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Abstract approved: _____
Andrew R. Moldenke and Gerald W. Krantz

Despite the recognized role of soil arthropod fauna on nutrient cycling and decomposition processes, many aspects of the effects of sylvicultural methods in forest ecosystems upon their biology remain poorly understood. The long term effects of prescribed fires on soil arthropods in forest ecosystems in the Pacific Northwest have never been studied.

Soil samples were taken from three sites located in the Willamette National Forest in 1992: paired sites that were either clear-cut without burning and clear-cut with burning 40 years ago. One hundred and eight samples were processed; the arthropods were separated, identified and counted. To study the biology and behavior of some arthropods, eight species of oribatid mites were reared in laboratory conditions. Their life cycle, feeding behavior and reproduction were studied.

Results indicated that there were no statistical significant treatment differences either in terms of total numbers of organisms or biomass. However, the majority of the commonest taxa did show offsetting treatment responses. A total of 204 taxa were found in the three sites. The most important groups included Collembola, mites, and insects. Other groups also represented, but in smaller numbers, were spiders, symphylans, pseudoscorpions, and centipedes. Of all these groups, oribatid mites was the best represented and appears to be a useful indicator of disturbances.

Species studied in the laboratory showed variation in life cycle from 2 months to more than one year. Information about feeding behavior and reproduction is also given for most species reared in laboratory conditions.

Soil Arthropods in the Central Cascades: Slash Burning Effects and Biology of Some Species

by

Edith G. Estrada-Venegas

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APPROVED:

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Co-Major Professor, representing Entomology

Redacted for Privacy

Co-Major Professor, representing Entomology

Redacted for Privacy

Chair of Department of Entomology

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Chapter 1

Effects of Forest Burning on Soil Arthropods in the Central Cascades

1.1 INTRODUCTION

Fires are natural occurrences in the forest and our first impression following a fire is one of destruction. Some fires may benefit early successional stage organisms and even increase regrowth rate of the dominant trees by releasing nutrient pools. Before we can evaluate overall benefit, we need to study the processes associated with both natural and prescribed fires in order to quantify the nature of the changes on the entire forest community.

Periodic fires have occurred for millennia in the Pacific Northwest. During the summer of 1986 more than 35000 lightning strikes were recorded in a period of 2 weeks in Oregon (Perry, 1994). The combination of dry conditions and large amounts of fuel resulted in catastrophic fires. By the late summer of 1987, western forests were affected by more than 1500 fires throughout California and southern Oregon (Perry, 1994). In the specific case of the eastern side of the Cascade Range in Oregon, historical records report major fire occurrence every 10 to 20 years (Walstad *et al.*, 1990). On the western face, where this study focuses, fires were less frequent but still occurred several times between stand-replacement events.

In the last century, the suppression of fires has taken a new dimension in its impact on the forest (Walstad *et al.*, 1990). This suppression has produced, in some instances, quite unexpected and undesirable side-effects (Perry, 1994). A debate has arisen about the use of prescribed fires in the

forest; some people believe that fires will promote a more natural regeneration by restoring the original pre-1900 species composition (Walstad and Seidel, 1994). Others believe that fires themselves will accelerate the decrease of present species diversity (both the vegetation itself and the suite of soil fauna), air and water quality, and long term forest productivity (McNabb and Cromack, 1990). Before new management practices are established, the effects of fires on both the vegetation and the soil fauna must be carefully analyzed.

The diversity of soil organisms is great, and individual autoecological studies on every taxon would be prohibitive. Study of some of the groups has revealed their importance in soil formation, nutrient retention and nutrient cycling. In the case of the arthropod soil fauna, its greatest importance lies in its impact upon nutrient cycling (Borchers and Perry, 1990). If radical changes in arthropod fauna result from different intensities or frequencies of fire, such shifts in species composition may result in altered cycling of nutrients.

It is difficult to generalize about how fires affect soil organisms because fires are so variable in intensity and duration. Basically, fire affects soils directly by killing the organisms and indirectly by removing habitat and sources of food. Studies reveal that most soil organisms are decreased after fire for a duration of months to several years (Metz and Dindal 1980, cited by Perry, 1994).

