpine meadow soil had considerably higher numbers of taxa and densities of microarthropods than reclaimed mine spoils. Mites numerically dominated the microarthropod fauna in all sites; most mites were of the suborder Prostigmata, and most prostigmatid mites were Tydeidae. Some members of this and the other abundant prostigmatid families have been reported to be early colonizers, and to occur predominantly in soils with a low organic matter content.

Collembolans and insects were minor contributors to the total soil fauna, although hypogastrurid collembolans did exhibit high densities on the 5-year site. Soil insect populations were predominantly Coleoptera and Diptera larvae, with an abundance of Thysanoptera on the youngest reclaimed site.

Soil nematodes were rare on the youngest reclaimed site, yet abundant in the remaining three sites. Nematode densities were lower in the undisturbed subalpine meadow soil than normally reported in undisturbed temperate grasslands, perhaps as a result of predation pressures by tydeid mites. Enchytraeid worms occurred mainly in undisturbed meadow soil.

A general pattern of increasing microarthropod densities over the 4-month sampling period was observed on most sites. Nematodes on the three oldest sites exhibited similar high densities in June and August, possibly reflecting synchronized reproductive peaks.

Poor soil physical conditions on all reclaimed sites is reflected in the occurrence of most soil fauna in the upper 3 cm. This trend was not observed between 0-3 cm and 3-7 cm depths on the subalpine meadow site, due to more amenable soil conditions.

Soil fauna colonization on these sites increased at a high rate of change during the early successional period (ie. between the 2 and 5-year sites), with no significant increase in faunal densities later in the successional sequence (ie. between the 5 and 9-year sites). A similar pattern was observed with increases in root, litter and above-ground biomass with site age. Decreases in pH and coarse fragment content, and increases in percent soil moisture, cation exchange capacity and soil nitrogen levels were also observed with increasing site age, due primarily to the weathering of spoil material and the accumulation of organic matter from decomposition processes. However, soil fauna and most soil physical conditions still differed considerably between the oldest reclaimed and subalpine meadow sites.

Given the paucity of important decomposer fauna on these sites, mites and collembolans probably play an important role in the decomposition process. Reclamation efforts should attempt to create microsites conducive to developing beneficial soil fauna populations. Mulch or topsoil applications may provide both favorable microsites, or sources of colonizing soil fauna and flora. The introduction of non-native beneficial species such as earthworms may also prove useful.

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TABLE OF CONTENTS

ABSTRACT ii

TABLE OF CONTENTS v

LIST OF TABLES vii

LIST OF FIGURES viii

ACKNOWLEDGEMENTS x

Chapter I: INTRODUCTION 1

DESCRIPTION OF THE STUDY AREA 3
The mining and reclamation process 7
Study sites 7

Chapter II: METHODS 12

1. FIELD SAMPLING 12
2. LABORATORY ANALYSES 13
3. DATA ANALYSES 15

Chapter III: RESULTS 16

1. ABUNDANCE PATTERNS 16
a) Microarthropods 16
Total microarthropods 21
Major taxonomic groups 31
Mite suborders 39
b) Microarthropod densities - subalpine forest 48
c) Nematodes and Enchytraeids 49
2. TEMPORAL PATTERNS 53
a) Microarthropods 53
b) Nematodes and Enchytraeids 58
3. VERTICAL DISTRIBUTION IN THE SOIL 61
a) Microarthropods 61
b) Nematodes and Enchytraeids 66

Chapter IV: DISCUSSION 71

1. SOURCES OF COLONIZING ORGANISMS 71
2. MITES 72
    Prostigmata 75
    Mesostigmata 76
    Cryptostigmata 77
    Astigmata 78
3. COLLEMBOLANS 79
4. INSECTS 81
5. OTHER ARTHROPODS 83
6. NEMATODES AND ENCHYTRAEIDS 84
7. VERTICAL DISTRIBUTION IN THE SOIL 86
8. RELATIONSHIPS BETWEEN SOIL FAUNA AND ECOSYSTEM DEVELOPMENT 88
9. IMPLICATIONS FOR RECLAMATION 90

Chapter V: SUMMARY AND CONCLUSIONS 92

REFERENCES 97

Appendix A: LIST OF TAXA EXTRACTED FROM STUDY SITES 113

Appendix B: SPEARMAN CORRELATION COEFFICIENTS BETWEEN SOIL FAUNA ABUNDANCE AND MOISTURE CONTENT OF EACH SOIL CORE, FROM EACH STUDY SITE. 119

LIST OF TABLES

1. Biological and physical characteristics of study sites. 11

2. The ten most abundant microarthropod taxa extracted from each study site. 19

3. Sørenson's Quotient of Similarity (%), indicating taxonomic affinities between sites. 20

4. Effects of site and month on total microarthropod abundance. 22

5. Effects of site and month on abundance of major microarthropod taxonomic groups. 33

6. Effects of site and month on abundance of mite suborders. 40

7. Effects of site and month on total nematode abundance. 50

8. Paired-sample t tests of total microarthropod densities at 0-3 and 3-7 cm soil depths. 62

9. Paired-sample t tests of microarthropod taxonomic group densities at 0-3 and 3-7 cm soil depths. 63

10. Paired-sample t tests of mite suborder densities at 0-3 and 3-7 cm soil depths. 67

11. Paired-sample t tests of nematode and enchytraeid densities at 0-3 and 3-7 cm soil depths. 68

12. Comparison of mean densities of mites and collembolans on reclaimed land, from various authors. 74

LIST OF FIGURES

1. Location of the study area. 5

2. Photograph of reclaimed areas 10

3. Total number of taxa extracted from each study site. 18

4. Microarthropod densities from each study site. 24

5. Percent soil moisture relative to site age. 26

6. Non-centered principal components ordination of all sites. 28

7. Non-centered principal components ordination of reclaimed sites. 30

8. Densities of major taxonomic groups from each study site. 35

9. Percent relative abundance of major taxonomic groups from each study site over 4-month sampling period. 38

10. Densities of mite suborders from each study site. 42

11. Percent relative abundance of mite suborders from each study site over 4-month sampling period. 45

12. Percent relative abundance of Tydeidae with respect to total Prostigmata from each site over 4-month sampling period. 47

13. Nematode densities from each study site. 52

14. Density of microarthropods from each site over the 4-month sampling period. 55

15. Non-centered principal components ordination for month of July, all sites. 57

16. Nematode densities from each study site over the 4-month sampling period. 60

17. Microarthropod densities with depth from each study site. 65

18. Nematode densities with depth from each study site. 70

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Chapter I

INTRODUCTION

Fresh mine spoils initially represent the first stage in primary succession and include few soil invertebrates and microflora. As organic matter accumulates, ecosystem development is modified by the activities of soil microorganisms which influence soil structure, nutrient cycling, and subsequent primary productivity (Wallwork 1976, Zlotin and Khodashova 1980, Petersen and Luxton 1982). In developing or mature soils, invertebrates ingest and fragment dead organic material, thus enabling further leaching of soluble minerals and increasing available surface area for decomposition by microflora (Curry 1969, Madge 1969, Lebrun 1979, Petersen and Luxton 1982). Their feeding activities improve soil structure, stimulate microbial growth (Lebrun 1979, Trofymow and Coleman 1982), disperse fungal and bacterial spores (Behan and Hill 1978) and translocate nitrogen-rich materials upwards from deeper soil horizons (Dindal 1985). Soil drainage and aeration may be improved by physical mixing of the soil (Mermut 1985, Edwards *et al.* 1970), and by opening passages occupied by decaying roots (Ghilarov 1975). Soil invertebrates help to accelerate the mineralization of nutrients by supplying additional organic material through dead bodies, secretions and fecal pellets (Petersen and Luxton 1982, Dindal 1985). They may also be important for the internal retention and cycling of nitrogen and phosphorus ions, thus contributing to ecosystem stability by preventing excessive fluctuations in nutrient availability (Petersen and Luxton 1982).

Little information exists on the structure and species composition of soil faunal communities on reclaimed coal mine spoils in North America. Most research on the refaunation of mine spoils has been done in Britain and Germany. A number of these studies focussed on a wide range of soil fauna (Brüning *et al.* 1965, Dunger 1968a 1969b, Remus 1969, Hutson 1980a,b); others concentrated on mites and/or collembolans (Davis 1963, Dunger 1968b, Bode 1975, Luxton 1982, Koehler 1985), earthworms (Dunger 1969a), or larger insects (Neumann 1973). Most of these studies were on spoils from low-elevation, lignite coal operations with adequate topsoil reserves. Spoil materials were most often reclaimed to productive pastureland, or forests. Similar work on colonization of Australian sand mines by ants was documented by Majer *et al.* (1982), and Majer (1984).

In North America, soil faunal colonization work has concentrated mainly on earthworms (Vimmerstedt and Finney 1973, Hamilton and Vimmerstedt 1980, Vimmerstedt 1983), termites (Ettershank *et al.* 1978), or nematodes (Stanton and Krementz 1982) on reclaimed coal mine spoils in the eastern or southwestern United States. Dindal and Wray (1977), however, studied the larger invertebrate fauna of limestone quarries, and Cross and Wilman (1982) investigated the colonization of Alabama coal spoils by a variety of soil fauna, predominantly mites and collembolans. In the Canadian Rocky Mountains, Parsons (1983), and Parsons and Parkinson (1986) investigated the colonization of coal spoils by Collembola and also supplied limited information on mites and Diptera larvae.

The goals of this study were:

1. to describe the soil fauna colonizing reclaimed high elevation coal mine spoils in the Rocky Mountains of southeastern British Columbia;
2. to compare this information with data from an undisturbed subalpine meadow on a physically similar site;
3. to describe the variation in composition and abundance of taxa in relation to selected site features; and
4. to relate this information to current reclamation techniques and objectives.

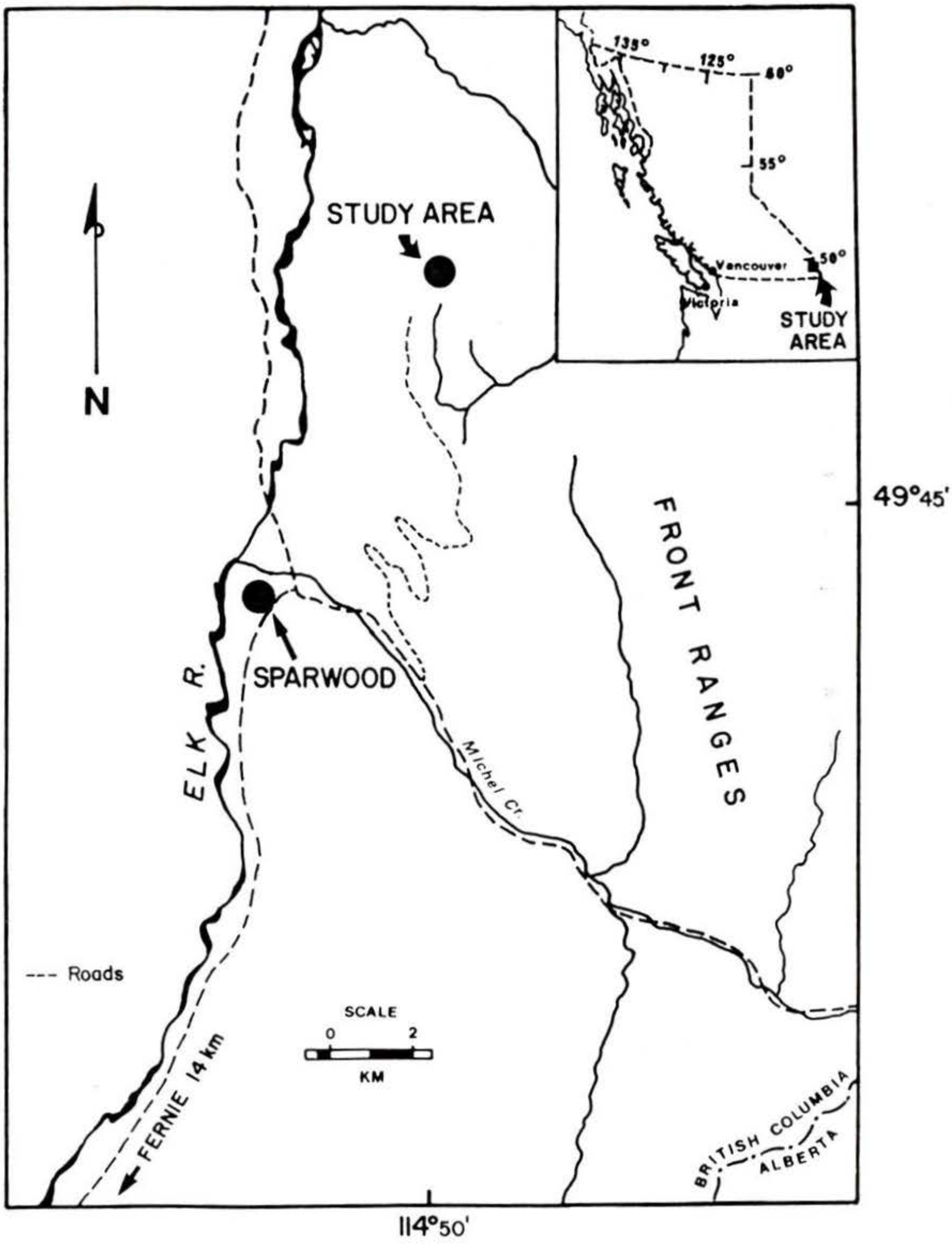
DESCRIPTION OF THE STUDY AREA

The study area is situated on a series of reclaimed coal mine waste dumps on the property of Westar Mining Ltd., near the village of Sparwood in the Rocky Mountains of southeastern British Columbia (Figure 1). These dumps lie along the summit of a high ridge, at an elevation of roughly 2000 m.

The topography is characterized by moderate to abruptly sloping ridges and peaks rising above broad glacial valleys. The major stratigraphic units of the study area are composed of soft, Mesozoic sandstones, siltstones, mudstones and conglomerates, with carbonaceous shales and fine to medium-grained sandstones in the coal-bearing formations (Price 1962, Gibson 1977, Dick 1978). The coal is low to medium volatile bituminous, with a low sulphur content (0.3-0.5%)(Dick 1978).

The area was extensively glaciated and at higher elevations, appreciable amounts of till are found only in gullies or depressions (Dick 1978). Soils under

Figure 1: Location of the study area.


N
STUDY AREA
135°
125°
60°
55°
50°
Vancouver
Victoria
STUDY AREA
49°45'
FRONT RANGES
SPARWOOD
ELK R.
Michel Cr.
--- Roads
SCALE
0
2
KM
FERNIE 14 km
BRITISH COLUMBIA
ALBERTA
114°50'

coniferous forests are mainly shallow Dystric Brunisols and Humo-Ferric Podzols, while Sombric Brunisols or Humic Regosols with thick Ah horizons (10-40 cm) occur on steep, southerly-facing native grasslands (Canada Soil Survey Committee 1978, Wittneben and Lacelle 1978, Ziemkiewicz 1979, Fyles 1984).

Prior to mining, the vegetation of the study area was predominantly subalpine forest of *Pinus albicaulis* Engelm., *P. contorta* Dougl., *Abies lasiocarpa* (Hook)Nutt. and *Picea engelmannii* Parry, with an understory of *Rhododendron albiflorum* Hook., *Menziesia ferruginea* Smith, *Vaccinium membranaceum* Dougl. and *V. scoparium* Leiberg. Native grassland species included *Festuca idahoensis* Elmer, *Lomatium dissectum*(Nutt.)Math.&Const., *Eriogonum umbellatum* Torr., *Carex hoodii* Boott, and scattered *Spiraea betulifolia* Hook. and *Rosa woodsii* Lindl. (Fyles *et al.* 1985). The area lies within the Engelmann Spruce - Subalpine Fir Biogeoclimatic Zone (Krajina 1965).

The climate of the study area may be described as continental cold humid (Dick 1978). Snow may occur in all months of the year, and accounts for approximately 78% of the annual precipitation of 855 mm. Precipitation is heaviest between November and February. The mean annual temperature is 4.5°C, with average temperatures of 12°C occurring in July, the warmest month, and average temperatures of -11°C occurring in January, the coolest month. In general, the growing season is short (averaging 4 months), cool and moist, with only 61 average frost-free days (Dick 1978). Data for the nearest climate recording station (2 km southwest of the reclaimed areas and 150 m lower in elevation) are summarized in Fyles *et al.* (1985). It is expected that temperatures on the reclaimed sites are slightly lower, and precipitation slightly higher than those recorded.

The mining and reclamation process

The mine is an open pit operation, in which rock material overlying the coal seams is blasted and removed by shovel and truck. This overburden material, consisting of differing combinations of sandstone and mudstone, is deposited in successive layers in large wrap-around dumps. The small amounts of topsoil present are not conserved, but become mixed with the overburden during blasting and removal.

Spoil overburden is resloped to an angle of 28° or less, and surfaces are loosened using a heavy pipe-stem harrow. This creates a highly permeable surface layer about 10 cm deep. The spoil is often severely compacted below this by the weight of heavy machinery, and may restrict downward movement of water and root penetration (Fyles 1984).

After harrowing, seed and fertilizer are broadcast by helicopter. The seed mixture includes the agronomic grasses *Festuca rubra* L., *Dactylis glomerata* L., *Poa pratensis* L. and *Alopecurus pratensis* L., and the legumes *Trifolium hybridum* L. and *Medicago sativa* L. Once reclaimed sites are established, fertilizer is applied annually at a rate of 200 kg/ha 13-16-10 (N-P-K).

Study sites

Three reclaimed areas, aged 2, 5 and 9 years since reclamation were chosen for study. The 2-year and 5-year sites were reclaimed in the fall of 1980 and 1977, respectively, while the 9-year site was reclaimed in the spring of 1974. These sites were originally seeded with agronomic species and fertilized annually until 1982 with the exception of the 9-year site, which was not fertilized in 1979 and 1980. Part of the 9-year reclaimed area was a construction site prior to 1974, and never received actual overburden mine spoil, although parent materials were similar. A typical reclaimed site and soil profile are shown in Figure 2. All reclaimed soils were Orthic Regosols (Canada Soil Survey Committee 1978).

The fourth study site, an undisturbed subalpine meadow, occurred nearby (0.3 km) on south-east facing, steeply sloping sandstone colluvium similar to the waste rock of the reclaimed sites, but with smaller proportions of siltstone, mud-stone (Fyles 1984) and coarse fragments. The soil type of the meadow was a Humic Regosol, with an Ah layer of at least 0.5 m, overlying a C horizon of colluvium (David F. Fraser 1986, personal communication). The meadow vegetation was composed entirely of native species, particularly *Festuca idahoensis* Elmer, *Poa* spp., *Aster conspicuus* Lindl., *Lomatium dissectum* (Nutt.)Math.&Const., *Lupinus sericeus* Pursh, and *Amelanchier alnifolia* Nutt. Table 1 summarizes a number of physical and biological features for each study site.

Figure 2: Photograph of reclaimed areas

a) Typical reclaimed site.

b) Soil profile of the 2-year site.

10

Table 1: Biological and physical characteristics of study sites.

	2-year site (1980)	**5-year site (1977)**	**9-year site (1974)**	**100+ years (subalpine meadow)**
elevation (m)	1945	2025	2075	2055
above-ground standing crop[1] ($g\ m^{-2}$ August 1982)	109.1 ± 12.9	150.1 ± 21.9	170.9 ± 40.9	170.2 ± 32.7
litter biomass[2] ($g\ m^{-2}$ August 1982)	8.2 ± 1.9	379.7 ± 64.3	274.4 ± 69.1	283.9 ± 51.7
root biomass[3] ($g\ m^{-2}$ August 1982)	315	600	725	650
clay (%)[3]	21	24	27	30
coarse fragments (%)[3]	80	80	70	24
pH[3]	7.1	7.0	6.5	6.7
CO_2 evolution[3] ($mg\ C\ g^{-1}$ soil 11 $days^{-1}$)	0.4	1.2	1.2	2.3
microbial C/N ratio[3] (August 1982)	89	27	34	12
cation exchange capacity[3] ($meq\ 100\ g^{-1}$)	8.1	11.9	13.7	39.7

[1] All green, above-ground plant material clipped from inside 15, $0.25 m^2$ frames, oven-dried at 80^o C, and weighed. Data are means ± 95% confidence intervals.

[2] All surface and standing dead plant material collected from inside 15, $0.25\ m^2$ frames, oven-dried at 80^o C, and weighed. Data are means ± 95% confidence intervals.

[3] Data from Fyles (1984). All soil depths to 10 cm.

Chapter II

METHODS

1. FIELD SAMPLING

Study plots were established on level reclaimed ground, within an elevational range of 130 m. The 2, 5 and 9-year sites were located 1100, 300 and 100 meters from undisturbed subalpine forest, respectively. All reclaimed sites were over 300 m from the subalpine meadow.

One 144 m^2 plot (8 m x 18 m) was established on each of the four study sites. Plots consisted of a grid of 50 sampling points, located at 2 m intervals. Two soil cores were taken from 10 randomly-located sampling points at monthly intervals between May and August, 1982. An additional 8 cores in 1983 and 12 cores in 1985 were taken from randomly-located transects in the previously-mentioned subalpine forest to allow for certain limited comparisons between the fauna of reclaimed mine spoils, undisturbed grassland soil and undisturbed forest soil. Cores were taken with a treeplanting shovel trimmed to 6 cm in diameter and driven into the coarse, rocky spoil with a hammer, to a depth of approximately 10 cm. Each core was divided into two samples of 0-3 cm and 3-7 cm depths, allowing for the angle at which the shovel was driven into the spoil. Samples were weighed, packed in ice, and transported to Victoria for extraction and analysis. Extractions were always started within seven days of sampling.

2. LABORATORY ANALYSES

Soil fauna were extracted from 640 samples at the soil zoology laboratory at the Canadian Forestry Service, Pacific Forestry Centre, Victoria B.C. The soil core pairs from each sampling point were extracted for either microarthropods or nematodes. Microarthropod cores were trimmed to a diameter of 5.7 cm and nematode cores to a diameter of 5.8 cm, to fit sample holders.

Eighty microarthropod samples (4 sites x 10 cores per site x 2 samples per core) were extracted each month into 2:1 (V:V) saturated picric acid:distilled water, using a modified high gradient Lussenhop extractor (Lussenhop 1971) for 72 samples, and 8 samples into 70% ethanol, using Berlese funnels. Microarthropods were transferred to 70% ethanol by vaccuum-filtering through a fine porosity sintered glass funnel, and washing with 70% ethanol until no picric acid remained. Particularly dirty samples were treated by adding kerosene, gently shaking, and vacuum-filtering the kerosene with 70% ethanol (Ettershank 1963). The extracted soil samples were oven dried for 24 hours at 110°C, weighed, and percentage moisture determined.