Some studies document that immediate to decade-long effects of stand-replacement fires upon soil fauna are severe (Metz and Farrier, 1973, Metz and Dindal, 1975, Fellin and Kennedy, 1972, and Fellin, 1980). Long-term study is necessary, however, to show whether significant effects persist through longer time periods, or whether sites recover shortly after canopy cover is reestablished. This research examines whether differences in soil arthropod fauna persist (after 40 years) within paired areas that were either clear-cut and partially burned, or clear-cut without burning.

Many ecologists believe that every species in an ecosystem, even in one as diverse as soil, has a unique role and that all these complex interrelationships are critical for long-term productivity (Shaw *et al.,* 1991). If this complex community structure is destroyed, most likely, re-establishment will not be easy.

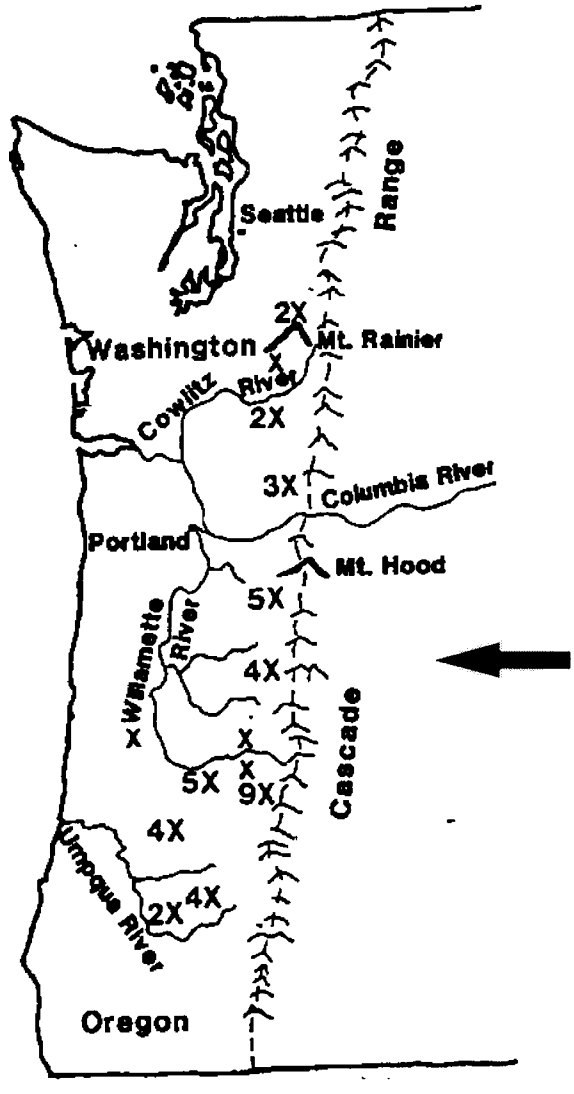
1.2 METHODS

1.2.1 Site Selection.

A field experiment to study the effects of slash-burning on Douglas-fir regeneration was established during 1947-1952 in the Pacific Northwest (Morris, 1958; Miller and Bigley, 1990). In a study plan on file at Forestry Sciences Laboratory in Olympia, WA., Morris installed 53 pairs of plots at different sites in western Washington and Oregon (Fig. 1). The plot pair (burn versus non-burn) at each site was matched visually by Morris (1958) for comparability in slope, aspect, soil and logging disturbance. The average size of each plot is approximately 0.25 ha. The non-burn plot was located in that portion of the landscape that could be protected from fire when the slash was burned on the remainder of the clear-cut.

Three sites (Table 1) were chosen in the Willamette National Forest (Official designation: sites 21, 30, and 31) for the present project studying the effects of fire on soil arthropods. Samples were taken in June, 1992 because soil fauna are at the peak abundance at this time (Moldenke and Fichter, 1988).