A further 80 samples were extracted for nematodes and enchytraeids using modified Baermann funnels (O'Connor 1962) at 20°C, 45% relative humidity, and no additional heat or light. Soil samples were inverted in a double-walled sample holder with the bottom screen lined with facial tissue. Each sample was placed in a glass funnel and partly submerged with distilled water.

After 48 hours the bottom 35 ml of water was drawn off, and any enchytraeids present were counted and placed in 80% ethanol. After 7 days an additional 35 ml of water was drawn off, allowed to settle for 24 hours, and all but 10 ml carefully drawn off and discarded. Nematodes were transferred to 25 ml vials using 95% ethanol, and allowed to settle. Ten ml were removed, and ethanol added to bring the final concentration to at least 70%.

Prior to counting, nematode samples were split into aliquots using a Folsom plankton sample splitter (McEwen *et al.* 1954). All microarthropod and nematode samples were counted using a Leitz dissecting microscope equipped with a cross-motion stand. To save time, only half of the 40 microarthropod cores taken from the undisturbed subalpine meadow soil were counted.

Nematodes were identified to phylum, and enchytraeids to family. Classification for all arthropods except Acari followed Danks (1979). Acarine taxonomy followed Krantz (1978). Acari and Collembola specimens were identified to Family, and verified by Dr. V.G. Marshall, Pacific Forestry Centre. Voucher specimens were deposited in the Soil Zoology Museum at the Pacific Forestry Centre, Victoria. Throughout this thesis, Acari will be referred to as mites, or more specifically, their commonly-used suborder names Mesostigmata, Prostigmata, Astigmata and Cryptostigmata.

The terms 'abundance' and 'density' are used interchangeably throughout this thesis to refer to numbers of individuals per unit area. 'Relative abundance' expresses the number of individuals of any particular taxon relative to the total number of individuals of all taxa (Wallwork 1976).

3. DATA ANALYSES

For all analyses not specifically addressing faunal densities with depth in the soil, counts from the 0-3 cm and 3-7 cm samples of each soil core were added together and mean faunal densities determined usint total core sums. Overall site means were determined using soil core densities from all months sampled.

Two-way ANOVAs were used to compare mean faunal densities between sites and months using total microarthropods, major taxonomic groups (nematodes, enchytraeids, mites, collembolans, insects and other arthropods), and mite suborders (Mesostigmata, Prostigmata, Astigmata, and Cryptostigmata). Data were first tested for homogeneity of variance (F-max test, Sokal and Rohlf 1981). As most data were not homogeneous, the Log10(x+1) transformation was applied, and all analyses were subsequently done on transformed homogeneous data. Differences between means were tested using Duncan's multiple range test (Duncan 1955). The probability level for all statistical tests was set at $P=0.05$.

Transformed Log10(x+1) microarthropod soil core densities were ordinated by both non-centered principal components analysis (PCA) (Gauch 1977) and detrended correspondence analysis (DCA)(Hill 1979). As ordination results were similar with both techniques, those of the simpler non-centered PCA are given herein.

Chapter III

RESULTS

1. ABUNDANCE PATTERNS

a) Microarthropods

Fifty-nine major arthropod taxa were extracted and identified over the sampling period (Appendix A). The number of taxa extracted increased with site age (Figure 3). Numbers of taxa were similar between samples from the forest and the undisturbed subalpine meadow. The ten most abundant taxa from each site are shown in Table 2.

The affinity between sites on the basis of the number of taxa extracted from each site and the number of taxa common to site pairs is indicated by Sørenson's quotient of similarity (Wallwork 1976) (Table 3). Sites closest in age were the most similar. The subalpine meadow showed its highest affinity with the oldest reclaimed site and the subalpine forest. The oldest reclaimed site was more similar to the subalpine meadow than to the subalpine forest.

Figure 3: Total number of taxa extracted from each study site. Subalpine forest included for comparison.

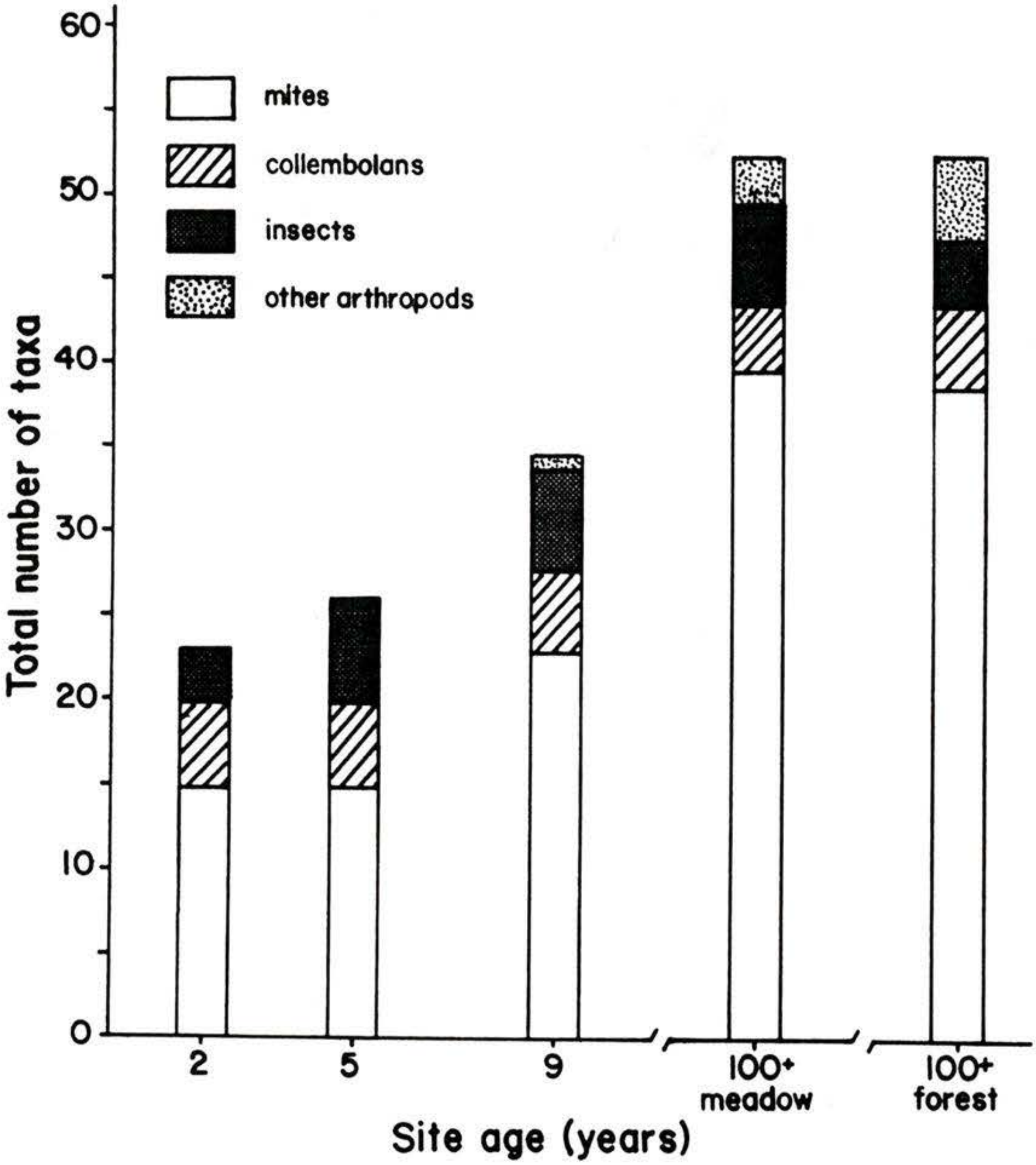

mites
collembolans
insects
other arthropods
Total number of taxa
0
10
20
30
40
50
60
2
5
9
100+ meadow
100+ forest
Site age (years)

Table 2: The ten most abundant microarthropod taxa extracted from each study site.

P = Prostigmata (mite), M = Mesostigmata (mite), Cr = Cryptostigmata (mite), C = collembolan, I = insect. Numbers indicate total relative abundance in percent.

		Site (by age)			
Taxon		**2-year**	**5-year**	**9-year**	**100+ years (meadow)**
(total taxa extracted)		**(23)**	**(26)**	**(35)**	**(54)**
Tydeidae	P	42.0	48.2	53.8	51.7
Tarsonemidae	P	11.3	4.1	13.8	13.4
Brachychthoniidae	Cr	1.8			12.8
Pygmephoridae	P	0.9	5.1	10.0	4.6
Eupodidae	P	1.1	1.2	1.0	
Onychiuridae	C		2.9	1.3	3.7
Hypogastruridae	C		32.9	3.7	
Nanorchestidae	P	21.0	2.1	5.5	3.3
Alicorhagiidae	P		0.8		2.1
Thysanoptera	I	6.9		1.2	
Tetranychidae	P	5.6			
Entomobryidae	C	1.7			
Phytoseiidae	M		0.4		
Ascidae	M			1.4	
Oppiidae	Cr		0.4		1.2
Gehypochthoniidae	Cr				1.2
Isotomidae	C	2.1		3.2	0.3
Others		5.6	1.9	5.1	5.7

Table 3: Sørenson's Quotient of Similarity (%), indicating taxonomic affinities between sites.

Site (by age)	2	5	9	Meadow 100+	Forest 100+
2	–	85.7	75.9	54.5	57.9
5		–	82.0	57.5	58.2
9			–	70.5	65.9
(meadow) 100+				–	72.9
(forest) 100+					–

Total microarthropods

Mean densities of all soil microarthropods over the sampling period increased with site age (Figure 4), although there was no significant difference between mean densities on the 5 and 9-year sites (Table 4). The undisturbed subalpine meadow had significantly greater soil faunal abundances than the reclaimed areas. Significantly lower abundances were observed on the 2-year site.

Mean percent moisture of extracted soil cores increased with site age (Figure 5). No significant correlations were found at any site between total microarthropod abundance and average percent moisture of each soil core (Appendix B).

The PCA of microarthropod cores from all sites and months shows a clear separation of all undisturbed subalpine meadow cores in ordination space from all reclaimed site cores (Figure 6). Within the reclaimed sites, soil cores from the 2-year site are clustered together in ordination space, while soil cores from the 5 and 9-year sites are more dispersed.

When reclaimed site cores were ordinated without the subalpine meadow data, 2-year soil cores form a fairly distinct cluster. Some separation is evident between 5 and 9-year soil cores (Figure 7), however, a high variability within these samples is indicated by the scattered distribution of points in ordination space.

Table 4: Effects of site and month on total microarthropod abundance.

TWO-WAY ANOVA

Factor	DF	Probability
Site	3	<0.001
Month	3	<0.001
Site x month	9	<0.003

DUNCAN'S MULTIPLE RANGE TEST

Site (by age)		n	Month		n
2	a[1]	40	May	a	31
5	b	40	June	b	35
9	b	35	July	b	35
100+	c	20	August	c	34

[1] Sites or months with the same letter(s) did not differ significantly at $P = 0.05$.

Figure 4: Microarthropod densities from each study site. Data are means ± 95% confidence intervals. n=40, 40, 35 and 20 for the 2, 5, 9-year and subalpine meadow sites, respectively.

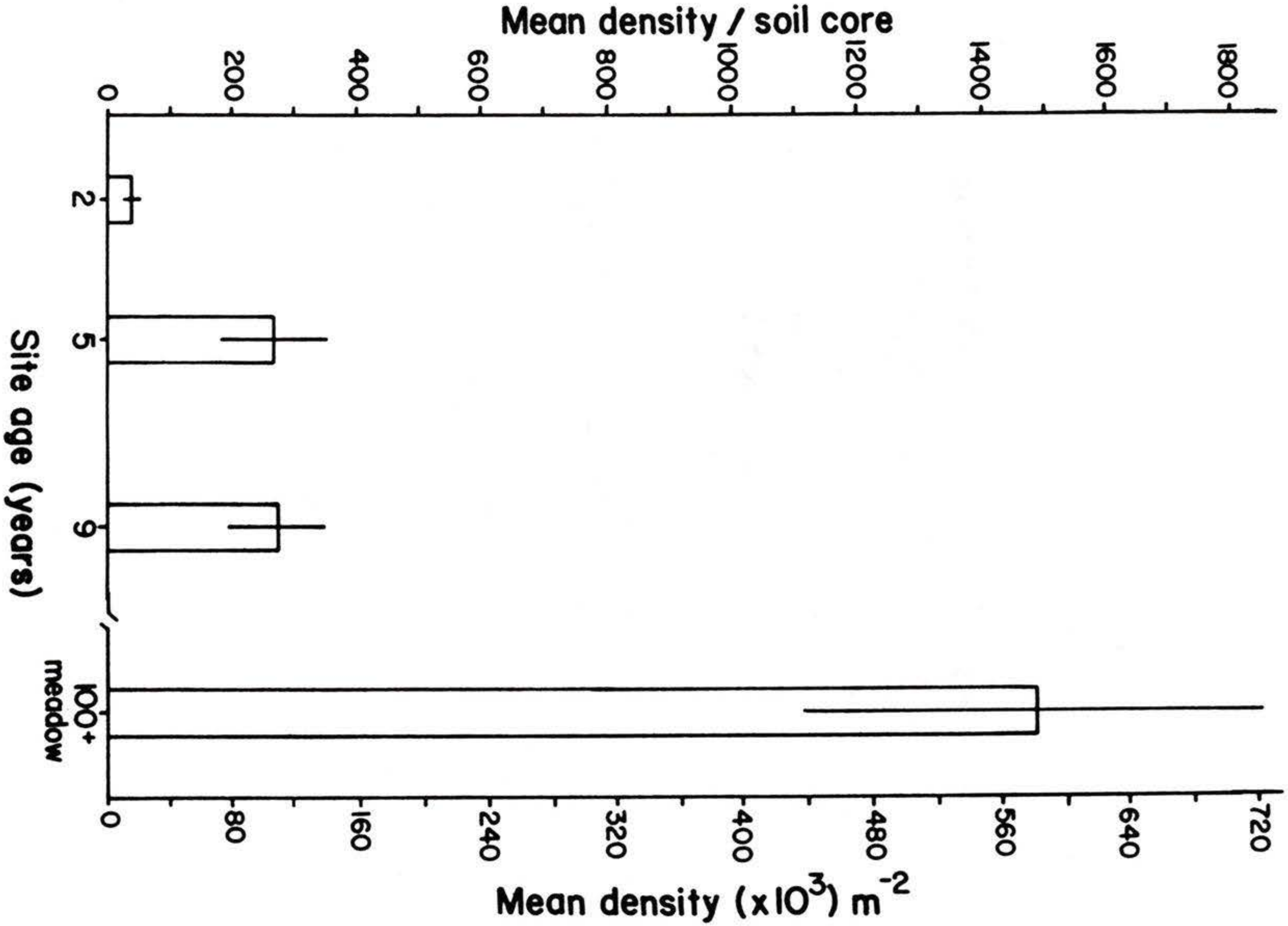

Mean density / soil core
0
200
400
600
800
1000
1200
1400
1600
1800
Site age (years)
2
5
9
100+
meadow
0
80
160
240
320
400
480
560
640
720
Mean density $(\times 10^3)$ m^{-2}

Figure 5: Percent soil moisture relative to site age. Data are means ± 95% confidence intervals. n=40, 40, 40 and 20 for the 2, 5, 9-year and subalpine meadow sites, respectively.

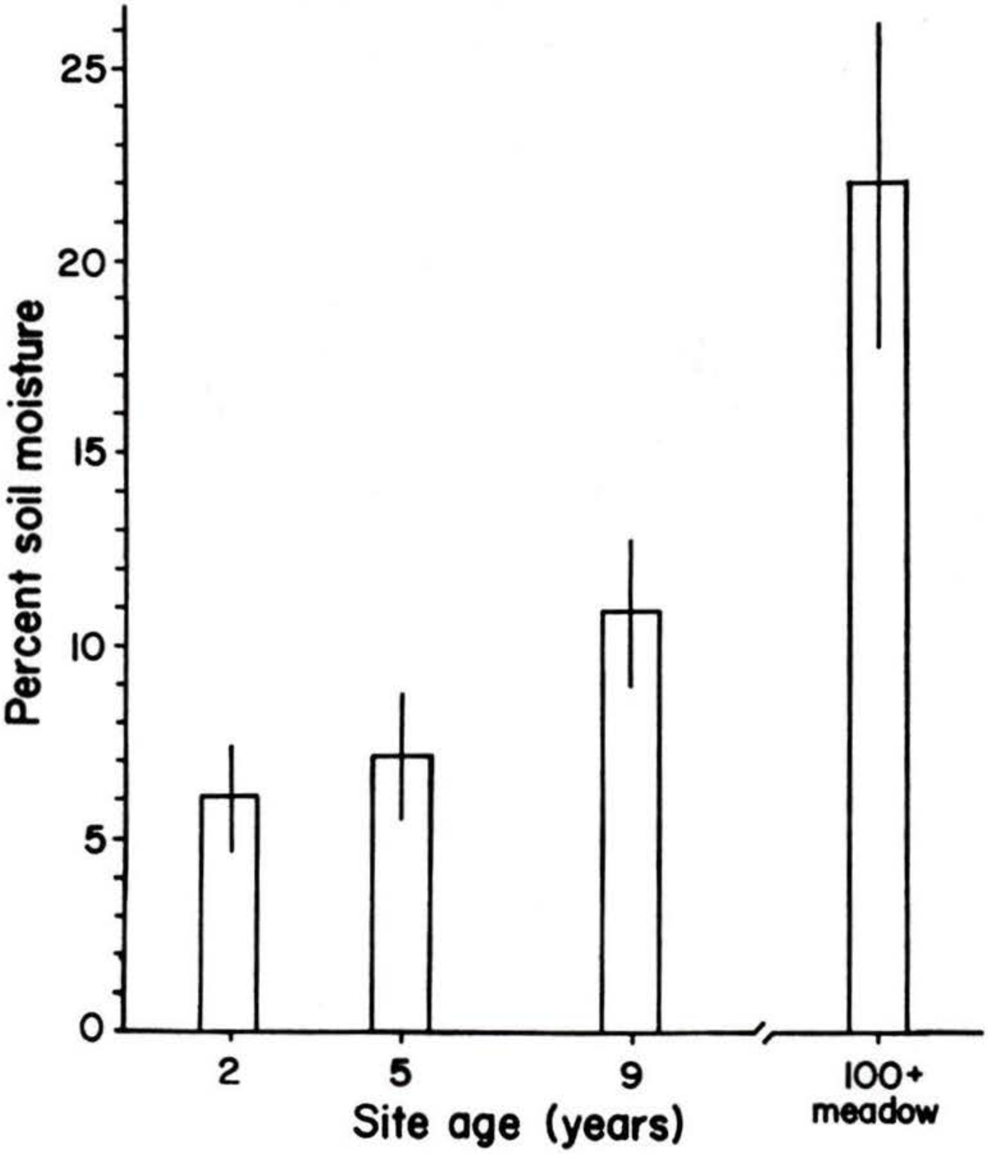

Percent soil moisture
25
20
15
10
5
0
2
5
9
100+
meadow
Site age (years)

Figure 6: Non-centered principal components ordination of all sites. n as in Figure 4. Total variances accounted for by axes 1 and 2 are indicated.

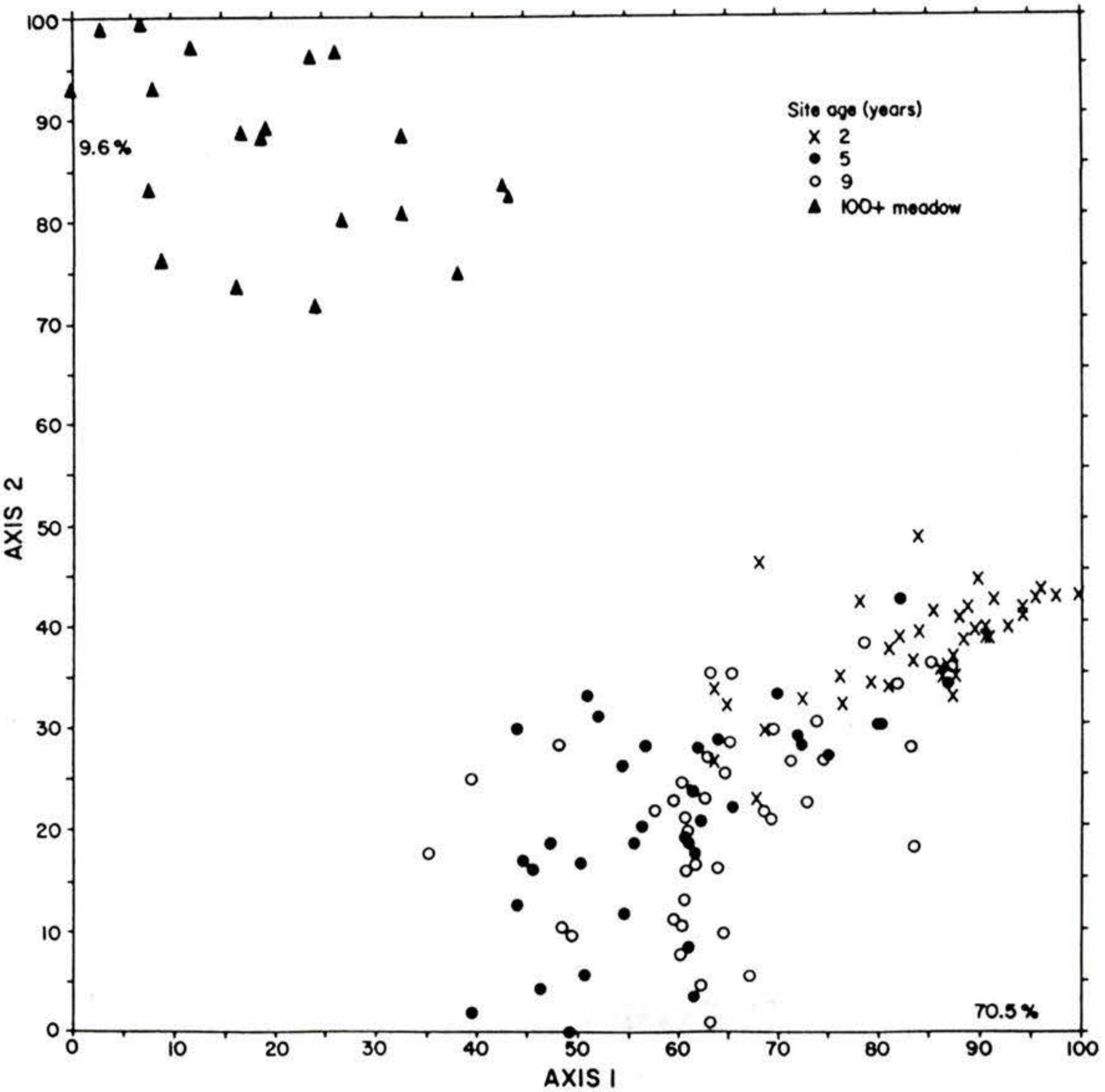
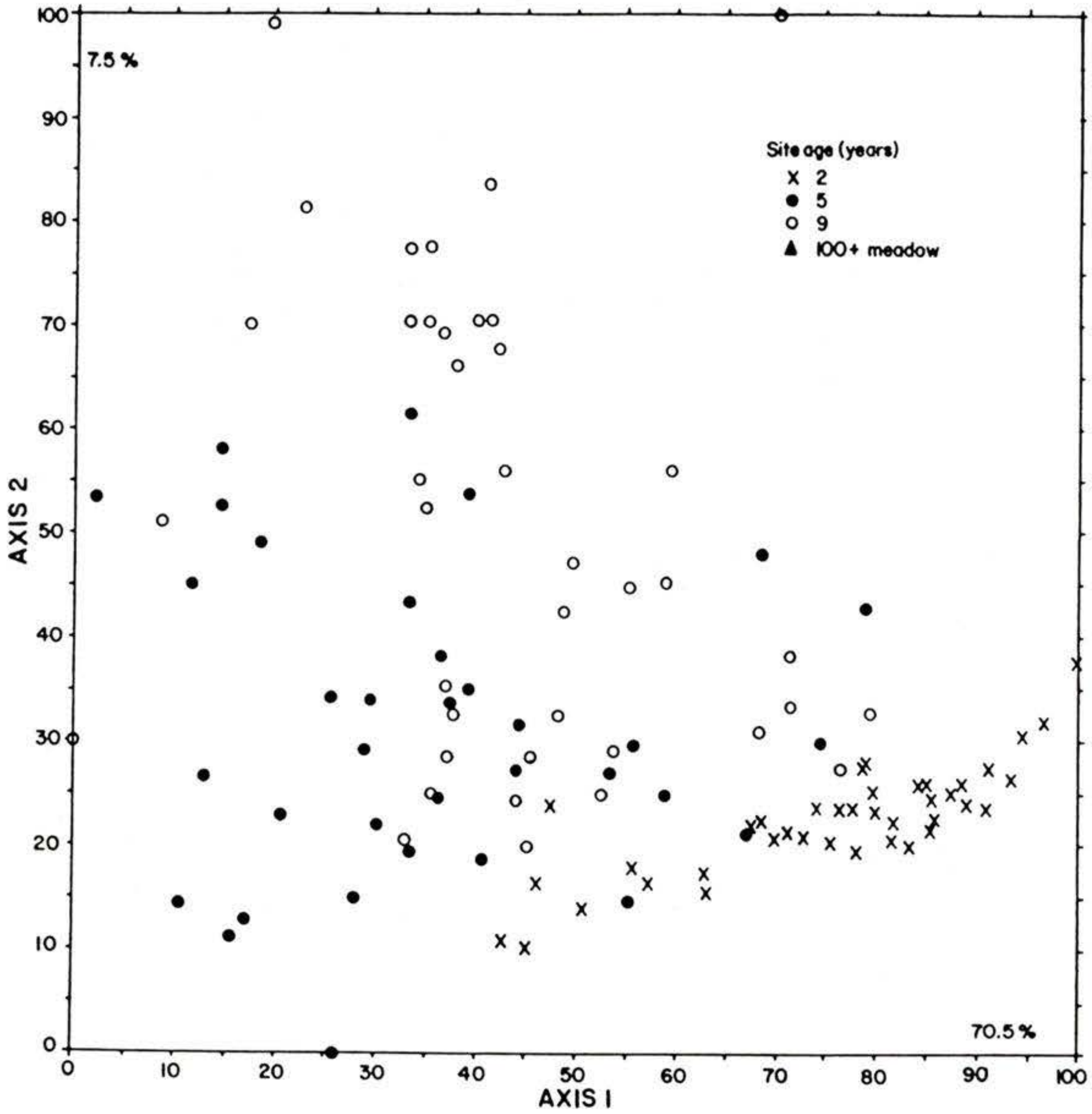

Site age (years)
X 2
● 5
○ 9
▲ 100+ meadow
9.6 %
70.5 %
AXIS 2
AXIS I
0
10
20
30
40
50
60
70
80
90
100

Figure 7: Non-centered principal components ordination of reclaimed sites. n as in Figure 4. Total variances accounted for by axes 1 and 2 are indicated.


7.5 %
70.5 %
Site age (years)
X 2
● 5
○ 9
▲ 100+ meadow
AXIS 2
AXIS 1
0
10
20
30
40
50
60
70
80
90
100

Major taxonomic groups

Mean densities of major taxonomic groups, i.e., mites, collembolans, insects and other arthropods (proturans, diplurans, pseudoscorpions and spiders), over the sampling period are summarized in Figure 8. Table 5 summarizes the results of the two-way ANOVAs used to compare the effects of site and month on abundance of these groups. Mites were the most abundant microarthropods on all sites, generally comprising between 80 and 90 percent of the total fauna (Figure 9). Mite densities on all sites increased significantly with site age (Figure 8).

Collembolan abundance also increased significantly with site age (Figure 8), except on the 5-year site where high densities of Hypogastruridae collembolans were extracted from the soil in June and August, accounting for reduced relative abundances of mites on these sites during these months (Figure 9).

Soil insect abundances were variable. Two and 5-year site densities did not differ significantly. Thrips (Insecta: Thysanoptera) were fairly numerous on the 2-year site in June, accounting for over 30 percent of the total fauna (Figure 9). Coleoptera larvae and adults, particularly Staphylinidae and to a lesser extent Carabidae, were the most abundant insects in all but the 2-year soil samples. Diptera larvae were collected, but less abundant. Although not identified, they may represent immature stages of families such as Phoridae, Sciaridae, or Cecidomyiidae which were fairly numerous in emergence trap collections made during the same time as this study (personal observation). The remaining arthropods were only present in low numbers on the 9-year site, and although densities of these arthropods on the undisturbed subalpine meadow were significantly higher than on all reclaimed sites, these densities were still very low (120 m^{-2} ± 110). Collembolans, insects and other arthropods had a low abundance relative to the total soil fauna.

Table 5: Effects of site and month on abundance of major microarthropod taxonomic groups.

n as in Table 4.

TAXA	TWO-WAY ANOVA			DUNCAN'S MULTIPLE RANGE TEST			
	Factor	**DF**	**Probability**	**Site (by age)**		**Month**	
				2	a[1]	May	a
Mites	Site	3	<0.001	5	b	June	b
	Month	3	<0.001	9	c	July	c
	Site x month	9	<0.065	100+	d	August	c
				2	a	May	a
Collembolans	Site	3	<0.001	5	b	June	b
	Month	3	<0.001	9	c	July	c
	Site x month	9	<0.001	100+	d	August	b
				2	a	May	a
Insects	Site	3	<0.001	5	a	June	b
	Month	3	<0.001	9	b	July	c
	Site x month	9	<0.003	100+	c	August	c
				2	a	May	a
Other Arthropods	Site	3	<0.001	5	a	June	a
	Month	3	<0.894	9	a	July	a
	Site x month	9	<0.158	100+	b	August	a

[1] Sites or months with the same letter(s) did not differ significantly at $P = 0.05$.

Figure 8: Densities of major taxonomic groups from each study site. Data are means ± 95% confidence intervals. n as in Figure 4.

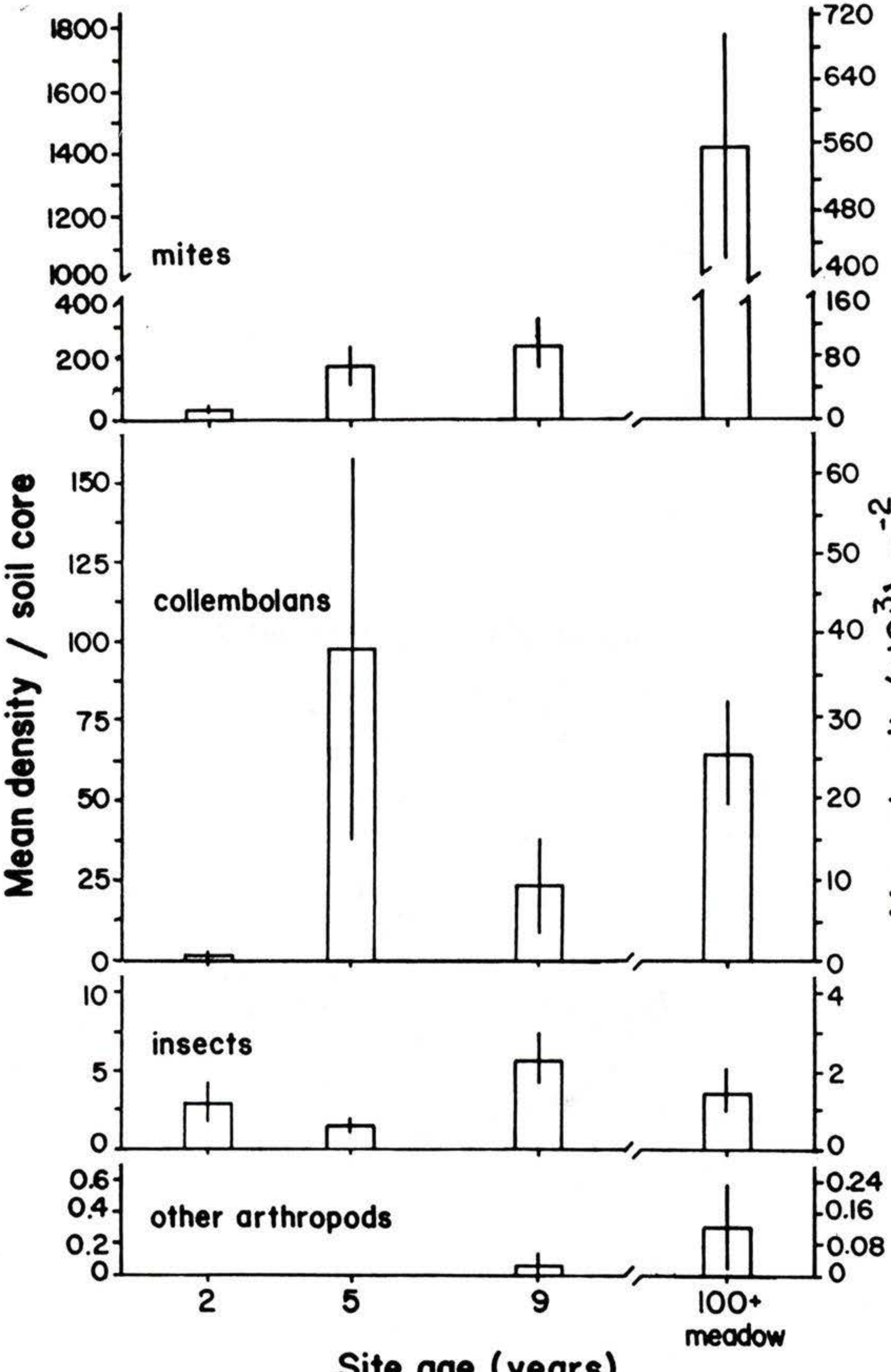
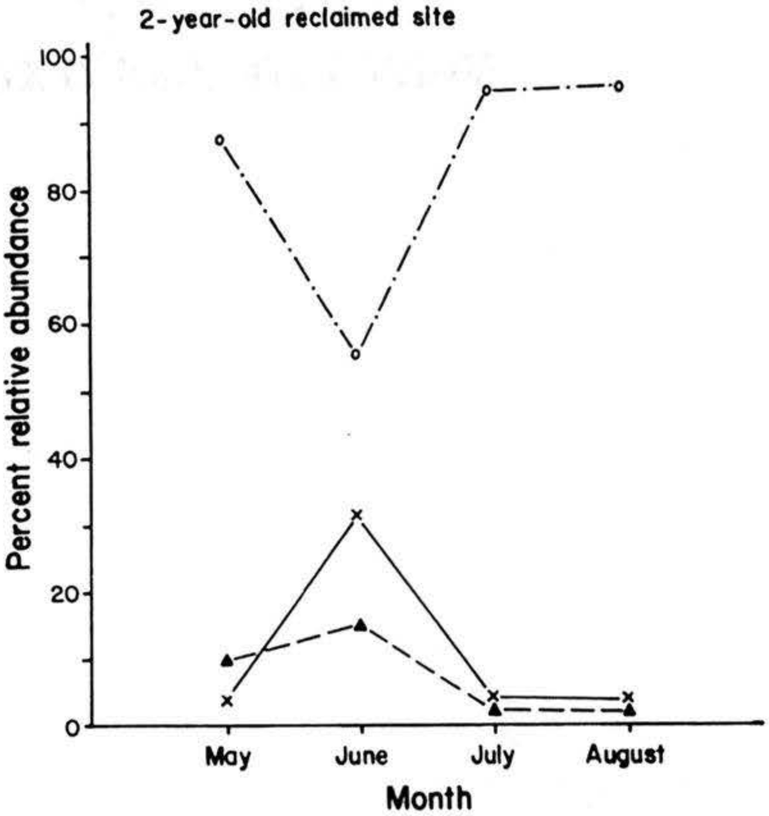
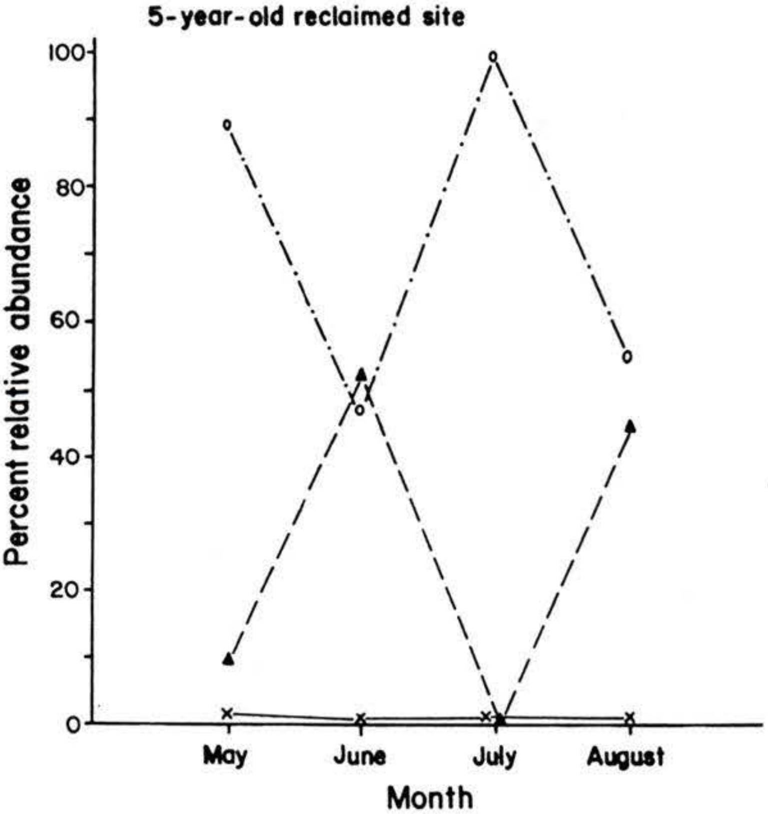
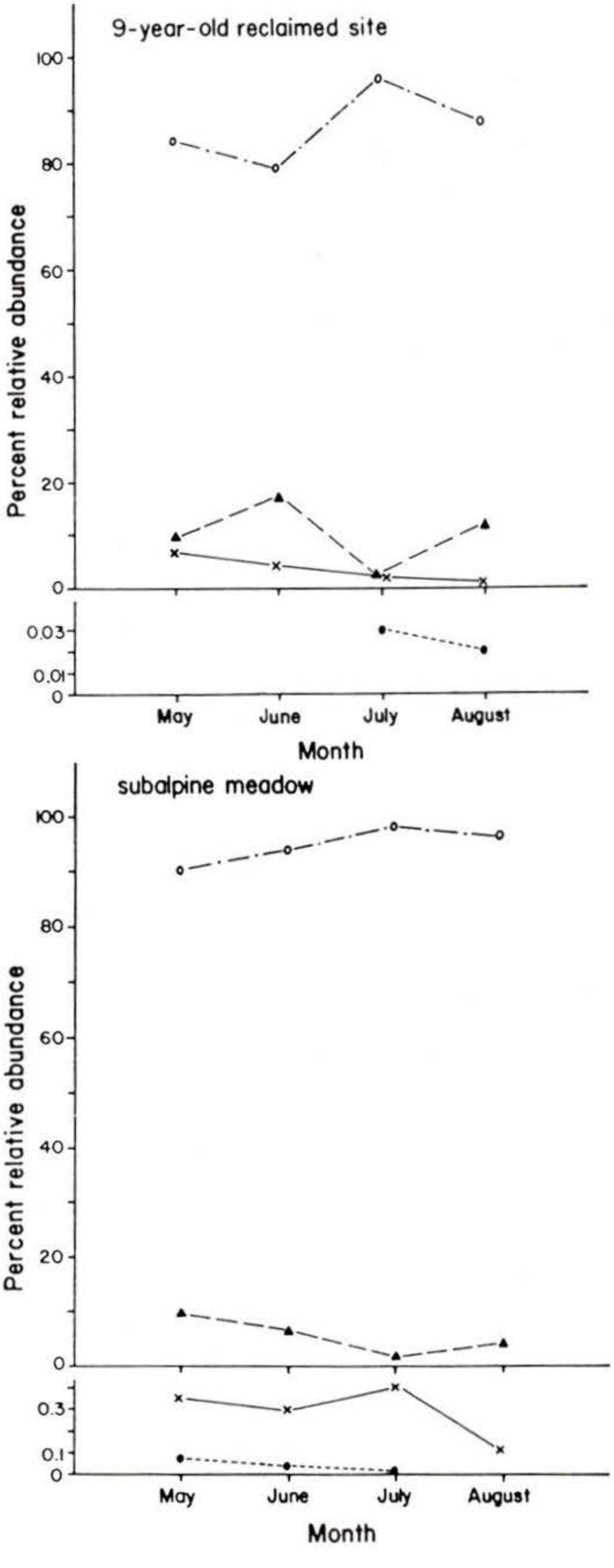

mites
collembolans
insects
other arthropods
Mean density / soil core
Mean density (x10^3) m^{-2}
1800
1600
1400
1200
1000
400
200
0
150
125
100
75
50
25
0
10
5
0
0.6
0.4
0.2
0
720
640
560
480
400
160
80
0
60
50
40
30
20
10
0
4
2
0
0.24
0.16
0.08
0
2
5
9
100+
meadow
Site age (years)

Figure 9: Percent relative abundance of major taxonomic groups from each study site over 4-month sampling period. n as in Figure 4.

circle - mites
triangle - collembolans
X - insects
solid circle - other arthropods


2-year-old reclaimed site
Percent relative abundance
0
20
40
60
80
100
May
June
July
August
Month


5-year-old reclaimed site
Percent relative abundance
0
20
40
60
80
100
May
June
July
August
Month


9-year-old reclaimed site
Percent relative abundance
100
80
60
40
20
0
0.03
0.01
0
May
June
July
August
Month
subalpine meadow
Percent relative abundance
100
80
60
40
20
0
0.3
0.1
0
May
June
July
August
Month

Mite suborders

Mean densities of most mite suborders increased with site age (Figure 10). Two-way ANOVAs comparing effects of site and month on mite suborder densities indicated that mesostigmatid mite densities increased significantly with site age (Table 6). However, their abundances were low in all soils. Mesostigmata consistently comprised less than 2 percent of the total mite fauna, except on the 9-year site, where their relative abundance was 17 percent in May (Figure 11).

Densities of prostigmatid mites increased with site age, but did not differ significantly between the 5 and 9-year sites. Prostigmata dominated the mite fauna (Figure 11). Relative abundances of these mites on reclaimed sites were consistently between 85 and 98 percent over the study period, while the subalpine meadow abundances were slightly lower - between 70 and 85 percent. At least 50 percent of all prostigmatid mites sampled were Tydeidae, except on the 2-year site during May and June where relative abundances were 11 and 28 percent, respectively (Figure 12). The family Nanorchestidae was more abundant on this site during these months.

Astigmatid mite densities on reclaimed sites were almost negligible (Figure 10), and did not differ significantly between sites or months (Table 6). Densities of astigmatid mites were significantly higher in the subalpine meadow soil (Figure 10), although abundances were still low. On all sites Astigmata never contributed more than one percent to the total mite fauna (Figure 11).

Table 6: Effects of site and month on abundance of mite suborders.

n as in Table 4.

TAXA	**TWO-WAY ANOVA**			**DUNCAN'S MULTIPLE RANGE TEST**			
	Factor	**DF**	**Probability**	**Site (by age)**		**Month**	
				2	a[1]	May	a
Mesostigmata	Site	3	<0.001	5	b	June	ab
	Month	3	<0.010	9	c	July	bc
	Site x month	9	<0.078	100+	d	August	c
				2	a	May	a
Prostigmata	Site	3	<0.001	5	b	June	b
	Month	3	<0.001	9	b	July	c
	Site x month	9	<0.033	100+	c	August	c
				2	a	May	a
Astigmata	Site	3	<0.001	5	a	June	a
	Month	3	<0.487	9	a	July	a
	Site x month	9	<0.590	100+	b	August	a
				2	a	May	a
Cryptostigmata	Site	3	<0.001	5	a	June	b
	Month	3	<0.001	9	a	July	a
	Site x month	9	<0.203	100+	b	August	b

[1] Sites or months with the same letter(s) did not differ significantly at $P = 0.05$.

Figure 10: Densities of mite suborders from each study site. Data are means ± 95% confidence intervals. n as in Figure 4.