At site 21 (western hemlock, sword fern community) the site preparation was 14% severely burned, 21% moderately burned, 35% lightly burned, and 29% unburned. At site 30 (western hemlock, rhododendron, bear-grass community) the site preparation was 1% severe, 17% moderate, 65% light and 17% unburned. At site 31 (silver fir, rhododendron, Oregon grape community) the site preparation was 7% severe, 18% moderate, 51% light



x single pair of plots
4x multiple experimental plots to close proximity

Fig. 1. Study area showing the original sites (taken from Morris, 1958). Sites number 21,30 and 31 (chosen in this study) are indicated by the 4X in the Central Cascade Range.

Table 1. Samples sites studied in the Willamette National Forest.

SITE		ELEVATION	SLOPE
(Official designation)	(Name)	(meters)	(%)
21	Andy Cr #3	916	20%
30	Spar # 40	1216	17%
31	Cristy Cr J	1125	10%

and 23 unburned. These burn descriptions refer to the entire site; there is no way to determine what the burn intensity was at any sample point. Site 21 ranks as one of the most severely burned experimental plots, while sites 30 and 31 represent very gentle treatments.

1.2.2 Sampling.

Twenty four random pairs of numbers were selected from a random number table. From these numbers 12 pairs were used to denote map coordinates to locate each of 12 points in each plot (12 points in clear-cut and burn plot and the same 12 points in clear-cut plot). Three soil horizons were sampled: 25 x 25 cm litter samples, 7.5 cm topsoil cores (0-8 cm deep), and subsoil (8-16 cm deep).

The samples were taken with a double-barreled soil corer. The samples were put in plastic bags into a cooler with ice and carried the following day to the laboratory for processing. In the laboratory the samples were extracted in modified high-gradient Tullgren funnels (Moldenke, 1994). From the funnels, the organisms were collected into vials containing alcohol. A few drops of vegetable oil were added to separate the organisms from soil particles. The

organisms float in the surface oil due to their differential solubility in organic solvents. Subsequently, all the organisms were removed to small petri dishes to facilitate counting and identification. A stereo microscope was used for identification and appropriate keys were used to identify the different groups (Balogh and Balogh, 1992, Borror *et al.,* 1989, Dindal, 1990, Krantz, 1978 and Norton, 1994). Permanent slides of mites were made using the Hoyer's medium when necessary for identification and archiving.

Population densities were converted to biomass using weights established in previous studies by Moldenke (unpublished). Weights were obtained by weighing several live individuals of each taxon on an electrobalance. Mite and springtail weights are correct to approximately 5μg.

1.2.3 Statistical analysis.

The original experimental design (Morris, 1958) was a randomized block, with only one replicate at each location. This lack of treatment replication plots at any location precludes statistically-based inferences about overall burning effect. However, pairwise comparison t-tests for the treatment effect on the entire entomofauna are appropriate within each of the three locations separately. The null hypotheses tested whether the mean difference between treatments was zero. The significance of all tests of these null hypotheses reported here was judged at $P \leq 0.05$. During the analysis the different taxa were divided into guilds on the basis of feeding habits (i.e., fungivorous springtails, oribatid mites, endeostigmatid mites and mesoarthropods; predaceous mites and mesoarthropods; and herbivorous mesoarthropods). Assignment of individual taxa to functional guild was largely based on taxonomy: the feeding habits of many taxa are imprecisely known.

1.3 RESULTS

A total of 204 taxa were found in the three study sites (Appendix 1). Most taxa were represented in both treatments at all three locations. Of the different guilds represented on each site, oribatid mites were the most abundant and most diverse, and the group in which most treatment effects were observed. The litter sample consistently contained more than 90% of the total arthropod density at each site, and the three strata were normalized to 625 cm^2 and summed for the analysis below.

1.3.1 Site 21:

There was a significant (P=0.01) burn/non-burn treatment effect on the total entomofauna at site 21 (Fig. 2). The mean number of total arthropods per sample was 2977 and 2031 for burned and unburned respectively. Fungivorous oribatid mites and endeostigmatid mites were the only individual guilds that showed a significant treatment effect (P = 0.03, and 0.05). The rest of the guilds showed some apparent variation, but were not statistically significant.

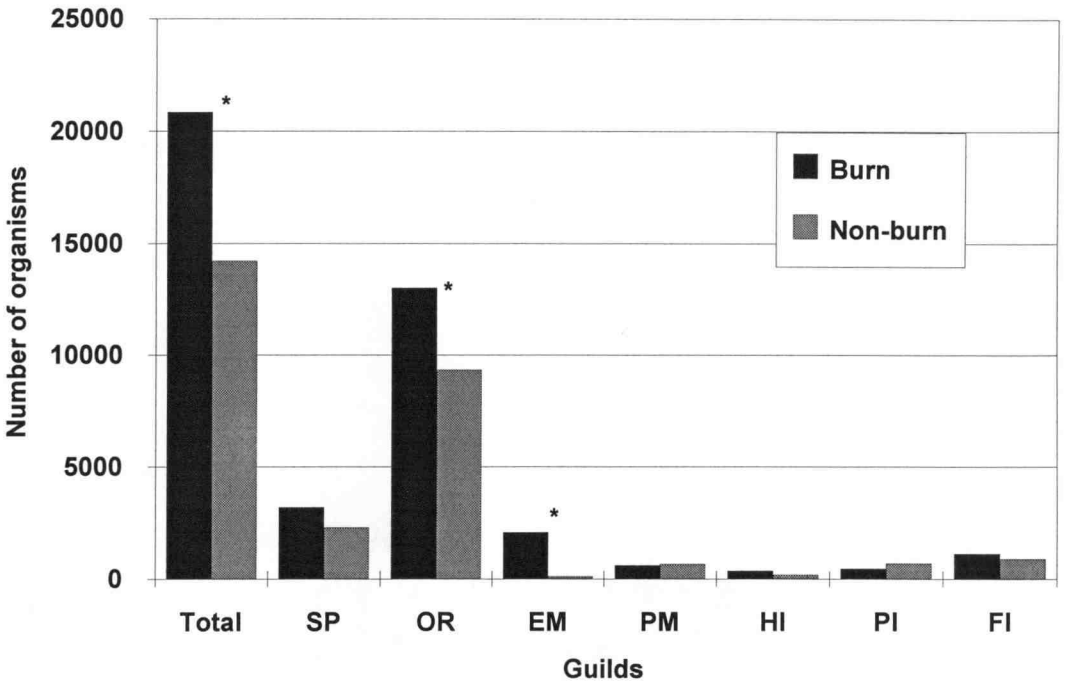


Fig. 2. Total number of organisms by guild in site 21 (SP=Collembola; OR=oribatid mites; EM=endeostigmatid mites; PM=predaceous mites; HI=herbivorous insects; PI=predaceous insects; FI=fungivorous insects). *significant treatment effect at $p < 0.05$.

Diversity indices used to compare the resultant fauna of both treatments on site 21 showed only a slight difference. Diversity was greater in the unburned area even though the density of organisms was higher in the burned area (Table 2).

Table 2. Diversity indices (based on individual count).

	Shannon Index			Simpson Index		
Treatment	**Sites**			**Sites**		
	21	30	31	21	30	31
Burn	2.97	2.84	2.84	0.90	0.87	0.86
Non-burn	3.48	2.88	3.05	0.94	0.90	0.90

No treatment effects were significant at the 0.05 confidence level (N= 12 within-treatment replicates).

Although arthropod density was 139% greater in the burned treatment, arthropod biomass was 167% greater (but not statistically significant) in the unburned control (Fig. 3). An increase of even a few individuals of the larger predaceous and fungivorous arthropods was capable of skewing the entire faunal biomass comparison. Both endeostigmatid mites and predaceous insects showed statistically significant treatment effect (P = 0.01 and 0.02).

Along with the contrasting differences in total faunal density and biomass at site 21, many individual taxa displayed significant treatment effects.

The springtails *Hypogastrura, Isotoma,* and *Onychiurus* sp. 1 increased their densities in burned conditions; *Entomobrya* and *Onychiurus* sp. 2 decreased. The prostigmatid mites *Nanorchestes* and *Speleorchestes* increased significantly in burned conditions.