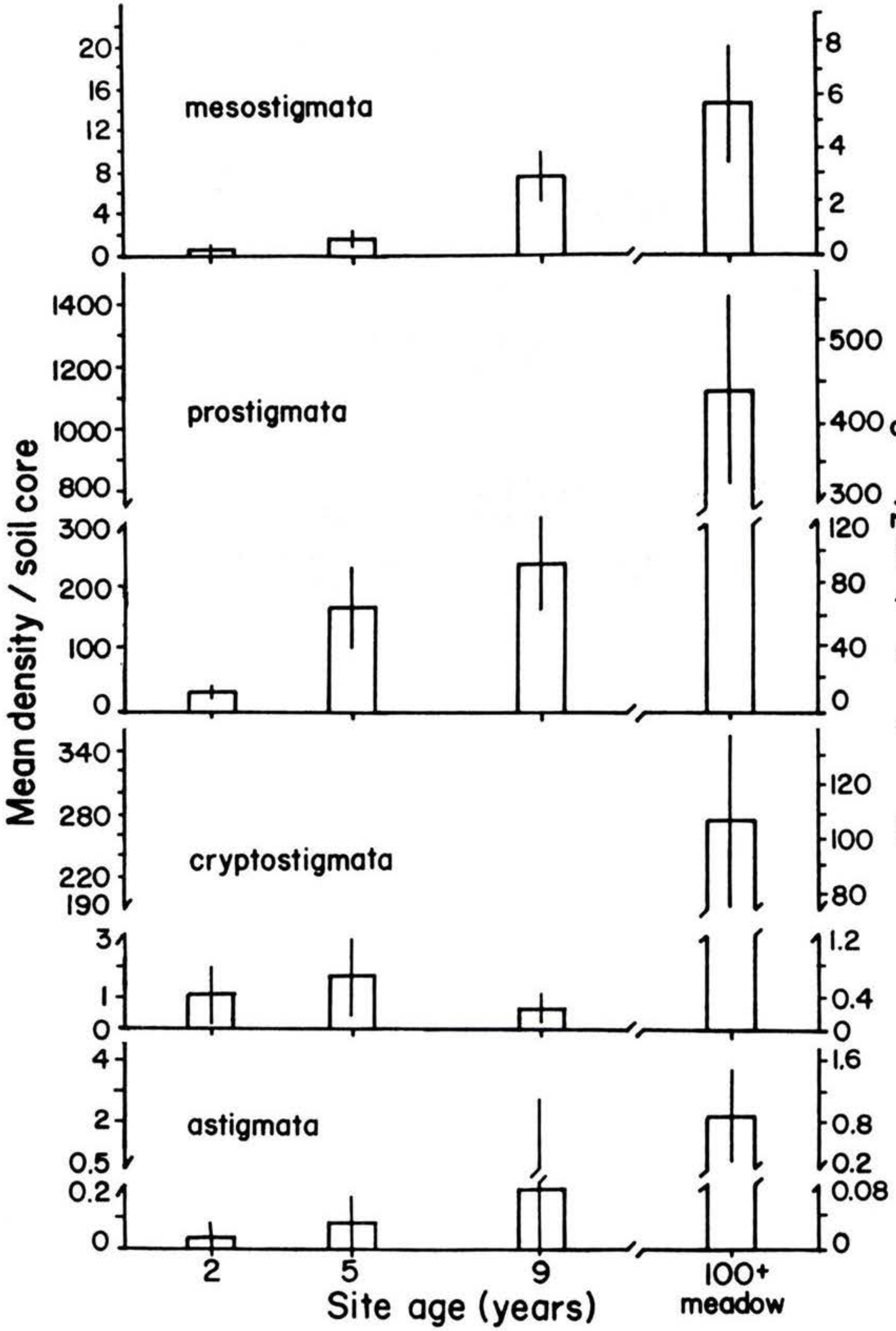
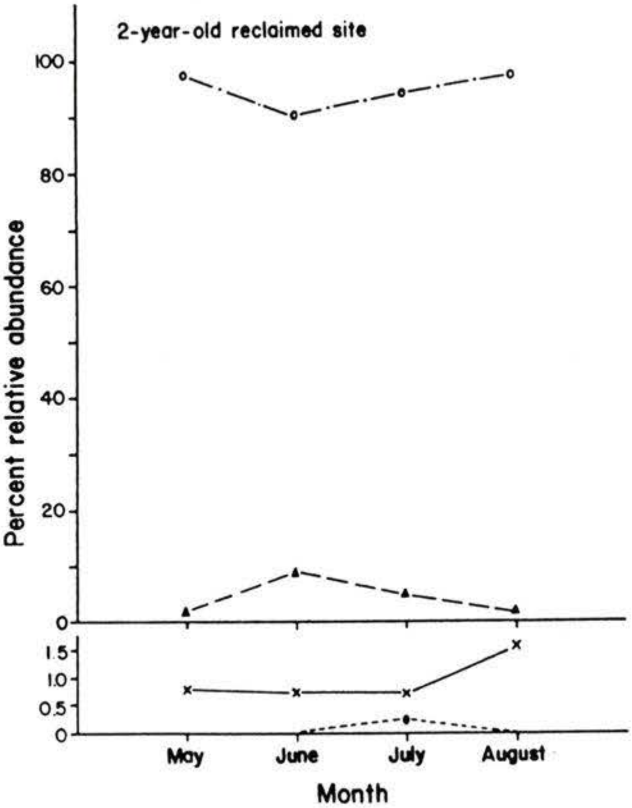
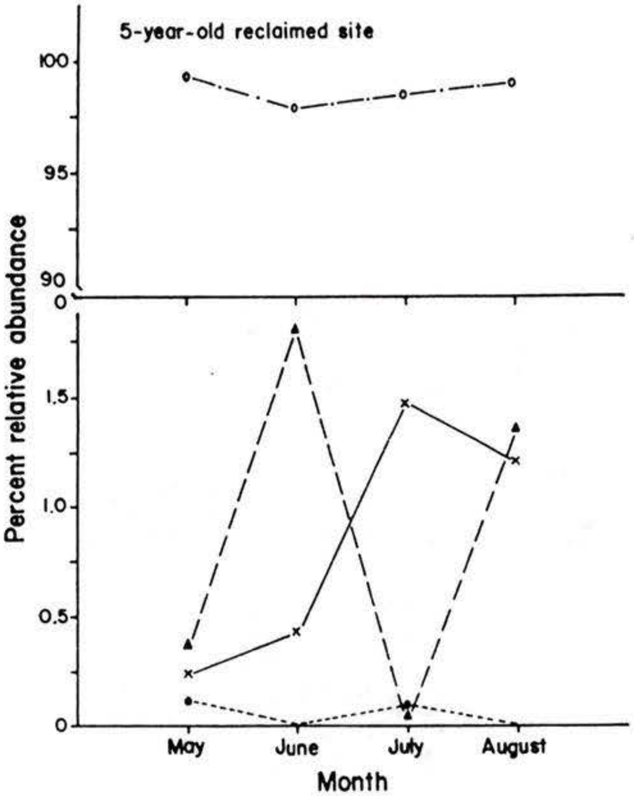
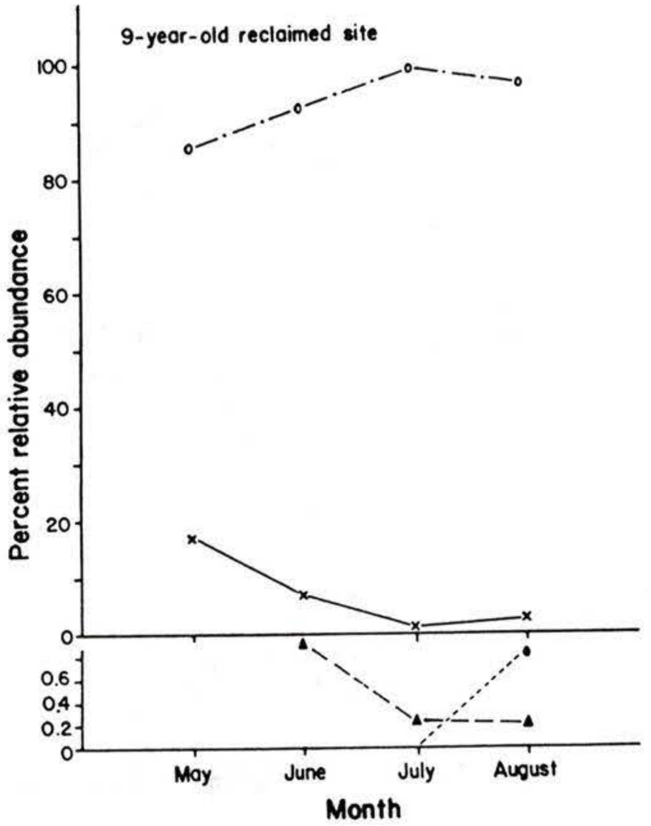

mesostigmata
prostigmata
cryptostigmata
astigmata
Mean density / soil core
Mean density (x 10^3) m^{-2}
0
4
8
12
16
20
800
1000
1200
1400
0
100
200
300
190
220
280
340
0
1
3
0.5
2
4
0
0.2
0
2
4
6
8
300
400
500
0
40
80
120
80
100
120
0
0.4
1.2
0.2
0.8
1.6
0
0.08
2
5
9
100+
meadow
Site age (years)

Figure 11: Percent relative abundance of mite suborders from each study site over 4-month sampling period. n as in Figure 4.

circle - Prostigmata
triangle - Cryptostigmata
X - Mesostigmata
solid circle - Astigmata


2-year-old reclaimed site
Percent relative abundance
100
80
60
40
20
0
1.5
1.0
0.5
0
May
June
July
August
Month


5-year-old reclaimed site
Percent relative abundance
100
95
90
0
1.5
1.0
0.5
0
May
June
July
August
Month


9-year-old reclaimed site
Percent relative abundance
100
80
60
40
20
0
0.6
0.4
0.2
0
May
June
July
August
Month

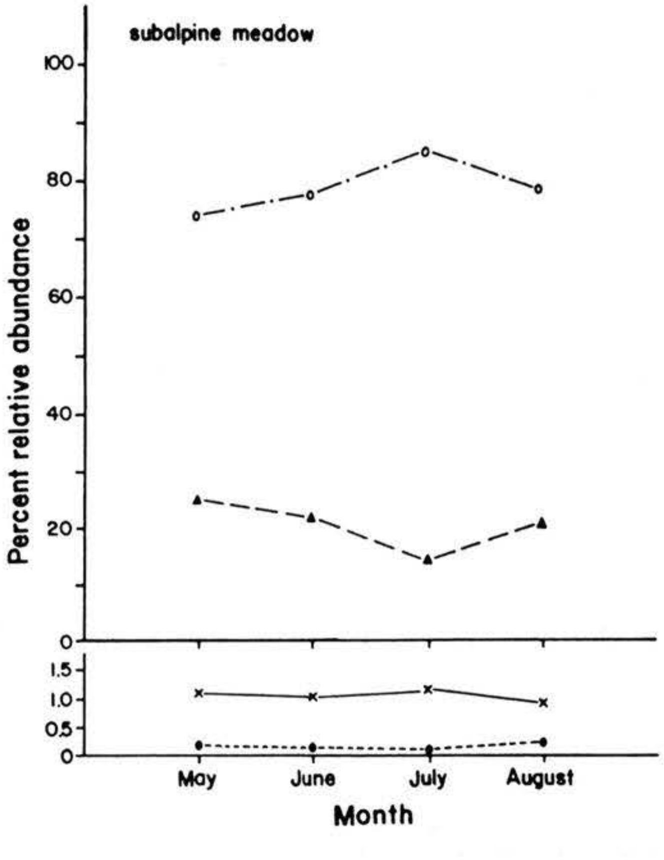
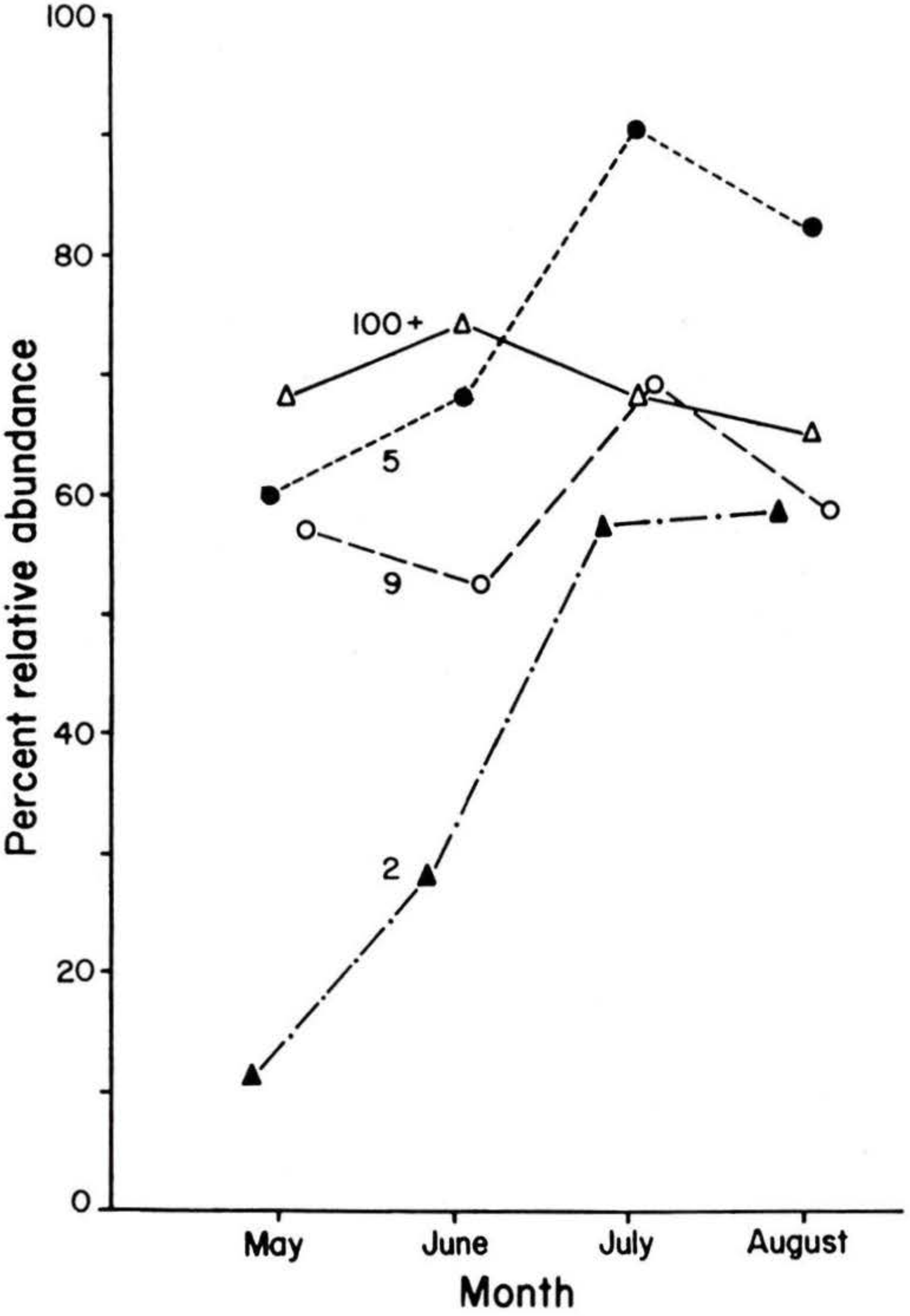

subalpine meadow
Percent relative abundance
100
80
60
40
20
0
1.5
1.0
0.5
0
May
June
July
August
Month

Figure 12: Percent relative abundance of Tydeidae with respect to total Prostigmata from each site over 4-month sampling period. Site age (in years) indicated on figure. n= 40, 40, 35 and 20 for the 2, 5, 9-year and subalpine meadow study sites, respectively.



100
80
60
40
20
0
Percent relative abundance
100+
5
9
2
May
June
July
August
Month

Cryptostigmatid mite densities were low and not significantly different among the reclaimed sites (Figure 10, Table 6). Undisturbed subalpine meadow soil had considerably greater densities of cryptostigmatid mites than any reclaimed soils over the sampling period. While the relative abundance of cryptostigmatid mites on reclaimed sites was generally below 5 percent, they comprised between 14 and 25 percent of the total mite fauna on the undisturbed subalpine meadow (Figure 11).

The more abundant cryptostigmatid mites which did occur in these reclaimed soils were Brachychthoniidae, Oppiidae, and to a lesser extent, Tectocepheidae. The families Ceratozetidae and Damaeidae were encountered only in samples from the 9-year, and undisturbed meadow and forest soils.

b) Microarthropod densities - subalpine forest

Total microarthropod densities in the subalpine forest were intermediate between the oldest reclaimed site and the subalpine meadow, averaging 202,500 ± 77,400 individuals m^{-2}. Mites comprised at least 90 percent of the total fauna, and collembolans most of the remainder. However, in these samples the relative abundance of mite suborders was split evenly between Cryptostigmata and Prostigmata; each suborder comprised 49 percent of the total mite fauna. Thus, Cryptostigmata contributed more in terms of total density in the forest soil than in any of the reclaimed or undisturbed meadow soils, although most Cryptostigmatid mites belonged to only a few families, notably Oppiidae, Brachychthoniidae, and Tectocepheidae.

c) Nematodes and Enchytraeids

Average nematode densities over the entire sampling period increased with site age (Figure 13). Densities on the 2-year site were extremely low compared to all other study sites (300 m^{-2} ± 200). Results of a two-way ANOVA comparing the effects of site and month on total nematode abundance on the three oldest study sites indicated that nematode densities did not differ significantly between the two oldest study sites (Table 7).

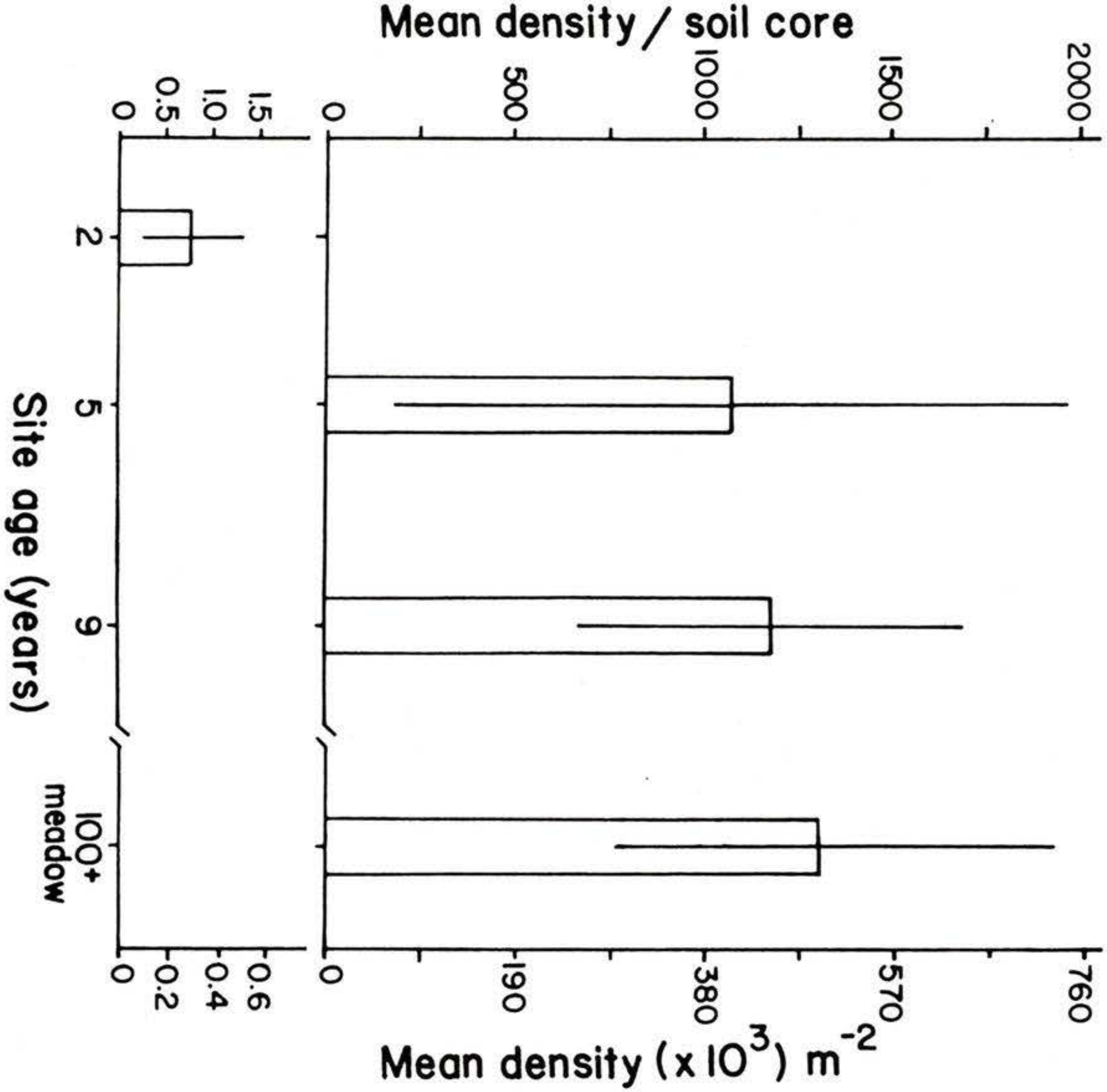
Enchytraeids were not found in any 2 or 5-year soil samples. Seven individuals were extracted from one sample from the 9-year site in May. Enchytraeid densities on the undisturbed subalpine meadow site averaged 740 m^{-2} ± 490 over the four-month sampling period. Most of the enchytraeids collected were immatures, making taxonomic identification difficult. One specimen, however, was identified as *Henlea* sp. (K. Coates 1983, personal communication).

Table 7: Effects of site and month on total nematode abundance.

TWO-WAY ANOVA			DUNCAN'S MULTIPLE RANGE TEST					
Factor	**DF**	**Probability**	**Site (by age)**		**n**	**Month**		**n**
						May	a	28
Site	2	<0.002	5	a[1]	34	June	b	22
Month	3	<0.001	9	b	40	July	c	25
Site x month	6	<0.444	100+	b	25	August	b	24

[1] Sites or months with the same letter(s) did not differ significantly at $P = 0.05$.

Figure 13: Nematode densities from each study site. Data are means ± 95% confidence intervals. n=38, 34, 40 and 25 for the 2, 5, 9-year and subalpine meadow sites, respectively.


Mean density / soil core
0
500
1000
1500
2000
0
0.5
1.0
1.5
2
5
9
100+
meadow
Site age (years)
0
190
380
570
760
0
0.2
0.4
0.6
Mean density (x 10^3) m^{-2}

2. TEMPORAL PATTERNS

a) Microarthropods

Mean monthly densities of total microarthropods increased over the summer months on all but the 5-year site where microarthropod densities were highest during June (Figure 14).

Mean microarthropod densities were not significantly different between June and July (Table 4). A significant interaction between site and month was present in the data, indicating that the relative magnitude of the changes in mean density over time were not the same on each site. However, Figure 14 reveals a clear increase in mean densities between sites and over the summer months.

Microarthropod data from the soil cores were ordinated for each month. Since all four ordinations were very similar, only the July PCA is shown (Figure 15).

This ordination shows a similar, but clearer pattern than that seen in Figure 6. Subalpine meadow soil cores are clearly separated from reclaimed soil cores in ordination space. Within the reclaimed sites, soil cores from similar-aged sites show a clearer tendency to cluster together. The same pattern was seen throughout the summer months.

Figure 14: Density of microarthropods from each site over the 4-month sampling period. n as in Figure 4. Site age (in years) is indicated on figure.