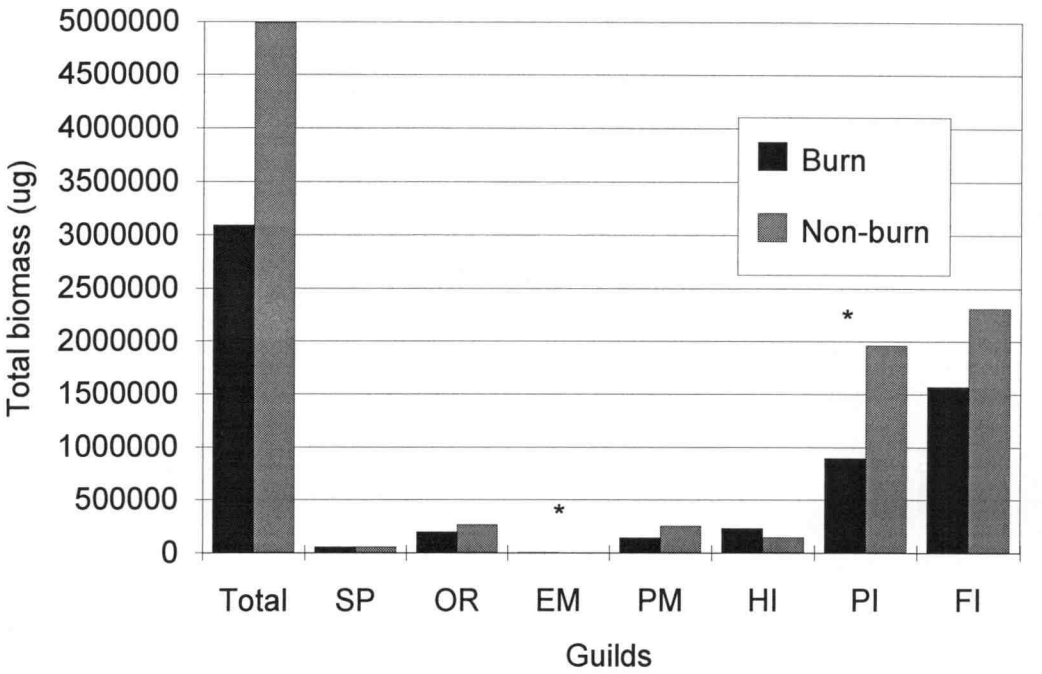


Fig. 3. Total biomass by guild in site 21 (SP=Collembola; OR=oribatid mites; EM=endeostigmatid mites (burn= 2081 μg; non-burn= 118 μg); PM=predaceous mites; HI=herbivorous insects; PI=predaceous insects; FI=fungivorous insects).* Significantly different at $p < 0.05$.

Other taxa that increased their numbers in burned conditions were Campodeidae, Pauropoda and Protura (all detritivores), and in non-burned habitats the groups that increased were Cantharidae, Geophilidae and *Apochthonius* (all predators). Oribatid mites were the group best represented in the soil fauna, and the group in which treatment effects were most notable. Increased numbers were observed in *Carabodes, Ceratozetes,* and *Oppiella* in burned conditions; *Epilohmannia, Hypochthoniella, Nothrus, Rhinosuctobelba, Scheloribates* sp.1 and *Tegoribates* in non-burned conditions (Table 3).

TABLE 3. Significantly different treatment effects ($p < 0.05$) on densities of the most abundant species of soil fauna. Densities of cited taxa increase under the listed treatment.

SITE 21		SITE 30		SITE 31	
BURN Increase 1/	NON-BURN Increase 2/	BURN Increase	NON-BURN Increase	BURN Increase	NON-BURN Increase
Collembola:					
Hypogastrura *Isotoma* *Onychiurus* sp 1	*Entomobrya* *Onychiurus* sp 2	*Hypogastrura*	*Isotoma* sp 1 *Onychiurus* sp 2 *Onychiurus* sp 1		*Entomobrya* *Folsomia* *Hypogastrura* *Onychiurus* sp 2
Oribatida:					
Achipteria *Brachychthonius* *Caenobelba* *Carabodes* *Ceratozetes* *Eupelops* *Hermannia* *Oppiella* *Phthiracarus*	*Ceratoppia* *Epilohmannia* *Hypochthoniella* *Liacarus* sp 2 *Nothrus* *Rhinosuctobelba* *Scheloribates*	*Achipteria* *Brachychthonius* *Caenobelba* *Carabodes* *Eporibatula* *Euphthiracarus* *Nanhermannia* *Oppia* *Oppiella* *Oribatula* *Quadroppia* *Rhinosuctobelba* *Scheloribates* sp	*Ceratoppia* *Eremaeus* *Galumna* *Jacotella* *Phthiracarus*	*Achipteria* *Brachychthonius* *Caenobelba* *Ceratozetes* *Eporibatula* *Oppiella* *Phthiracarus*	*Ceratoppia* *Jacotella* *Oppia* *Propelops* *Quadroppia* *Suctobelbella*
Prostigmata:					
Nanorchestes *Speleorchestes*		*Nanorchestes* *Speleorchestes*		*Nanorchestes* *Speleorchestes*	
Pred. mites:					
	Traychetes sp. 2 Zerconidae		Gamasida		
Insects:					
Campodeidae	Cantharidae	Protura Ptiliidae	Sciaridae	Protura	*Aphaenogaster* *Apochthonius* Ptiliidae *Stenus* *Tapinoma*
Myriapods:					
Pauropoda	Geophilidae				Geophilidae Pauropoda Symphyla

1/ Significant increase in the number of organisms in the burn treatment in site 21.
2/ Significant increase in the number of organisms in the non-burn treatment in site 21.

1.3.2 Site 30:

Total arthropod population densities did not differ significantly between the two treatments (Fig. 4). However, oribatid mites, endeostigmatid mites, and herbivorous insects showed statistically significant treatment responses (P = 0.01, 0.01, and 0.04) using t-test pairwise comparisons. They all showed relative increases under burned conditions. Mean values for burned was 5634 and 4504 for non-burned. The diversity indices used to compare the two treatments on site 30 did not show a significant difference (Table 2).

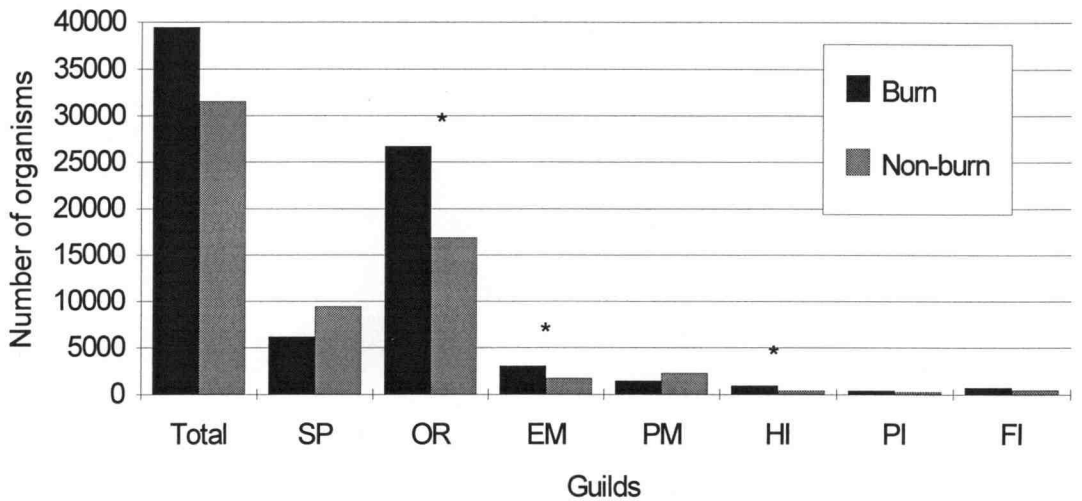


Fig. 4. Total number of organisms by guild in site 30 (SP=Collembola; OR=oribatid mites; EM=endeostigmatid mites; PM=predaceous mites; HI=herbivorous insects; PI=predaceous insects; FI=fungivorous insects). *Significantly different at p <0.05.

Total arthropod biomass was not statistically significant between the treatments (Fig. 5). There was little significant treatment difference when analyzed in terms of individual functional guild comparisons. Endeostigmatid

mites and herbivorous insects were the only guilds that showed statistically significant differences (P = 0.01 and 0.04: burn greater than non-burn). The apparent treatment response of herbivorous arthropods is based on only a small number of individually very large individuals.