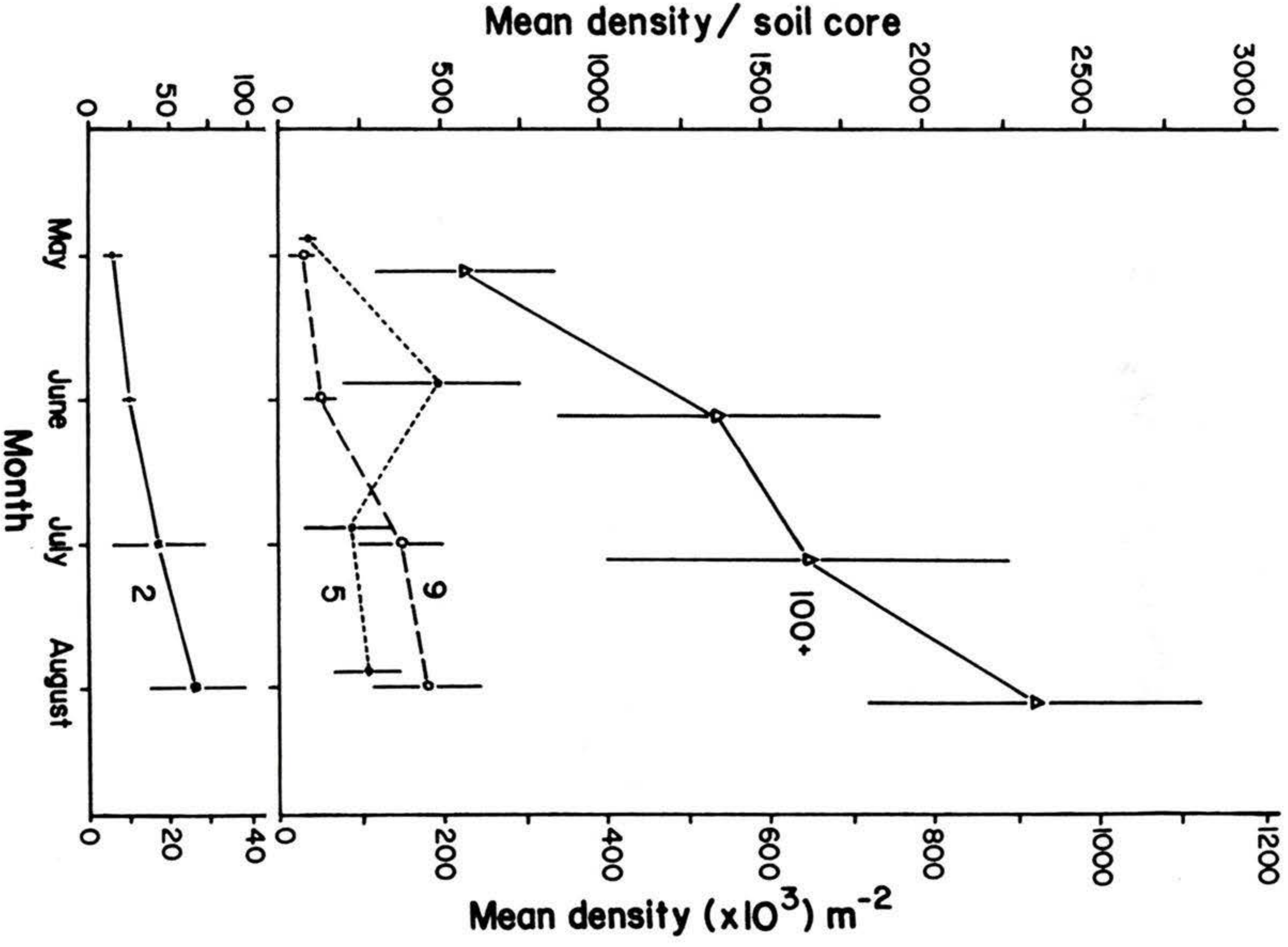
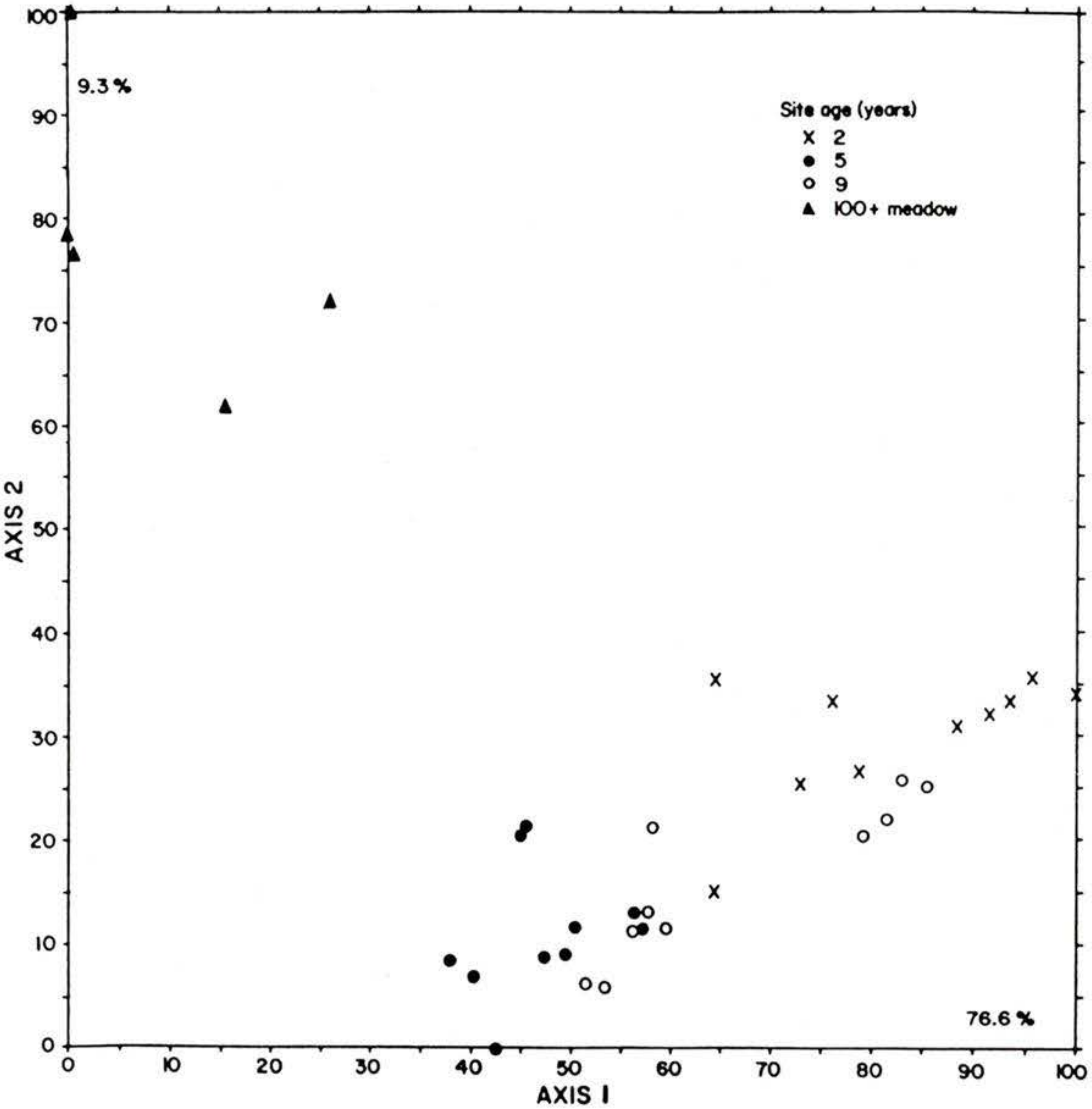

Mean density / soil core
0
500
1000
1500
2000
2500
3000
0
50
100
May
June
July
August
Month
100+
9
5
2
0
200
400
600
800
1000
1200
0
20
40
Mean density ($\times 10^3$) m^{-2}

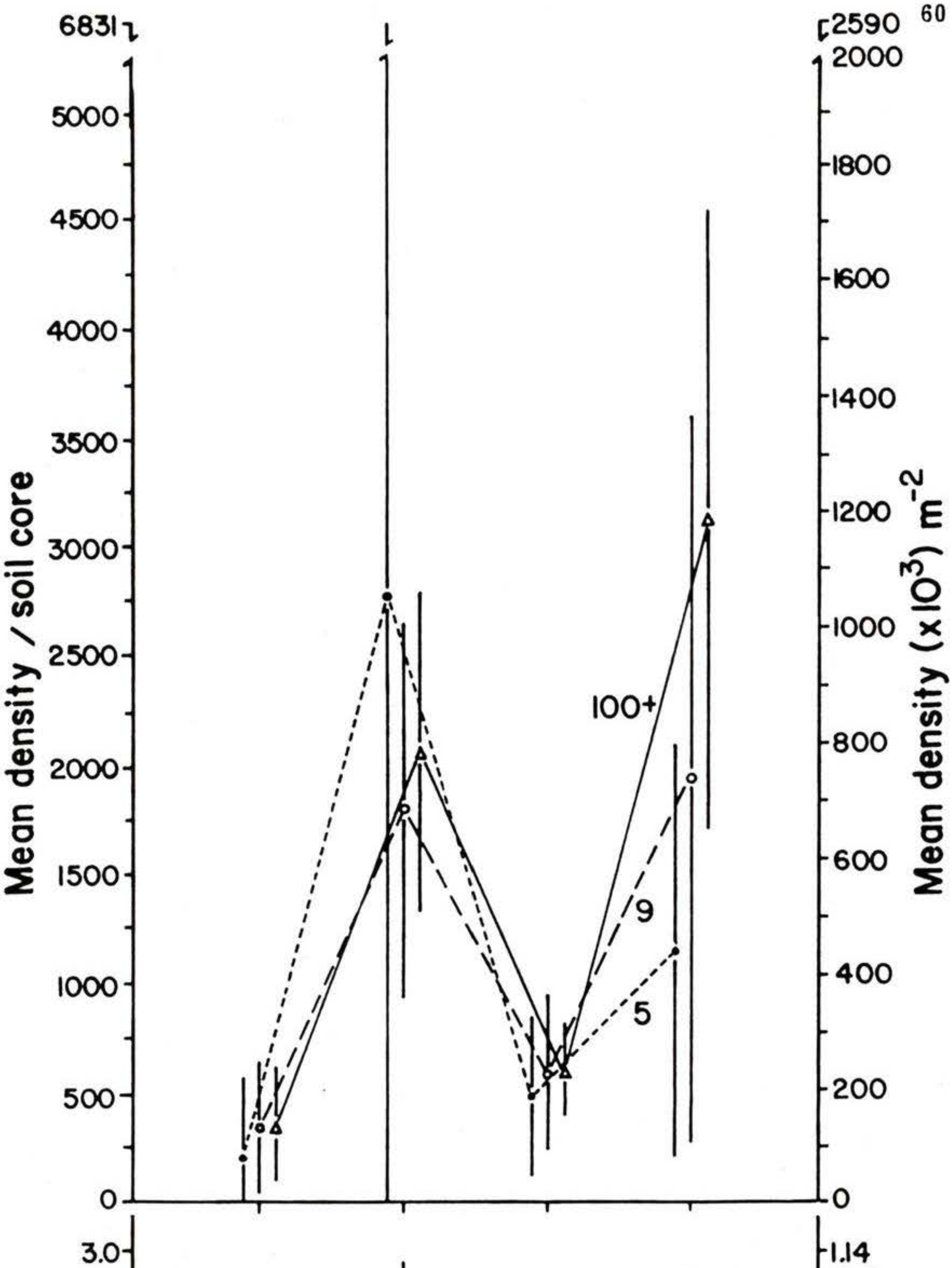
Figure 15: Non-centered principal components ordination for month of July, all sites. Total variances accounted for by axes 1 and 2 are indicated. n=10, 10, 10 and 5 for the 2, 5, 9-year and subalpine meadow sites, respectively.


9.3 %
Site age (years)
X 2
● 5
○ 9
▲ 100+ meadow
AXIS 2
0
10
20
30
40
50
60
70
80
90
100
AXIS I
0
10
20
30
40
50
60
70
80
90
100
76.6 %

b) Nematodes and Enchytraeids

Mean densities of nematodes in the 2-year site were consistently low throughout the summer months (Figure 16). All other sites showed a similar pattern of abundance over time, with low densities in May and July and higher densities during June and August. Mean nematode densities on the three older study sites did not differ significantly between June and August (Table 7).

Figure 16: Nematode densities from each study site over the 4-month sampling period. Data are means ± 95% confidence intervals. Site age (in years) indicated on figure. n as in Figure 13.


6831
2590
Mean density / soil core
Mean density (x10^3) m^{-2}
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
100+
9
5
2
3.0
2.0
1.0
0
1.14
0.76
0.38
0
May
June
July
August
Month

3. VERTICAL DISTRIBUTION IN THE SOIL

a) Microarthropods

At the time of collection, soil cores were divided into samples of 0-3 cm and 3-7 cm depths. Differences in mean density of total microarthropods with depth in the soil profile were tested for each site using a paired-sample t test (Zar 1974). All reclaimed sites exhibited significant differences in mean densities of total microarthropods with depth (Table 8, Figure 17), the majority of soil fauna occurring in the upper 3 centimeters of the soil profile. However, mean densities in the undisturbed subalpine meadow soil did not differ with depth.

The vertical distribution of mean densities of major taxonomic groups was similar to that for the total microarthropods. They did not differ significantly with depth in the subalpine meadow but differed with depth in the reclaimed sites (Table 9). Mean mite and collembolan densities were significantly different with depth in all reclaimed soils, the majority being extracted from the upper 3 cm. Mean densities of insects were not significantly different with depth on the 5-year site.

Paired-sample t test comparisons of mean mite suborder densities with depth in soil indicated that mean densities of prostigmatid mites were significantly different on all reclaimed study sites, and mean mesostigmatid mite densities were significantly different with depth on the 5 and 9-year sites (Table 10).

Table 8: Paired-sample t tests of total microarthropod densities at 0-3 and 3-7 cm soil depths.

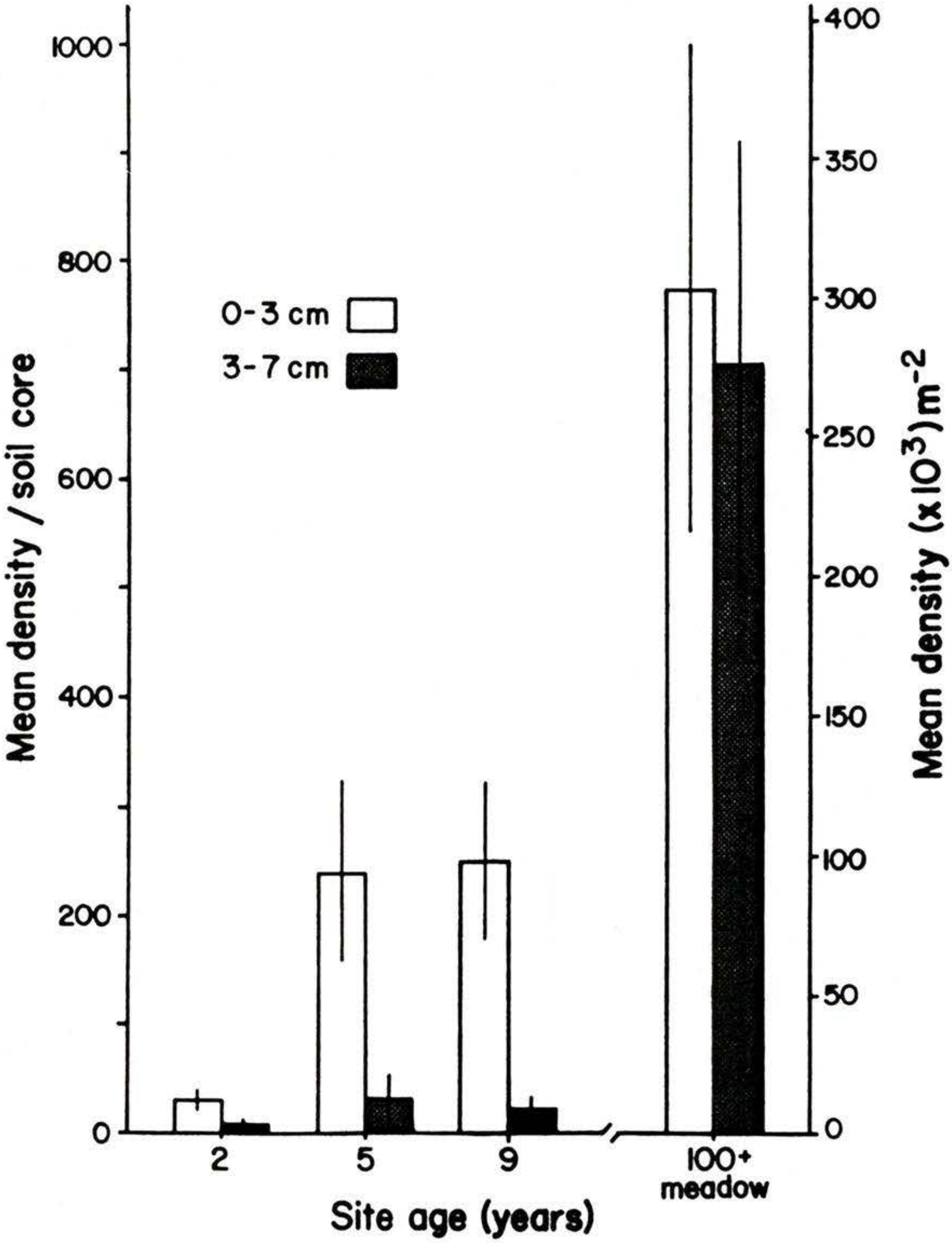
Site (by age)	n	T	Probability
2	40	4.21	<0.001
5	40	4.72	<0.001
9	35	6.68	<0.001
100+	20	0.61	<0.552

Table 9: Paired-sample t tests of microarthropod taxonomic group densities at 0-3 and 3-7 cm soil depths.

n for each site as in Table 8.

Site (by age)	**Taxonomic group**	**T**	**Probability**
2	Mites	3.66	<0.001
	Collembolans	4.83	<0.001
	Insects	3.49	<0.001
	Other arthropods	-	-
5	Mites	4.56	<0.001
	Collembolans	2.02	<0.050
	Insects	1.40	<0.169
	Other arthropods	-	-
9	Mites	6.39	<0.001
	Collembolans	2.46	<0.019
	Insects	5.82	<0.001
	Other arthropods	1.44	<0.160
100+	Mites	0.76	<0.457
	Collembolans	1.99	<0.062
	Insects	0.38	<0.709
	Other arthropods	0.00	<1.000

Figure 17: Microarthropod densities with depth from each study site. Data are means ± 95% confidence intervals. n as in Figure 4.


0-3 cm ☐
3-7 cm ■
Mean density / soil core
0
200
400
600
800
1000
Mean density (x10^3) m^{-2}
0
50
100
150
200
250
300
350
400
2
5
9
100+
meadow
Site age (years)

b) Nematodes and Enchytraeids

The two older reclaimed sites exhibited greater nematode densities in the upper 3 cm of the soil profile (Figure 18). Mean nematode densities did not differ significantly with depth on the 2-year site, nor on the subalpine meadow (paired-sample t test, Table 11). Enchytraeid densities were low where they occurred, and did not differ significantly with depth.

Table 10: Paired-sample t tests of mite suborder densities at 0-3 and 3-7 cm soil depths.

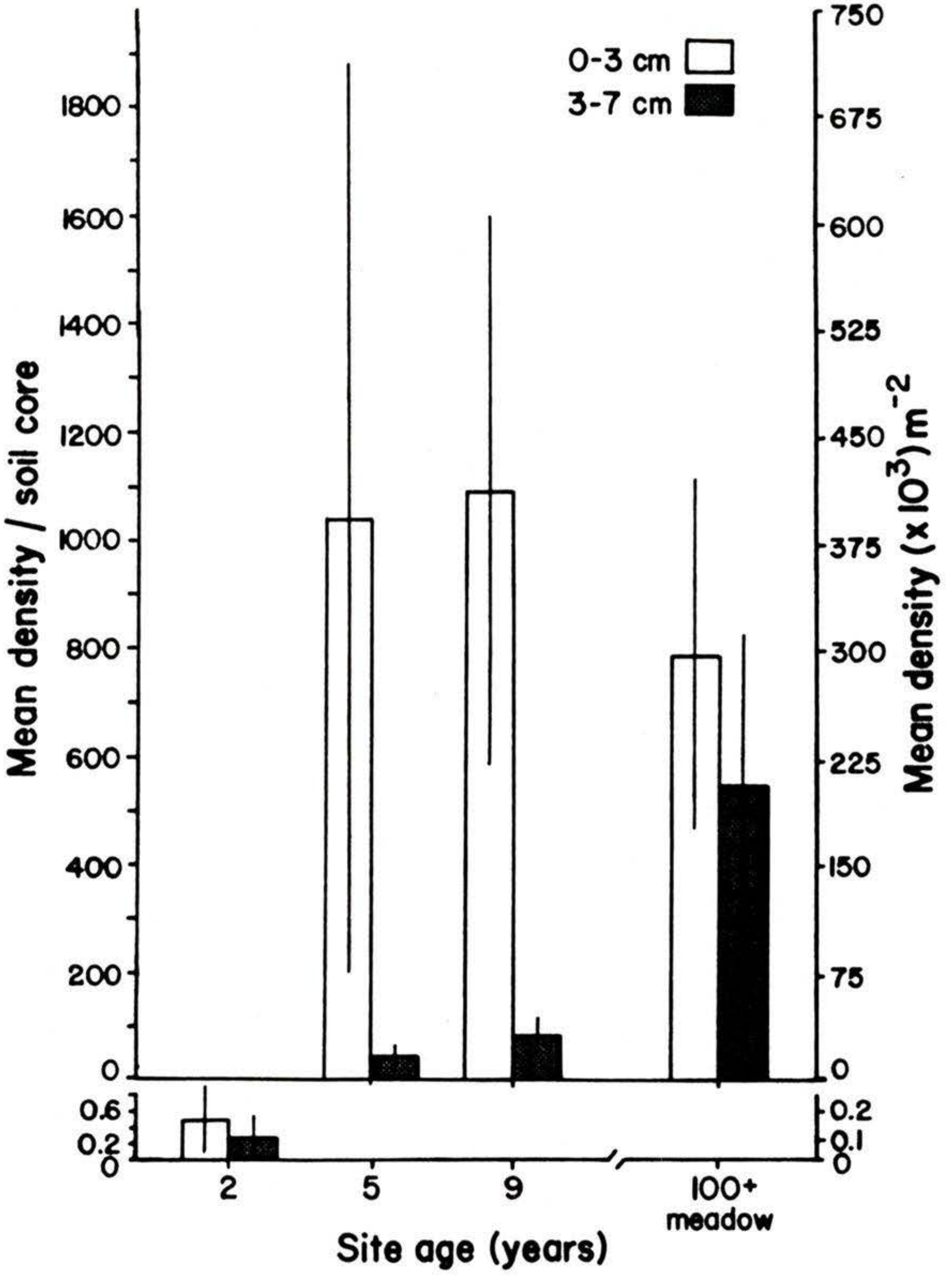
n for each site as in Table 8.

Site (by age)	Mite suborder	T	Probability
2	Mesostigmata	0.90	<0.372
	Prostigmata	3.65	<0.001
	Astigmata	1.00	<0.324
	Cryptostigmata	0.19	<0.854
5	Mesostigmata	3.61	<0.001
	Prostigmata	4.52	<0.001
	Astigmata	0.57	<0.570
	Cryptostigmata	1.48	<0.147
9	Mesostigmata	5.49	<0.001
	Prostigmata	6.15	<0.001
	Astigmata	1.00	<0.324
	Cryptostigmata	1.99	<0.055
100+	Mesostigmata	0.68	<0.506
	Prostigmata	0.81	<0.430
	Astigmata	0.61	<0.549
	Cryptostigmata	0.02	<0.984

Table 11: Paired-sample t tests of nematode and enchytraeid densities at 0-3 and 3-7 cm soil depths.

	Site (by age)	n	T	Probability
Nematodes	2	38	1.00	<0.323
	5	34	2.17	<0.037
	9	40	3.86	<0.001
	100+	24	1.90	<0.071
Enchytraeids	9	40	0.00	<1.000
	100+	25	0.85	<0.403

Figure 18: Nematode densities with depth from each study site. Data are means ± 95% confidence intervals. n as in Figure 13.


0-3 cm □
3-7 cm ■
Mean density / soil core
1800
1600
1400
1200
1000
800
600
400
200
0
0.6
0.2
0
Mean density (x 10³) m⁻²
750
675
600
525
450
375
300
225
150
75
0
0.2
0.1
0
2
5
9
100+
meadow
Site age (years)

Chapter IV

DISCUSSION

1. SOURCES OF COLONIZING ORGANISMS

The means by which soil fauna colonize new areas are poorly understood. Transport by wind has been reported (Glick 1939, Saiz *et al.* 1970, Edwards 1986), as well as phoretic dispersal by other animals (Desender and Vaneechoutte 1984, Olynyk and Freitag 1979), including birds (Meijer 1972) and man (Woolley 1960, Reynolds 1977). Downwash by snowmelt and rainwater may also disperse soil fauna such as mites and collembolans (Saiz *et al.* 1970, Rapoport and Sanchez 1963). Overland migrations of Collembola have been reported (Lyford 1974), although the rates and distances travelled by soil fauna are not well documented. Berthet (1964) reports mean displacement values of 4.1 and 1.7 cm per day for two mite species.

The most likely means of colonization of these spoils is through slow overland movement, wind, or phoretic transport by insects or ungulates. Colonizing soil fauna probably originate in forest soils, which comprise the majority of undisturbed soil near these reclaimed sites. Subalpine meadows are not common, nor are they oriented topographically so as to act as sources for overland movement.

Lawrence (1986) investigated the use of forest topsoil as a potential source of colonizing organisms for these reclaimed soils. The 2-year site, 6 years of age in 1986, was inoculated with small amounts of forest topsoil in selected microsites in June 1985. Replicate samples taken at increasing distances from the topsoil inoculum one year later revealed that while the topsoil still had significantly greater microarthropod densities and numbers of taxa than reclaimed soil, there were no significant differences in either variable between distances of 1 m and 15 m. Microarthropod densities in the reclaimed spoil were actually lower (in most microsites) in 1986 than the baseline densities in uninoculated reclaimed soil, determined in 1985, indicating that the lack of significance between 1 m and 15 m was not simply due to a rapid spread of soil fauna out of the topsoil inoculum. If significant differences in reclaimed soil fauna could not be detected after one year at a distance of 1 m from a source, it is possible that the reclaimed soil fauna of this present study are not greatly influenced by their proximity to undisturbed forest soil.

2. MITES

Comparisons of microarthropod densities with results of studies elsewhere (Table 12) must be made cautiously due to wide differences in sampling and extraction techniques, extraction efficiencies, nature of the spoil material, vegetative cover, and reclamation techniques. For example, some spoils were afforested (Dunger 1968a, Hutson 1980a, Cross and Wilman 1982), while others were returned to agricultural use, such as cattle grazing (Hutson 1980a).

Mites numerically dominated the microarthropod fauna on all sites, with mean reclaimed site densities being comparable to a number of previous surveys, notably Dunger (1968a) and Hutson (1980a). Densities are slightly higher on the 5 and 9-year sites than similar-aged sites elsewhere. All workers but Cross and Wilman (1982) found initially low mite densities.

Curiously, mite densities reported by Parsons and Parkinson (1986) at ecologically similar sites on 1, 3 and 7-year-old reclaimed spoils are much lower than mite densities observed at Sparwood, even though extraction efficiencies of 73 to 80 percent were reported. Nearby undisturbed forest soils differ between the two studies, and may have influenced what organisms colonized and became established in the reclaimed soils. Parsons (1983) reports an understory of *Lycopodium annotinum* L. and *Hylocomium splendens* (Hedw.) B.S.G. with an L F H layer of 25 cm; this thick moss and litter layer suggesting fairly moist, organic conditions. Forest soils near the Sparwood reclaimed areas are probably drier, as indicated by a dominant understory of ericaceous shrubs and lichens, with an L F H layer not more than 5 cm deep.

Table 12: Comparison of mean densities of mites and collembolans on reclaimed land, from various authors.

Data are mean densities (x 10^3 m^{-2}).

Source	Site Description	Site age (years)	Total Mites	Total Collembolans
Davis (1963) Northants, England	- unreclaimed levelled ironstone quarry	ca. 9	7.7	6.8
	- reclaimed ironstone heaps	10	11.9	7.1
	- old pasture	ca. 12	14.1	11.1
Dunger (1968a) Berzdorf, G.D.R.	- lignite coal spoil reclaimed to mixed alder, poplar and black locust forest	1	19.0	2.9
		3	74.9	39.7
		7	17.6	16.0
		10	12.7	8.8
Hutson (1980a) Northumberland, England	coal pitheaps reclaimed to:			
	- pasture (site A)	ca. 1	55.3	2.9
	- pasture (site B)	ca. 1	37.8	53.6
	- pasture (topsoiled) (site C1)	ca. 2	58.8	11.2
	- afforested (site C2)	ca. 2	26.7	28.5
Cross and Wilman (1982) Walker County, Alabama	coal spoil reclaimed to:			
	- bare or sparse vegetation	2	50.5	2.0
	- mixed pine, grass and legume	8	23.7	0.7
Parsons (1983), and Parsons and Parkinson (1986) Luscar, Alberta	- bituminous coal spoil reclaimed to grassland	1	8.3	3.6
		3	9.8	2.5
		7	8.3	7.0
present study Sparwood, British Columbia	- bituminous coal spoil reclaimed to grassland	2	12.7	0.7
		5	67.0	38.2
		9	95.9	9.0
	- undisturbed subalpine meadow	100+	553.9	25.4
	- undisturbed subalpine forest	100+	72.4	6.8

Prostigmata

The dominance of prostigmatid mites on all reclaimed sites agrees with results obtained by Hutson (1980a) and Cross and Wilman (1982) on other coal spoils. Prostigmatid mites are known to be more abundant in soils with low rather than high organic matter content (Loots and Ryke 1967), such as deserts (Petersen and Luxton 1982), and were observed to be the first mite colonizers in the high Antarctic (Janetschek 1970).

The prostigmatid families Tydeidae, Tarsonemidae, Nanorchestidae and Pygmephoridae were consistently among the ten most abundant taxa extracted from all sites, including the subalpine meadow (Table 2). Nanorchestidae was most abundant on the youngest spoil. Similar patterns have been reported from other works; Pyemotidae (=Pygmephoridae), Nanorchestidae, Tarsonemidae and Astigmata initially colonized Hutson's (1980a) sites, while the important pioneer mites colonizing Alabama mine spoils were two species of Nanorchestidae, one species of Tydeidae, and to a lesser degree, Eupodidae and Tarsonemidae (Cross and Wilman 1982). Amended stripmine spoils in New Mexico were also colomized by Tydeidae, Nanorchestidae, Tarsonemidae and Pygmephoridae (Elkins *et al.* 1984). Tydeid mites have been reported as early colonizers in habitats as diverse as buried creosote bush litter (Santos and Whitford 1981) to the high Antarctic (Janetschek 1970). The mite families colonizing these spoils may have been, to a large extent, characteristically opportunist species showing rapid growth, short life cycles and broad dispersal powers (Drury and Nisbet 1973, Connell and Slayter 1977). Since most mite densities tend to increase following fertilization (Marshall

1977), such opportunistic mites would exhibit high densities more rapidly than other soil fauna.

Feeding habits for most of these organisms are poorly known. Tydeid species may be unspecialized feeders, predators, microphytophages, or phytophages (Krantz 1978, Krantz and Lindquist 1979, Santos and Whitford 1981, Cross and Wilman 1982). Krantz (1978) reported that Tarsonemid feeding habits include algivory, fungivory, or phytophagy. Nanorchestid and pygmephorid mites are likely to be microphytophages (Krantz 1978, Cross and Wilman 1982), while eupodid mites may be predaceous, fungivorous or phytophagous (Krantz 1978). The early prostigmatid colonizers of these Sparwood reclaimed spoils are probably either phytophagous, or microherbiverous on bacteria, since mine spoils tend to have higher numbers of bacteria than fungi (Visser *et al.* 1979) because of generally alkaline conditions (Wallwork 1970, Yeates 1979). Other early colonizers on the 2-year site, notably Tetranychidae and Thysanoptera, are probably phytophagous (Wallwork 1970, Krantz 1978, Borror *et al.* 1981, Greenslade 1985).

Mesostigmata

The increase in mean densities and number of families of mesostigmatid mites with site age (Figure 10, Appendix A) may be a reflection of increasing complexity of food webs and trophic interactions. Mesostigmatid mites are mainly predaceous (Wallwork 1967, 1970), and generally comprise from a few to about 20 percent of the total mite fauna (Petersen and Luxton 1982). The lack of predaceous mites on young spoil materials here may have allowed initial colonizers to increase rapidly in population size, a phenomenon also reported by Hutson (1980a) and Cross and Wilman (1982).

The mesostigmatid family Zerconidae was present only in the two oldest soils. As members of this family generally feed on fungi or dead organic material (Wallwork 1967, Ghilarov 1975), their presence, coupled with a lower pH on the 9-year site (Table 1), may indicate higher organic matter levels resulting from greater plant biomass, decomposition processes, and spoil weathering.

Cryptostigmata

Cryptostigmatid mites were present in appreciable numbers only in the subalpine meadow soil. A paucity of Cryptostigmata on reclaimed mine spoils has been observed by Brüning *et al.* (1965), Hermosilla (1976), Hutson (1980a), Cross and Wilman (1982) and Elkins *et al.* (1984). Luxton (1982), on the other hand, reported Cryptostigmata to be the dominant mite suborder on several coal shale tips in northwest England, and Dunger (1968a, 1969b) reported well-developed Cryptostigmata populations only three years after reclamation. However, Luxton's spoils were moist and acidic, and Dunger's sites were afforested and receiving a high annual litter input of up to 440 g m^{-2}, conditions which are more amenable to developing Cryptostigmata populations.

A number of factors may have contributed to the low cryptostigmatid densities observed in these Sparwood spoils. Cryptostigmata generally respond more slowly to soil fertilization than other mite suborders, perhaps because of their longer life cycles and saprophagous feeding habits (Marshall 1977). Cryptostigmatid mites may be less tolerant of the adverse environmental conditions found in these soils, they may experience a lack of preferred food such as fungi or decaying organic material, or they may be less mobile and therefore disperse poorly into such areas (Petersen and Luxton 1982).

With respect to the more abundant mite families occurring in the reclaimed Sparwood spoils, Brachychthoniidae are generally more abundant in the surface layers of mineral soil (Luxton 1982) and have been demonstrated to be fairly insensitive to environmental change (Aoki 1979). Aoki also noted that the cryptostigmatid families Oppiidae and Tectocepheidae were tolerant of environmental change, which perhaps accounts for their presence in the reclaimed spoils.

Cryptostigmata usually constitute the major proportion of the mite fauna in most ecosystems. A small contribution of Cryptostigmata to total mite abundance is most often associated with high numbers of Prostigmata, for example, in some tundra, desert, or temperate grassland habitats (Petersen and Luxton 1982). Such was the pattern observed in this study. Even in the subalpine meadow soil, Cryptostigmata never accounted for more than 23 percent of the total mite fauna. Only in the subalpine forest soil did the relative abundance of Cryptostigmata increase, mainly because of the abundance of the brachychthoniid, oppiid and tectocepheid mite families, which also occurred in the reclaimed soils.

Astigmata

The low abundance of Astigmata in the study soils, compared to other mite orders, is similar to data from most ecosystems (Petersen and Luxton 1982), although Hutson (1980a) recorded very high densities of Astigmata on two of his sites, and both Davis (1963) and Hermosilla (1976) recorded high numbers of Astigmata on reclamation sites. Generally, Astigmata are not abundant in most soils. They are more commonly associated with drier situations (Wallwork 1967), or soils with deep organic horizons (Petersen and Luxton 1982). Soil conditions on these Sparwood spoils probably do not favor colonization by large numbers of these mites.

3. COLLEMBOLANS

Collembolan densities on the 2-year site were lower than densities recorded from 1 or 2-year reclaimed spoils by Dunger (1968a), Hutson (1980b), Cross and Wilman (1982), or Parsons (1983) (Table 12). Early colonizers on the 2-year site, notably Isotomidae and Entomobryidae, were also early colonizers of Hutson's spoils, while Parsons and Parkinson (1986) reported Isotomidae and Hypogastruridae to be abundant on 1-year spoil. Dunger (1968b, 1969b) also found high densities of edaphic collembolan forms such as *Tullbergia* and *Hypogastrura*, three years after sites were afforested.

The high numbers of Collembola recorded on the 5-year site in June and August correspond to high collembolan densities recorded on similar-aged sites in Germany (Dunger 1968a) and England (Hutson 1980a). Most collembolans on this site were Hypogastruridae, and two factors may contribute to the high densities observed.

These collembolans may have exhibited r-selected characteristics such as efficient dispersal and the ability to produce several generations per season (Purvis and Curry 1980) to enable them to respond quickly to favorable food conditions in the absence of predators such as mesostigmatid mites. Collembolans generally reproduce whenever environmental conditions permit, and species in north temperate localities often produce two generations per year (Wallwork 1970, Aitchison 1984, Straalen 1985). The high densities of Hypogastruridae in June and August on this site may reflect two population peaks, in early spring and late summer.

These collembolans may have also formed an aggregation in response to pheromones (Verhoef *et al.* 1977), food distribution, optimal breeding sites, overwintering sites, or moisture conditions (Fjellberg 1985). Such non-random distributions are common in both collembolans and mites (Christiansen 1964, Joosse 1970, Butcher *et al.* 1971, Schenker 1984). The r-type response in the absence of predators, plus the tendency to aggregate, may both be influencing collembolan densities on this site. The present data are insufficient to confirm either or both of these factors.

The low abundance of Collembola on these reclaimed Sparwood spoils may have also been influenced by soil moisture conditions. Even though numerous positive and negative correlations have been reported (Petersen and Luxton 1982), Fjellberg (1985) suggested that moisture is one of the most important factors influencing collembolans. Parsons and Parkinson (1986) correlated densities of a number of collembolan species with soil moisture availability, and Hutson (1980a) also felt that drought limited collembolan abundance on mine spoils.

However, factors other than soil moisture are probably influencing collembolan densities on the two youngest spoils, since mean soil moisture values are fairly similar (Figure 5), and mean collembolan densities are very different (Figure 8). This lack of correlation between total faunal abundance and soil moisture on the Sparwood mine spoils may be more a reflection of the level of taxonomic identification. Responses to soil moisture may be significant at the species level but not at higher categories, and thus not detected. Gross estimates of percent moisture in the entire soil core may have little relevance for many soil arthropods since the distribution and retention of water in the microhabitat of the animal may vary greatly between two samples that have identical soil moisture readings (Brand 1979). This suggestion may be further expanded to consider the nature of the soil itself. Often what appears to be a uniform habitat with regards to vegetation, soil type and various physical and chemical properties, may consist of a number of distinct microhabitats for soil microarthropods (Davis 1963, Wood 1966, Mermut 1985), resulting in large variations in soil faunal abundance and distribution patterns.

4. INSECTS

The low densities of insects observed on these reclaimed sites correspond with low insect densities recorded for other mine spoils (Dunger 1968a, Hutson 1980a, Cross and Wilman 1982, Parsons and Parkinson 1986). Coleoptera and Diptera were generally the most abundant insects on all sites, as with the previously-mentioned studies, although high numbers of Thysanoptera were occasionally observed on the 2-year and 9-year sites. Thysanopterans are generally plant feeders and not considered part of the permanent soil fauna, although they are often recorded from soil (Salt *et al.* 1948, Purvis and Curry 1980, Cross and Wilman 1982). Thrips may inhabit grass sheaths, dying grass clumps, or leaf litter, where they may be predaceous (Ananthakrishnan 1979) or microphytophagous on a range of unicellular algae, lichens, fungal hyphae, and spores (Greenslade 1985). Thysanopterans on the youngest site are most likely plant feeders responding to the absence of predators and to the presence of vegetation.

The remaining insects were primarily predaceous Coleoptera. Diptera larvae were less abundant, and may have consisted of saprophagous or fungivorous forms such as Phoridae, Sciaridae and Cecidomyiidae (Borror *et al.* 1981), which might be expected to occur more in soils with a higher organic matter content. Diptera larvae were reported to be more abundant than Coleoptera larvae in other studies (Hutson 1980a, Parsons and Parkinson 1986). Dunger (1968a) had previously reported insect densities similar to Hutson's, and noted a pioneer shrubby stage which was characterized by Collembola and Diptera larvae, three years after reclamation.

Early colonization by carabid beetles has been recorded on newly-reclaimed coal spoils in Germany (Neumann 1973). The beetle association was gradually replaced by isopods (Isopoda) and millipedes (Diplopoda) as the woodland developed. Carabid and staphylinid beetles were also among the first colonizers of the blast zone on Mount St. Helens, following the 1980 eruption (Edwards 1986). Since these insects scavenge or prey upon stranded arthropod 'fallout,' Edwards suggests that initial successional species may actually be consumers, as opposed to primary producers. A similar phenomenon may occur on unreclaimed mine spoil in this area, although this has not been tested. The 2-year site already supported a vegetative cover, and wind-dispersed arthropods arriving on this site would likely not experience such harsh conditions.

5. OTHER ARTHROPODS

Other arthropods, such as Pseudoscorpionida, Araneae, Protura and Diplura, were essentially absent from reclaimed soils, as was found by Dunger (1968a), Hutson (1980a), Cross and Wilman (1982) and Parsons and Parkinson (1986). Spiders (Araneae) were observed on reclaimed sites, but would not have been sampled accurately with the extraction technique used. Protura and Diplura likely play a minor role in the soil community (Petersen and Luxton 1982), although again sampling and extraction techniques may have been inefficient. They have a tendency to favor deep, moist organic soils (Wallwork 1970), a condition likely only to be encountered in the undisturbed subalpine meadow soil, and beyond the depth of the 7 cm soil cores.

Isopods were never encountered during this present study and only one millipede specimen was found, from the subalpine forest. Petersen and Luxton (1982) suggested that isopods are absent or of only minor importance in tundra biomes, and exhibit low densities in temperate grasslands. An association of isopods and millipedes similar to that reported by Neumann (1973) would probably not develop on the types of reclaimed grassland sites sampled at Sparwood. Millipedes were occasionally observed on the 5 and 9-year reclaimed sites, but were never caught, probably due to inappropriate extraction techniques. Behan and Hill (1978) suggested that in soils which lack the important shredders of warm temperate regions (earthworms, millipedes and isopods), mites may play a larger role in energy turnover. This is probably the case in this present study, particularly in light of the high relative abundance of mites.

6. NEMATODES AND ENCHYTRAEIDS

Stanton and Krementz (1982) studied the trophic structure and densities of nematode populations in coal mine spoils in south-central Wyoming. The authors reported that significantly fewer nematodes were obtained from disturbed soils than from undisturbed soils, and stockpiled topsoil supported the lowest nematode densities of all sites.

In the present study, extremely low densities of nematodes were found on only the 2-year site. Perhaps nematodes are poorer dispersers than the other fauna extracted, and had not yet colonized the site to any great extent. The lower root litter and above-ground vegetative biomass on this site (Table 1), along with lower soil moisture levels (Figure 5) are also possible contributing factors. Nematode populations are correlated with primary production (Yeates 1979), particularly plant root and litter biomass (Wallwork 1970, Kimpinski and Welch 1971). The physical structure of the soil, especially particle size and pore size distributions, also greatly influences nematode populations by affecting plant biomass, or the availability of water films or nutrients (Nicholas 1975, Freckman 1982).

Although variable, nematode densities from undisturbed grassland ecosystems are generally higher (Nicholas 1975, Sohlenius 1980, Petersen and Luxton 1982) than those recorded for the oldest reclaimed site and subalpine meadow. These relatively low nematode densities may be a reflection of the high numbers of tydeid mites present on these sites (Table 2, Figure 12), and perhaps their feeding activities resulted in lower nematode populations on all but the 2-year reclaimed site. Santos and Whitford (1981) and Santos *et al.* (1981) found that the bacterial decomposition of litter in a desert ecosystem was affected by the preying of microarthropods, particularly Tydeidae, on bacteriophagic nematodes. Tydeids were also observed to feed on bacteriophagic nematode eggs in the laboratory (Santos and Whitford 1981).

On the remaining three sites, mean nematode densities ranged between 400,000 and 500,000 m^{-2}. A consistent distinct fluctuation in densities was observed over the summer on all three sites, likely indicating some factor other than sampling error. Wallwork (1970) stated that fluctuations in population sizes of soil nematodes do not appear to conform to any regular cyclical pattern. But given five or six (Wallwork 1970) or even one to eight (Freckman 1982) generations per year, well-marked density peaks would not be observed unless the number of generations of numerically important species were synchronized and restricted to a relatively short time period (Wallwork 1970). On the Sparwood sites, the short active season may have telescoped the reproductive activities into two generations per year, with a peak in late spring (June), and again in late summer (August). However, information regarding the species composition, trophic structure, or life histories of these nematode species is not available,

Enchytraeid worms were found only in low densities on the undisturbed subalpine meadow, and were essentially absent from reclaimed soils. Although enchytraeids tend to favor damp soils with a high organic matter content (Wallwork 1970), they may also survive in drier situations. Santos and Whitford (1981) found large numbers of enchytraeids colonizing litter bags that had been buried in desert soil for a year. Wallwork (1970) reported that *Henlea* may be tolerant of a wide range of availability of soil moisture. Conditions may have been fairly dry on the subalpine meadow due to its steep, well-drained slope and the south-east exposure. Enchytraeids on this site may have been present either in aggregated (Peachy 1963) or low densities, or below the 7 cm sampling depth.

Adverse soil conditions, particularly low levels of organic matter and poor fungal development, may account for the absence of enchytraeids, although their absence may be due in part to slow dispersal rates. The topographic position of the subalpine meadow with respect to the reclaimed areas would deter immigration into reclaimed soils from the undisturbed meadow soil.

Lumbricid earthworms were absent from all study sites, probably due to the historical scarcity of earthworms in Canadian soils (Reynolds 1977).

7. VERTICAL DISTRIBUTION IN THE SOIL

The general pattern observed for most soil fauna is one of decreasing density with soil depth (Salt *et al.* 1948, Sheals 1957, Davis 1963, Wood 1967, Marshall 1974, Nicholas 1975, Price and Benham 1977), a pattern also observed in the Sparwood spoils. Some microarthropod taxa such as Cryptostigmata and Astigmata, along with nematodes on the 2-year site, may have been present in densities which were too low to indicate significant patterns with depth.

Soil fauna exhibit a tendency to accumulate in regions of high organic matter content (Foster 1985). The weakly-developed reclaimed soils would have appreciable amounts of organic matter either at the soil surface-plant litter interface, or in and around plant roots. Most soil fauna would be expected to be found in high densities in these areas. Poor physical conditions of reclaimed soils also mean that subsurface layers have a lower porosity and higher bulk density (Rimmer 1982). Because most soil fauna cannot burrow and must utilize existing pore spaces (Wallwork 1970) these poor physical conditions in the lower profile would have restricted many fauna to the upper layers.

Especially deep distributions of soil fauna showing concentrations of fauna below the surface layer have been reported in dry, natural temperate grasslands (Petersen and Luxton 1982). A vertical distribution of this type was seen in the subalpine meadow soil where microarthropods, nematodes and enchytraeids did not occur predominantly in the upper 3 cm of the soil profile. This is probably due in part to the age and developmental state of the soil, which have produced a fairly even distribution of organic matter with depth, as evidenced by the well-developed Ah horizon. Surface temperatures were probably fairly warm throughout the sampling period, due to the slope and exposure of the grassland. Soil fauna in this undisturbed soil would not experience the lack of organic matter and the adverse bulk density and porosity conditions experienced by the soil fauna of the deeper reclaimed spoil.

8. RELATIONSHIPS BETWEEN SOIL FAUNA AND ECOSYSTEM DEVELOPMENT

Vegetation and soil development (Fyles 1980, Fyles *et al.* 1985), nitrogen cycling (Fyles 1984), and other nutrient cycling and organic matter characteristics (Ziemkiewicz 1979, 1982) have been documented on these high elevation reclaimed spoils at Sparwood. Ziemkiewicz (1979, 1982) concluded that a 3-year-old subalpine reclaimed area (the 9-year site of this present study) was dependent upon fertilization, and that nutrients appeared to be accumulating in surface litter. Further research indicated that the same site, then six years old, was similar to the subalpine meadow in a number of respects except that a large stabilized pool of organic matter was absent in the reclaimed soil (Fyles *et al.* 1985). If a reclaimed soil may be regarded as being 'self-sufficient' when mineralization rates of the limiting nutrient, nitrogen, are sufficient to support the required level of vegetative growth, the 9-year site may have been close to this stage when it was six years old (Fyles 1980). Fyles (1984) traced the path of labelled ammonium sulphate fertilizer through soil and plant components on the same sites and at the same time as the present study, concluding that while the 2-year site was dependent on fertilizer inputs to maintain site productivity, much of the nitrogen utilized by the vegetation on the remaining sites was supplied by pools of organic nitrogen which had accumulated in the spoil. While competition for mineral nitrogen on the 5-year site was intense, the 9-year site was mineralizing sufficient nitrogen to maintain plant productivity without additional fertilizer inputs. However, a large stabilized pool of organic nitrogen, such as was present in the subalpine meadow, was still absent on this site.

Examination of Table 1 further reveals a pattern of soil development where a number of biotic and abiotic features exhibit large differences between the 2 and 5-year sites, and less pronounced differences between the 5, 9-year and subalpine meadow sites. Root, litter and vegetative biomass levels were very similar on the three older study sites. Rates of CO_2 evolution paralleled the increases in faunal densities with site age. Such a trend is expected, since this measure reflects the overall biological activity of the soil (Buckman and Brady 1969, Richardson 1975). Soil pH decreased with site age, a process likely caused by the leaching of bases released by spoil weathering, and the production of humic and fulvic acids from decomposition processes (Swift *et al.* 1979, Fyles *et al.* 1985). The percentage of clay particles increased with site age, along with a decrease in the percentage of coarse fragments. The coarse fragment content in the subalpine meadow soil was very much lower than that observed for the reclaimed sites. Cation exchange capacity levels were also higher in the undisturbed meadow soil. Given that the measure of cation exchange capacity refers only to the fine fraction of the soil, these differences between the reclaimed and undisturbed soils are even more pronounced. The fine fraction comprises between 20 to 30 percent of the total soil volume in the reclaimed soils, compared to 75 percent in the subalpine meadow.

The trends observed in these features help to strengthen and clarify the understanding of both the colonization patterns of soil fauna observed in this study, and the developmental or successional state of these reclaimed soils. The observed changes in soil faunal densities, numbers of taxa, and various biotic and physical characteristics correspond to known successional trends (Odum 1971) of changes occurring most rapidly at the beginning of a successional sequence, followed by a longer period of a slower rate of change. Early colonizers, such as Tydeidae, Nanorchestidae and Tarsonemidae, are probably opportunistic species which are good dispersers, with a greater reproductive potential under these conditions than other soil fauna. Since the successional sequence is artificially accelerated by the actual reclamation process, phytophagous forms such as Tetranychidae and Thysanoptera were also abundant on the youngest site, particularly in the absence of a large number of predators.

The actual reclamation process produced sites which did not differ greatly in plant biomass, after five years of age, from the undisturbed meadow. However, patterns in soil faunal densities, number of taxa and ordination results, along with certain soil features such as cation exchange capacity, nitrogen cycling, and percentage of clay and coarse fragments, indicate that these reclaimed soils are still poorly developed.

9. IMPLICATIONS FOR RECLAMATION

A number of workers have identified important factors affecting the soil fauna of mine spoils, and have made recommendations for improving spoil conditions for soil fauna. The amount and kind of vegetative cover, root biomass levels (Remus 1969, Cross and Wilman 1982), soil moisture (Neumann 1973, Parsons and Parkinson 1986, Davis 1963), organic matter content and porosity (Davis 1963), distance from a colonizing source (Neumann 1973, Dindal and Wray 1977), and the species composition and density in the colonizing source (Remus 1969), have all been identified as important factors. Hutson (1980a) and Parsons and Parkinson

(1986) suggested that these soil properties may initially be more important than site age.

Topsoiling or mulching procedures were often recommended for improving spoil conditions (Dindal and Wray 1977, Dunger 1969a, Ettershank *et al.* 1978, Jurgensen 1979, Parkinson 1979, Luxton 1982, Elkins *et al.* 1984). Other suggestions for improving microsite conditions involve the formation of surface depressions or microrelief to help alleviate soil temperature and moisture extremes (Harrison 1977, Harthill and McKell 1979). Using small amounts of topsoil from nearby undisturbed forest areas may also be a viable means of inoculating specific areas of newly reclaimed mine spoils on this property with potential colonizers of both soil flora and fauna, particularly since future areas to be reclaimed will be further away from colonizing sources. Dindal and Wray (1977) have emphasized the value of maintaining colonizing loci in and around mining operations. It may prove useful to also consider introducing and encouraging non-native lumbricid earthworm fauna onto these spoils, given the well-documented beneficial effects of earthworms on overall soil structure and fertility (Edwards and Lofty 1972, Bal 1982) and the initial success of introduced populations of *L. terrestris* in afforested Ohio coal spoils.

Chapter V

SUMMARY AND CONCLUSIONS

The pattern of microarthropod colonization on these reclaimed spoils was similar to that observed by other researchers. Total microarthropod densities increased at a high rate of change during the early successional period (i.e. between the 2 and 5-year sites), with no significant increases in faunal densities later in the successional sequence (i.e. between 5 and 9-year sites). The undisturbed subalpine meadow soil exhibited considerably higher microarthropod densities and number of taxa than all reclaimed sites. Early colonizers were probably opportunistic species which may not only be fairly tolerant of adverse environmental conditions, but which may exhibit good dispersal abilities, high reproductive rates, and subsequent rapid density increases in response to fertilization. Initial colonizing fauna were probably plant feeders, bacterial feeders, or unspecialized feeders. Predator densities were low.

Mites numerically dominated the microarthropod fauna in all sites. The suborder Prostigmata dominated the mite fauna, and mites of the family Tydeidae were the most abundant prostigmatids. Members of this and the other abundant prostigmatid families have been reported to be early colonizers by other workers, and to occur predominantly in soils with low organic matter content. Densities of other mite suborders were low, Cryptostigmata only reaching a relative abundance of 23 percent in undisturbed subalpine meadow soil.

Although other microarthropod densities increased with site age, they were considerably less abundant in these soils than were mites. Hypogastrurid collembolans were an exception to this general trend and exhibited high densities on the 5-year site, a condition paralleling high collembolan densities in early successional stages reported by Dunger(1968a) and Hutson(1980a). The soil insect community was predominantly comprised of Coleoptera (particularly Staphylinidae) and Diptera larvae, with an abundance of Thysanoptera on the youngest reclaimed site.

Soil nematodes were rare on the youngest reclaimed site, yet very abundant in the 5-year reclaimed soil, with 9-year reclaimed soil exhibiting similar nematode densities to those in the undisturbed subalpine meadow soil. The very low densities on this 2-year site may be attributed to the influence of low primary productivity, coupled with poor nematode dispersal abilities.

A general pattern of increasing microarthropod densities over the 4-month sampling period was observed on most sites. Nematode densities on the three oldest study sites exhibited similar high densities in June and August, possibly reflecting synchronized reproductive peaks.

The pattern of soil faunal colonization on these study sites augments the understanding of the development of these reclaimed mine spoil ecosystems. Initially, the reclaimed spoil was characterized by low root, litter and above-ground biomass levels, a low clay content, low cation exchange capacity, higher pH, and high coarse fragment content. Soil faunal densities were low, predominantly unspecialized or bacterial feeders. Nitrogen, the limiting nutrient, was supplied mainly from external applications of fertilizer. By five years of age, the reclaimed-site vegetation had reached a point where biomass levels were only slightly below that of the similar 9-year and undisturbed meadow sites. Clay content and cation exchange capacity had increased. Increased soil faunal densities were also reflected in higher rates of CO_2 evolution. Much of the nitrogen present in the vegetative material was obtained not from external fertilizer applications, but from an active pool of nitrogen which had accumulated in the soil.

By nine years of age, competition for this active nitrogen fraction was less intense, and a stabilized pool of nitrogen and organic matter was beginning to accumulate. Although total soil microarthropod densities between the 5 and 9-year sites were not significantly different, the 9-year site exhibited higher numbers of taxa and higher predator densities. Mite families encountered on the 9-year site, such as Zerconidae, Ceratozetidae and Damaeidae, may also indicate increasing amounts of soil organic matter, as well as a shift towards increasing levels of fungi. This is further supported by a decrease in soil pH from the weathering of spoil material, as indicated by a reduction in the soil coarse fragment content, and increases in clay content and cation exchange capacity.

Reclamation practices have helped to develop reclaimed soil subsystems that can support vegetative biomass at levels similar to the undisturbed subalpine meadow and supply adequate amounts of nitrogen for plant growth, at approximately five years of age. However, in many respects the reclaimed soils are still quite undeveloped. Microarthropod densities and number of taxa between the reclaimed sites and the subalpine meadow and forest soils were very different. Faunal densities in the reclaimed soils were always greatest in the upper 3 cm of the soil profile, a common phenomenon likely augmented by the lack of organic matter and soil structure with depth.

Given the paucity of important decomposer species such as earthworms, isopods, or millipedes on these study sites, mites and collembolans probably play the major invertebrate role of fragmenting organic material for decomposition by soil bacteria and fungi. Although the means of dispersal for these soil fauna are not well understood, these mine spoils are likely colonized either from overland movement out of nearby undisturbed subalpine forest patches, phoretic transport on other animals, or by wind.

As the area of disturbance increases with mining activity, reclamation efforts should be directed towards creating microsites such as depressions or other areas of microrelief, which would be conducive to developing beneficial soil fauna populations. The use of undisturbed topsoil may provide not only potential sources of colonizing soil fauna, but also sources of soil flora such as mycorrhizal fungi. Such topsoil may further provide improved seedbed conditions for reforestation or other planting projects. Mulch applications have also been recommended to improve reclaimed soils. Other viable techniques might involve the introduction and establishment of beneficial earthworm species.

Vegetation may be established and erosion controlled fairly quickly on these coal mine spoils. However, the development of soil and the accumulation of organic matter will likely proceed at a much slower rate. It is organic matter which ultimately provides the nutrient pool for the growth of vegetation and ensures the development of good soil tilth. The biotic component of the soil community (microflora and microfauna) is responsible for regulating the rate at which soil formation occurs, and it is this biotic component upon which the success of reclamation on these spoils will depend.

REFERENCES

Aitchison, C.W. (1984). The phenology of Collembola from South Central Canada. *Pedobiologia*, **27**,405-423.

Ananthakrishnan, T.N. (1979). Biosystematics of Thysanoptera. *Annual Review of Entomology*, **24**,159-183.

Aoki, J. (1979). Difference in sensitivities of oribatid families to environmental change by human impacts. *Revue d'Écologie et de Biologie du Sol*, **16**,415-422.

Bal, L. (1982). *Zoological Ripening of Soils.* Agricultural Research Reports, No. 805, Pudoc,Wageningen.

Behan, V.M. and S.B. Hill. (1978). Feeding habits and spore dispersal of Oribatid mites in the North American arctic. *Revue d'Écologie et de Biologie du Sol*, **15**,497-516.

Berthet, P. (1964). Field study of the mobility of Oribatei (Acari) using radioactive tagging. *Journal of Animal Ecology*, **33**,443-449.

Bode, E. (1975). Pedozoologische Suksessionsuntersuchungen auf Rekultivierungsflächen des Braunkohlentagebaues. *Pedobiologia*, **15**,284-289.

Borror, D.J., D.M. DeLong and C.A. Triplehorn. (1981). *Introduction to the Study of Insects, Fifth Edition.* Saunders College Pub., Philadelphia.

Brand, R. (1979). Effect of sampling time on estimates of soil Arthropod populations. *Revue d'Écologie et de Biologie du Sol,* **16**,499-515.

Brüning, E., H. Unger and W. Dunger. (1965). Untersuchungen zur Frage der biologischen Aktivierung alttertiärer Rohbodenkippen des Braunkohlentagebaues in Abhängigkeit von Bodenmelioration und Rekultivierung. *Zeitschrift für Landeskultur,* **6**,9-38.

Buckman, H.O. and N.C. Brady. (1969). *The Nature and Properties of Soils, Seventh Edition.* Macmillan Co., New York.

Butcher, J.W., R. Snider and R.J. Snider. (1971). Bioecology of edaphic Collembola and Acarina. *Annual Review of Entomology,* **16**,249-288.

Canada Soil Survey Committee. (1978). *The Canadian System of Soil Classification.* Canada Department of Agriculture Publication 1646. Supply and Services Canada, Ottawa.

Christiansen, K. (1964). Bionomics of Collembola. *Annual Review of Entomology,* **9**,147-178.

Connell, J.H. and R.O. Slayter. (1977). Mechanisms of succession in natural communities and their role in community stability and organization. *American Naturalist,* **111**,1119-1144.

Cross, E.A. and J.M. Wilman. (1982). A preliminary study of the refaunation of alkaline shale coal surface mine spoil by soil arthropods. pp.353-358. *Proceedings of the 1982 Symposium on Surface Mining, Hydrology, Sedimentation and Reclamation*, Lexington, Kentucky.

Curry, J.P. (1969). The decomposition of organic matter in soil. Part III. The fauna of decaying grassland herbage. *Soil Biology and Biochemistry*, **1**,259-266.

Danks, H.V. (Ed.). (1979). Canada and its insect fauna. *Memoirs of the Entomological Society of Canada*, No. 108.

Davis, B.N.K. (1963). A study of microarthropod communities in mineral soils near Corby, Northants. *Journal of Animal Ecology*, **32**,49-71.

Desender, K. and M. Vaneechoutte. (1984). Phoretic associations of carabid beetles (Coleoptera, Carabidae) and mites (Acari). *Revue d'Écologie et de Biologie du Sol*, **21**,363-371.

Dick, J. (1978). *A Plan for the Reclamation of Surface Mine Coal Lands in the East Kootenays.* MSc. thesis. University of British Columbia.

Dindal, D.L. (1985). Soil animals and soil fabric production: facts and perceptions. *Quaestiones Entomologicae*, **21**,587-594.

Dindal, D.L. and C.C. Wray. (1977). Community structure and role of macroinvertebrate decomposers in the rehabilitation of a limestone quarry. (ed. by E.J. Perry and N.A. Richards). pp.72-99. *Limestone Quarries: Responses to Land Use Pressures.* Allied Chemical Corp., Jamesville, New York, and SUNY College of Environmental Science and Forestry, Syracuse, New York.

Drury, W.B. and I.C.T. Nisbet. (1973). Succession. *Journal of the Arnold Arboretum*, **54**,331-368.

Duncan, D.B. (1955). Multiple range and multiple F-tests. *Biometrics*, **11**,1-42.

Dunger, W. (1968a). Die Entwicklung der Bodenfauna auf Rekultivierten Kippen und Halden des Braunkohlentagebaues. *Abhandlungen und Berichte des Naturkundemuseums Görlitz*, **43**,1-256.

Dunger, W. (1968b). Produktionsbiologishe Untersuchungen an der Collembolen-Fauna gestörter Böden. *Pedobiologia*, **8**,16-22.

Dunger, W. (1969a). Fragen der natürlichen und experimentellen Besiedlung kulturfeindlicher Böden durch Lumbriciden. *Pedobiologia*, **9**,146-151.

Dunger, W. (1969b). Über den Anteil der Arthropoden an der Umsetzung des Bestandesabfalles in Anfangs-Bodenbildungen. *Pedobiologia*, **9**,366-371.

Edwards, C.A., D.E. Reichle and D.A. Crossley, Jr. (1970). The role of soil invertebrates in turnover of organic matter and nutrients. (Ed. by D.E. Reichle). pp.147-172. *Analysis of Temperate Forest Ecosystems*. Springer-Verlag, New York.

Edwards, C.A. and J.R. Lofty. (1972). *Biology of Earthworms*. Chapman and Hall Ltd., London.

Edwards, J.S. (1986). Derelicts of dispersal: arthropod fallout on Pacific Northwest volcanoes. (Ed. by W. Danthanarayana). pp.196-203. *Insect Flight*. Springer-Verlag, New York.

Elkins, N.Z., L.W. Parker, E. Aldon and W.G. Whitford. (1984). Responses of soil biota to organic amendments in stripmine spoils in northwestern New Mexico. *Journal of Environmental Quality*, **13**,215-219.

Ettershank, G. (1963). A method of separating arthropods from debris in Berlese funnel samples. *Turtox News*, **41**,98-100.

Ettershank, G., N.Z. Elkins, P.F. Santos, W.G. Whitford and E.F. Aldon. (1978). The use of termites and other soil fauna to develop soils on strip mine spoils. *United States Department of Agriculture Forest Service Research Note* RM-361.

Fjellberg, A. (1985). Recent advances and future needs in the study of Collembola biology and systematics. *Quaestiones Entomologicae*, **21**,559-570.

Foster, R.C. (1985). *In situ* localization of organic matter in soils. *Quaestiones Entomologicae*, **21**,609-633.

Freckman, D.W. (1982). Parameters of the nematode contribution to ecosystems. (Ed. by D.W. Freckman). pp.81-97. *Nematodes in Soil Ecosystems*. University of Texas Press, Austin.

Fyles, I.H. (1984). *Nitrogen Cycling Through Soil-plant Systems on High Elevation Reclaimed Coal Mine Spoils*. MSc. thesis, University of Alberta.

Fyles, J.W. (1980). *Vegetation and soil development on Reclaimed Mine Lands at High Elevation in South Eastern British Columbia*. MSc. thesis, University of Victoria.

Fyles, J.W., I.H. Fyles and M.A.M. Bell. (1985). Vegetation and soil development on coal mine spoil at high elevation in the Canadian Rockies. *Journal of Applied Ecology*, **22**,239-248.

Gauch, H.G. Jr. (1977). ORDIFLEX - A flexible computer program for four ordination techniques: weighted averages, polar ordination, principal components analysis, and reciprocal averaging, Release B. Ecology and Systematics, Cornell University, Ithaca, New York.

Ghilarov, M.S. (1975). *A Key to the Soil-inhabiting Mites. Sarcoptiformes.* (Ed. by M.S. Ghilarov), Moscow, USSR.

Gibson, D.W. (1977). The Kootenay Formation of Alberta and British Columbia - A stratigraphic summary. *Report of Activities, Part A.* Geological Survey of Canada, Paper 77-1A.

Glick, P.A. (1939). The distribution of insects, spiders and mites in the air. *United States Department of Agriculture Technical Bulletin*, No.673.

Greenslade, P.J.N. (1985). Pterygote insects and the soil: their diversity, their effects on soils and the problem of species identification. *Quaestiones Entomologicae*, **21**,571-585.

Hamilton, W.E. and J.P. Vimmerstedt. (1980). Earthworms on forested spoil banks. (Ed. by D.L. Dindal). *Soil Biology as Related to Land Use Practices.* pp.409-417. Proceedings of the VII International Soil Zoology Colloquium of the International Society of Soil Science (ISSS), EPA, Washington, D.C.

Harrison, J.E. (1977). Summer soil temperatures as a factor in revegetation of coal mine waste. pp.329-332. *Report of Activities, Part A*. Geological Survey of Canada, Paper 77-1A.

Harthill, M. and C.M. McKell. (1979). Ecological stability - is this a realistic goal for arid land reclamation? (Ed. by M.K. Wali). pp.557-567. *Ecology and Coal Resource Development*. Pergamon Press, New York.

Hermosilla, W. (1976). Beobachtungen an der Bodenfauna von rekultivierten Böden im Braunkohlentagebaugebeit der Ville. *Decheniana (Bonn)*, **129**,73-75.

Hill, M.O. (1979). DECORANA - A FORTRAN program for detrended correspondence analysis and reciprocal averaging. Ecology and Systematics, Cornell University, Ithaca, New York.

Hutson, B.R. (1980a). Colonization of industrial reclamation sites by Acari, Collembola, and other invertebrates. *Journal of Applied Ecology*, **17**,255-275.

Hutson, B.R. (1980b). The influence on soil development of the invertebrate fauna colonizing industrial reclamation sites. *Journal of Applied Ecology*, **17**,277-286.

Janetschek, H. (1970). Environments and ecology of terrestrial arthropods in the high Antarctic. (Ed. by M.W. Holdgate). pp.871-885. *Antarctic Ecology*. Academic Press, London.

Joosse, E.N.G. (1970). The formation and biological significance of aggregations in the distribution of Collembola. *Netherlands Journal of Zoology*, **20**,299-314.

Jurgensen, M.F. (1979). Microorganisms and the reclamation of mine wastes. (Ed. by C.T. Youngberg). pp.251-286. *Forest Soils and Land Use.* Proceedings of the Fifth North American Soils Conference, Colorado State University, Ft. Collins.

Kimpinski, J. and H.E. Welch. (1971). The ecology of nematodes in Manitoba soils. *Nematologica,* **17**,308-318.

Koehler, H. (1985). Reclamation as an ecological problem. 5. Development of the Gamasina communities (Acari, Parasitiformes) in the cover layer of a rubble dump and how this is affected by reclamation measures. *Verhandlungen der Gesellschaft für Okologie,* **13**,781-785.

Krajina, V.J. (Ed.). (1965). *Ecology of Western North America, Vol.1.* University of British Columbia, Vancouver, B.C.

Krantz, G.W. (1978). *A Manual of Acarology, Second Edition.* Oregon State University, Corvallis.

Krantz, G.W. and E.E. Lindquist. (1979). Evolution of phytophagous mites (Acari). *Annual Review of Entomology,* **24**,121-158.

Lawrence, J.M. (1986). A trial inoculation of soil fauna on a high elevation reclaimed site. *Westar Mining Ltd., Annual Reclamation Report for 1986.* 26 pp.

Lebrun, P. (1979). Soil mite community diversity. (Ed. by J.G. Rodriguez). pp.603-613. *Recent Advances in Acarology.* Academic Press, New York.

Loots, G.C. and P.A. Ryke. (1967). The ratio Oribatei: Trombidiformes with reference to organic matter content in soils. *Pedobiologia*, **7**,121-124.

Lussenhop, J. (1971). A simplified canister-type soil arthropod extractor. *Pedobiologia*, **11**,40-45.

Luxton, M. (1982). The ecology of some mites from coal shale tips. *Journal of Applied Ecology*, **19**,427-442.

Lyford, W.H. (1974). Overland migration of Collembola *(Hypogastrura nivicola* Fitch) colonies. *American Midland Naturalist*, **94**,205-209.

Madge, D.S. (1969). Litter disappearance in forest and savanna. *Pedobiologia*, **9**,288-299.

Majer, J.D., M. Sartori, R. Stone and W.S. Perriman. (1982). Recolonisation by ants and other invertebrates in rehabilitated mineral sand mines near Eneabba, Western Australia. *Reclamation and Revegetation Research*, **1**,63-81.

Majer, J.D. (1984). Recolonisation by ants in rehabilitated open-cut mines in northern Australia. *Reclamation and Revegetation Research*, **2**,279-298.

Marshall, V.G. (1974). Seasonal and vertical distribution of soil fauna in a thinned and urea-fertilized Douglas fir forest. *Canadian Journal of Soil Science* **54**,491-500.

Marshall, V.G. (1977). Effects of manures and fertilizers on soil fauna: A review. *Commonwealth Bureaux of Soils Special Publication No. 3.*

McEwen, G.F., M.W. Johnson and T.R. Folsom. (1954). A statistical analysis of the performance of the Folsom Plankton Sample Splitter based upon test observations. *Archiv für Meteorologie Geophysik und Bioklimatologie, Serie A,* **7**,502-527.

Meijer, J. (1972). An isolated earthworm population in the recently reclaimed Lauwerzsee-polder. *Pedobiologia,* **12**,409-411.

Mermut, A.R. (1985). Faunal influences on soil microfabrics and other soil properties. *Quaestiones Entomologicae,* **21**,595-608.

Neumann, U. (1973). Succession of soil fauna in afforested spoil banks of the brown-coal mining district of Cologne. (Ed. by R.J. Hutnik and G. Davis). pp.335-348. *Ecology and Reclamation of Devastated Land, Vol. 1.* Gordon and Breach, New York.

Nicholas, W.L. (1975). *The Biology of Free-living Nematodes.* Clarendon Press, Oxford.

O'Connor, F.B. (1962). The extraction of Enchytraeidae from soil. (Ed. by P.W. Murphy). pp.279-285. *Progress in Soil Zoology.* Butterworths, London.

Odum, E.P. (1971). *Fundamentals of Ecology, Third Edition.* W.B. Saunders and Co., Philadelphia.

Olynyk, J.E. and F. Freitag. (1979). Some phoretic associations of ground beetles (Coleoptera: Carabidae) and mites (Acarina). *Canadian Entomologist*, **111**,333-335.

Parkinson, D. (1986). Microbes, mycorrhizae and mine spoil. (Ed. by M.K. Wali). pp.634-642. *Ecology and Coal Resource Development*. Pergamon Press, London.

Parsons, W.F.J. (1983). *Decomposition Processes in a Reclaimed Strip-mined Soil.* MSc thesis, University of Calgary.

Parsons, W.F.J. and D. Parkinson. (1986). Species composition, distribution and abundance of Collembola colonizing reclaimed mine spoil in Alberta. *Pedobiologia*, **29**,33-45.

Peachy, J.E. (1963). Studies on the Enchytraeidae (Oligochaeta) of moorland soil. *Pedobiologia*, **2**,81-95.

Petersen, H. and M. Luxton. (1982). A comparative analysis of soil fauna populations and their role in decomposition processes. *Oikos*, **39**,287-388.

Price, D.W. and G.S. Benham. (1977). Vertical distribution of soil inhabiting microarthropods in an agricultural habitat in California, U.S.A. *Environmental Entomology*, **6**,575-580.

Price, R.A. (1962). Fernie map-area, east half, Alberta and British Columbia. *Geological Survey of Canada*, Paper 61-24.

Purvis, G. and J.P. Curry. (1980). Successional changes in the arthropod fauna of a new ley pasture established on previously cultivated arable land. *Journal of Applied Ecology*, **17**,309-321.

Rapoport, E.H. and L. Sanchez. (1963). On the epineuston or the superaquatic fauna. *Oikos*, **14**,96-109.

Remus, A. (1969). Effects of loess reclamation by the wet method on the soil fauna, and development of animal communities in reclaimed loess soil. *Zeitschrift für Acker und Pflanzenbau*, **129**,206-224.

Reynolds, J.W. (1977). *The Earthworms of Ontario.* Life Sciences Miscellaneous Publication, Royal Ontario Museum.

Richardson, J.A. (1975). Physical problems of growing plants on colliery waste. (Ed. by M.J. Chadwick and G.T. Goodman). pp.275-286. *The Ecology of Resource Degradation and Renewal.* Blackwell Scientific Pub., Oxford.

Rimmer, D.L. (1982). Soil physical conditions on reclaimed colliery spoil. *Journal of Soil Science*, **33**,567-579.

Saiz, F., E.R. Hajek and W. Hermosilla. (1970). The colonization of introduced litter by subantarctic soil and moss arthropods. (Ed. by M.W. Holdgate). pp.897-907. *Antarctic Ecology*. Academic Press, London.

Salt, G., F.S.J. Hollick, F. Raw and M.V. Brian. (1948). The arthropod population of pasture soil. *Journal of Animal Ecology*, **17**,139-150.

Santos, P.F. and W.G. Whitford. (1981). The effects of microarthropods on litter decomposition in a Chihuahuan desert ecosystem. *Ecology*, **62**,654-663.

Santos, P.F., J. Phillips and W.G. Whitford. (1981). The role of mites and nematodes in early stages of buried litter decomposition in a desert. *Ecology*, **62**,664-669.

Schenker, R. (1984). Spatial and seasonal distribution patterns of oribatid mites (Acari; Oribatei) in a forest soil ecosystem. *Pedobiologia*, **27**,133-149.

Sheals, J.G. (1957). The Collembola and Acarina of cultivated soils. *Journal of Applied Ecology*, **26**,125-134.

Sohlenius, B. (1980). Abundance, biomass and contribution to energy flow by soil nematodes in terrestrial ecosystems. *Oikos*, **34**,186-194.

Sokal, R.R. and F.J. Rohlf. (1981). *Biometry*. W.H. Freeman and Company, San Francisco.

Stanton, N.L. and D. Krementz. (1982). Nematode densities on reclaimed sites on a cold desert shrub-steppe. *Reclamation and Revegetation Research*, 1,233-241.

Straalen, N.M. van. (1985). Comparative demography of forest floor Collembola populations. *Oikos*, **45**,253-265.

Swift, M.J., O.W. Heal and J.M. Anderson. (1979). *Decomposition in Terrestrial Ecosystems*. Studies in Ecology, Vol. 5. Blackwell Scientific Publications, Oxford.

Trofymow, J.A. and D.C. Coleman. (1982). The role of bacterivorous and fungivorous menatodes in cellulose and chitin decomposition in the context of a root/rhizosphere/soil conceptual model. *Nematodes in Soil Ecosystems* (Ed. by D.W. Freckman),pp. 117-138. University of Texas Press, Austin.

Verhoef, H.A., C.J. Nagelkerke and E.N.G. Joosse. (1977). Aggregation pheromones in Collembola (Apterygota); a biotic cause of aggregation. *Revue d'Écologie et de Biologie du Sol*, **14**,21-25.

Vimmerstedt, J.P. (1983). Earthworm ecology in reclaimed opencast coal mining sites in Ohio. (Ed. by J.E. Satchell). pp.229-240. *Earthworm Ecology*. Chapman and Hall, London and New York.

Vimmerstedt, J.P. and J.H. Finney. (1973). Impact of earthworm introduction on litter burial and nutrient distribution in Ohio strip-mine spoil banks. *Scientific Proceedings of the American Society of Soil Science*, **37**,388-391.

Visser, S., J. Zak and D. Parkinson. (1979). Effects of surface mining on soil microbial communities and processes. (Ed. by M.K. Wali). pp.647-651. *Ecology and Coal Resource Development*. Pergamon Press, London.

Wallwork, J.A. (1967). Acari. (Ed. by A. Burges and F. Raw). pp.363-395. *Soil Biology*. Academic Press, London.

Wallwork, J.A. (1970). *Ecology of Soil Animals*. McGraw-Hill, London.

Wallwork, J.A. (1976). *The Distribution and Diversity of Soil Fauna*. Academic Press, London.

Wittneben, U. and L. Lacelle. (1978). The Columbia Mountains and the southern Rockies. (Ed. by K.W.G. Valentine, P.N. Sprout, T.E. Baker and L.M. Lavkulich). pp.135-147. *The Soil Landscapes of British Columbia.* Resource Analysis Branch, Ministry of the Environment, Victoria, British Columbia.

Wood, T.G. (1966). The fauna of grassland soils with special reference to Acari and Collembola. *Proceedings of the New Zealand Ecological Society,* **13**,79-85.

Wood, T.G. (1967). Acari and Collembola of moorland soils from Yorkshire, England. II. Vertical distribution in four grassland soils. *Oikos,* **18**,137-140.

Woolley, T.A. (1960). Some interesting aspects of oribatid ecology. *Annals of the Entomological Society of America,* **53**,251-253.

Yeates, G.W. (1979). Soil nematodes in terrestrial ecosystems. *Journal of Nematology,* **11**,213-229.

Zacharda, M. (1979). Strandmaniidae - A new family of Eupodoidea (Acarina: Prostigmata). *Věstník Československé Společnosti Zoologické,* **43**,76-81.

Zar, J.H. (1974). *Biostatistical Analysis.* Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Ziemkiewicz, P.F. (1979). *Effects of Fertilization on the Nutrient and Organic Matter Dynamics of Reclaimed Coal-mined Areas and Native Grassland in Southeastern British Columbia.* Ph.D. thesis, University of British Columbia.

Ziemkiewicz, P.F. (1982). Determination of nutrient recycling capacity of two reclaimed coal mine sites in British Columbia. *Reclamation and Revegetation Research*, 1,51-61.

Zlotin, R.I. and K.S. Khodashova. (1980). *The Role of Animals in Biological Cycling of Forest-steppe Ecosystems.* Dowden, Hutchinson and Ross, Inc., Stroudsburg, PA.

APPENDIX A

LIST OF TAXA EXTRACTED FROM STUDY SITES

Taxon	**Site Age (Years)**				
	2	**5**	**9**	**100+ (meadow)**	**100+ (forest)**
Phylum Nematoda	X	X	X	X	X
Phylum Annelida					
Class Oligochaeta					
Enchytraeidae			X	X	
Phylum Arthropoda (after Danks 1979)					
Class Arachnida					
Order Pseudoscorpionida				X	
Order Araneae			X		
Class Acari (after Krantz 1978)					
Order Parasitiformes					
Suborder Mesostigmata[1]					
Ascidae	X	X	X	X	X
Antennoseius sp.					
Arctoseius cetratus (Sellnick, 1940)					
Arctoseius idiodactylus Lindquist, 1961					
Blattisocius keegani Fox, 1947					
Eviphididae			X		
Alliphis sp.					
Laelapidae			X	X	
Hypoaspis nolli Karg, 1962					
Ololaelaps sp.					
Parasitidae				X	X
Phytoseiidae	X	X	X	X	X
Amblyseius salish Chant and Hansell, 1971					
Amblyseius sp. near *chilcotti* Chant and Hansell, 1971					
Amblyseius sp. near *iroquois* Chant and Hansell, 1971					

Taxon	**2**	**5**	**9**	**100+ (meadow)**	**100+ (forest)**
Amblyseius sp. near *kapjik* Chant and Hansell, 1971					
Amblyseius sp. near *masseei* (Nesbitt, 1951)					
Amblyseius sp. 6					
Amblyseius sp.					
Rhodacaridae		X	X	X	X
Gamasellus sp.					
Rhodacarellus sp.					
Zerconidae			X	X	X
Order Acariformes					
Suborder Actinedida (=Prostigmata)					
Alicorhagiidae	X	X	X	X	X
Anystidae				X	
Bdellidae		X	X	X	X
Cunaxidae			X	X	X
Eriophyidae			X	X	
Erythraeidae	X		X	X	X
Eupodidae	X	X	X	X	X
Nanorchestidae	X	X	X	X	X
Speleorchestes sp.					
Pachygnathidae (=Bimichaelidae)					X
Penthalodidae					X
Pygmephoridae	X	X	X	X	X
Raphignathidae				X	
Rhagidiidae	X	X	X	X	X
Scutacaridae				X	X
Strandtmaniidae[2]				X	
Tarsonemidae	X	X	X	X	X
Tetranychidae	X	X	X	X	
Bryobia sp.					
Tydeidae	X	X	X	X	X
Trombidiidae[3]					X
Allothrombium sp.					
Suborder Acaridida (=Astigmata)					
Acaridae	X	X	X	X	X
Schwiebea sp.					
Tyrophagus sp.					
Suborder Oribatida (=Cryptostigmata)[4]					
Achipteriidae				X	
Parachipteria sp.					
Brachychthoniidae	X	X	X	X	X
Caleremaeidae				X	
Veloppia kananaskis Norton, 1978					
Ceratozetidae			X	X	X
Ceratozetes cuspidatus Jacot, 1939					
C. thienemanni Willman, 1943					

Taxon	Site Age (Years)				
	2	5	9	100+ (meadow)	100+ (forest)
Dentizetes rudentiger Hammer, 1952					
Charassobatidae				X	X
Ametroproctus sp.					
Coropoculia reticulata Aoki and Fujikawa, 1972					
Damaeidae			X	X	X
Caenobelba alleganiensis Norton, 1980					
Dyobelba sp.					
Epidamaeus sp.					
Quatrobelba montana Norton, 1980					
Eremaeidae				X	X
Eremaeus sp.					
Galumnidae				X	X
Pergalumna formicaria (Berlese, 1914)					
Gehypochthoniidae				X	X
Gymnodamaeidae				X	X
Gymnodamaeus sp.					
Jacotella sp.					
Nortonella gildersleevae (Hammer, 1952)					
Liacaridae					X
Licnodamaeidae				X	
Licnodamaeus n.sp.					
Nothridae					X
Nothrus n.sp.					
Oppiidae	X	X	X	X	X
Microppia sp.					
Quadroppia sp.					
Oribatulidae				X	X
Oribatula n.sp.					
Palaeacaridae					X
Parakalummidae					X
Pelopidae				X	X
Propelops canadensis (Hammer, 1952)					
Scheloribatidae				X	X
Scheloribates sp.					
Suctobelbidae				X	
Suctobelba sp.					
Tectocepheidae	X			X	X
Tectocephus sarekensis Trägårdh, 1910					
Class Pauropoda					X
Class Diplopoda					X
Class Protura				X	X

Taxon	**Site Age (Years)**				
	2	**5**	**9**	**100+ (meadow)**	**100+ (forest)**
Class Collembola[5]					
Hypogastruridae	X	X	X	X	X
Anurida (Micranurida) pygmaea (Börner, 1901) *					
A. n.sp.					
Friesea claviseta Axelson, 1900					
F. millsi Christiansen and Bellinger, 1974 *					
F. mirabilis (Tullberg, 1871)					
Hypogastrura pannosa (Macnamara, 1922) *					
H. (Ceratophysella) denticulata (Bagnall, 1941) *					
H. (Ceratophysella) succinea Gisin, 1949 *					
H. (Ceratophysella) pseudarmata (Folsom, 1916)					
H. (Ceratophysella) cf. *brevis* Christiansen and Bellinger, 1981					
H. sp. (*notha/packardi* group)					
H. (Mitchellania) horrida Yosii, 1960 *					
Neanura n.sp.					
Odontella cornifer Mills, 1934					
O. sp. *					
O. (Xenyllodes) n.sp.					
Paranura colorata Mills, 1934					
Pseudachorutes cf. *subcrassoides* Mills, 1934 *					
P. cf. *indiana* Christiansen and Bellinger, 1981					
Willemia anophthalma Börner, 1901 *					
W. denisi Mills, 1932					
W. similis Mills, 1934 *					
W. sp. *					
Xenylla humicola (O. Fabricius, 1780) *					
X. pallescens (Scott, 1960)					
X. cf. *duchesnea* Wray, 1958					
Onychiuridae	X	X	X	X	X
Onychiurus affinis Ågren, 1903					
O. cocklei (Folsom, 1908) *					
O. ramosus Folsom, 1917					
O. sp. *subtenuis* group *					
Tullbergia ampla Christiansen and Bellinger, 1981 *					
T. fjellbergi Rusek (Fjellberg, 1983 in lit.)					
T. mala Christiansen and Bellinger, 1981					
Isotomidae	X	X	X	X	X
Agrenia n.sp.					
Anurophorus (Pseudanurophorus) binoculatus (Kseneman, 1934)					
A. sp.					
Folsomia diplophthalma (Axelson, 1902)					
F. elongata (MacGillivray, 1896)					
F. fimetaria (Linnaeus, 1758)					

Taxon	Site Age (Years)				
	2	5	9	100+ (meadow)	100+ (forest)
F. nivalis (Packard, 1873) *					
F. quadrioculata (Tullberg, 1871)					
F. sp. *bisetosa* group *					
F. fimetaria group					
Folsomides teres Christiansen and Bellinger, 1981					
Isotoma creli Fjellberg, 1978					
I. ekmani Fjellberg, 1977					
I. hiemalis Schött, 1893					
I. notabilis Schäffer, 1896 *					
I. (*Pseudisotoma*) *sensibilis* Tullberg, 1876 *					
I. (*Pseudisotoma*) near *sensibilis* Tullberg, 1876					
I. (*Vertagopus*) *pseudocinereus* Fjellberg, 1975					
I. viridis Bourlet, 1839					
I. sp. near *ruseki* Fjellberg, 1979					
I. sp. near *subviridis* Folsom, 1937					
I. sp. *multisetis* group					
I. spp. (4 or 5 different species in addition to above) *					
Isotomiella minor (Schäffer, 1896)					
Metisotoma grandiceps (Reuter, 1891) *					
Proisotoma (*Ballistura*) sp. near *antiqua/alpa*					
P. (*Appendisotoma*) cf. *macgillivrayi* (Dalla Torre, 1895) *					
P. (*Appendisotoma*) sp.					
Entomobryidae	X	X	X	X	X
Entomobrya comparata Folsom, 1919 *					
E. confusa Christiansen, 1958 *					
Tomocerus flavescens Tullberg, 1871					
T. sp.					
Neelidae					
Neelus minutus (Folsom, 1901)					
Sminthuridae	X	X	X		X
Arrhopalites benitus (Folsom, 1896)					
Bourletiella sp. *					
Class Diplura				X	X
Class Insecta					
Order Hemiptera (including Homoptera)	X	X	X	X	X
Order Thysanoptera	X	X	X	X	X
Order Neuroptera		X	X	X	
Order Coleoptera	X	X	X	X	X
Order Diptera		X	X	X	X
Order Lepidoptera		X			
Order Hymenoptera			X		

1. Species identifications provided by Dr. E.E. Lindquist, Biosystematics Research Centre, Ottawa.
2. After Zacharda (1979).
3. Species identifications provided by Dr. I. Smith, Biosystematics Research Centre, Ottawa.
4. Species identifications provided by Dr. V. Behan-Pelletier, Biosystematics Research Centre, Ottawa.
5. List of Collembola species provided by Dr. Arne Fjellberg, University of Tromsø, Norway, who collected in the Sparwood area during 1983. Species marked with * were collected from the reclaimed mine spoils of this study.

APPENDIX B

SPEARMAN CORRELATION COEFFICIENTS BETWEEN SOIL FAUNA ABUNDANCE AND MOISTURE CONTENT OF EACH SOIL CORE, FROM EACH STUDY SITE.

n=40, 40, 35 and 20 for the 2, 5, 9-year and subalpine meadow sites, respectively. Abundance and percent moisture data are means ± 95 percent confidence intervals.

Site (by age)	Abundance	Percent Moisture	Spearman Correlation Coefficient, R
2	37.3 ± 11.8	6.1 ± 1.4	0.938[1]
5	269.7 ± 86.9	7.1 ± 1.6	0.407
9	273.5 ± 77.6	10.9 ± 1.9	0.285
100+ (meadow)	1481.3 ± 363.6	19.6 ± 3.0	0.058

1. No correlations were significant at P=0.05.

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Lawrence, J.M. 1984. Soil fauna recolonization of high elevation mine spoils in southeastern British Columbia. Proceedings of the Eighth Annual British Columbia Mine Reclamation Symposium. B.C. Ministry of Energy, Mines and Petroleum Resources. pp. 75-81.

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in the Canadian Rockies.

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February 9th, 1987
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