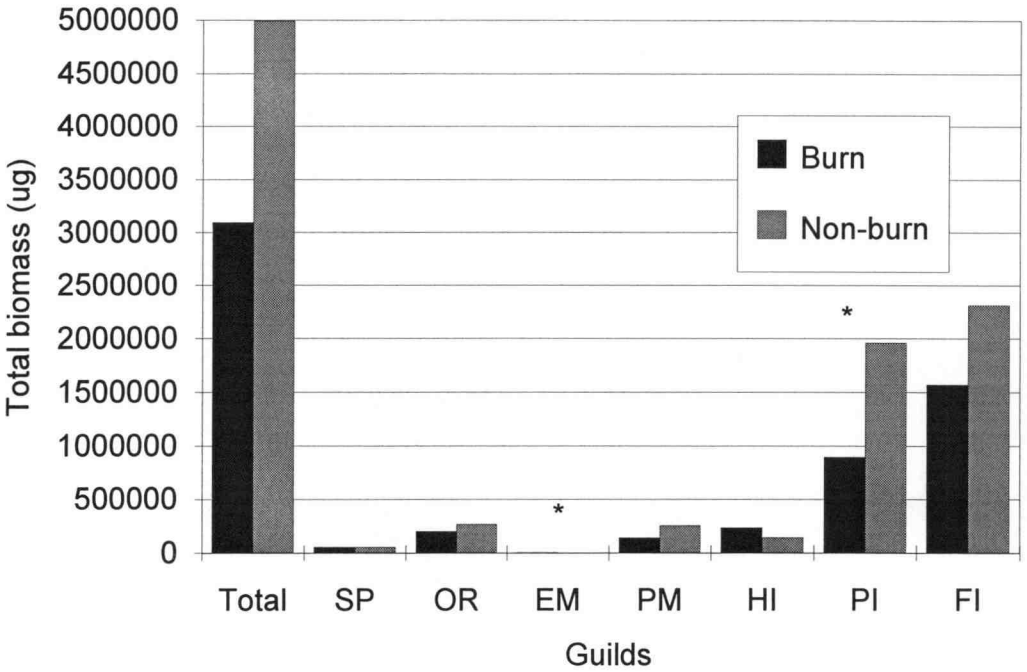


Fig. 5. Total biomass by guild in site 30 (SP=Collembola; OR=oribatid mites; EM=endeostigmatid mites (burn= 3045 μg; non-burn= 1737 μg) PM=predaceous mites; HI=herbivorous insects; PI=predaceous insects; FI=fungivorous insects).* Significantly different at $p< 0.05$.

Population density significantly varied between treatments for individual taxa (Table 3). The springtail *Hypogastrura* increased its density in the burned treatment, while *Isotoma* sp.1, *Onychiurus* sp.1, and *Onychiurus* sp.2 increased significantly in the non-burned conditions. Endeostigmatid mite (*Nanorchestes* and *Speleorchestes*) densities increased on burned conditions while, predaceous mesostigmatid mites increased in number in the non-

burned control treatment. Other groups of arthropods that increased on burned conditions were Protura, Ptiliidae, and Symphyla. Increasing in the non-burned treatments were Geophilomorpha and Sciaridae. Again, oribatid mites were the dominant group in terms of both density and species richness, and were the group in which most treatment effects were detectable at the specific level. Thirteen taxa increased on burned conditions (i.e., *Achipteria, Eporibatula,* and most dramatically *Euphthiracarus).* In non-burned treatments, however, only three genera significantly increased their numbers (*Eremaeus, Galumna,* and *Nanhermannia).*

1.3.3 Site 31:

Through a comparison of total arthropod density within burned and non-burned treatments approached significance, they were, in fact, not statistically significant using t-test pairwise comparisons (Fig. 6). Shannon and Simpson diversity indices were used to compare the total diversity of the two treatments on site 31, and did not show a significant difference (Table 2). There were significant treatment effects on oribatid mites, herbivorous insects, and predaceous insects (P = 0.04, 0.02, 0.02), all of which were much denser in the non-burned sites.

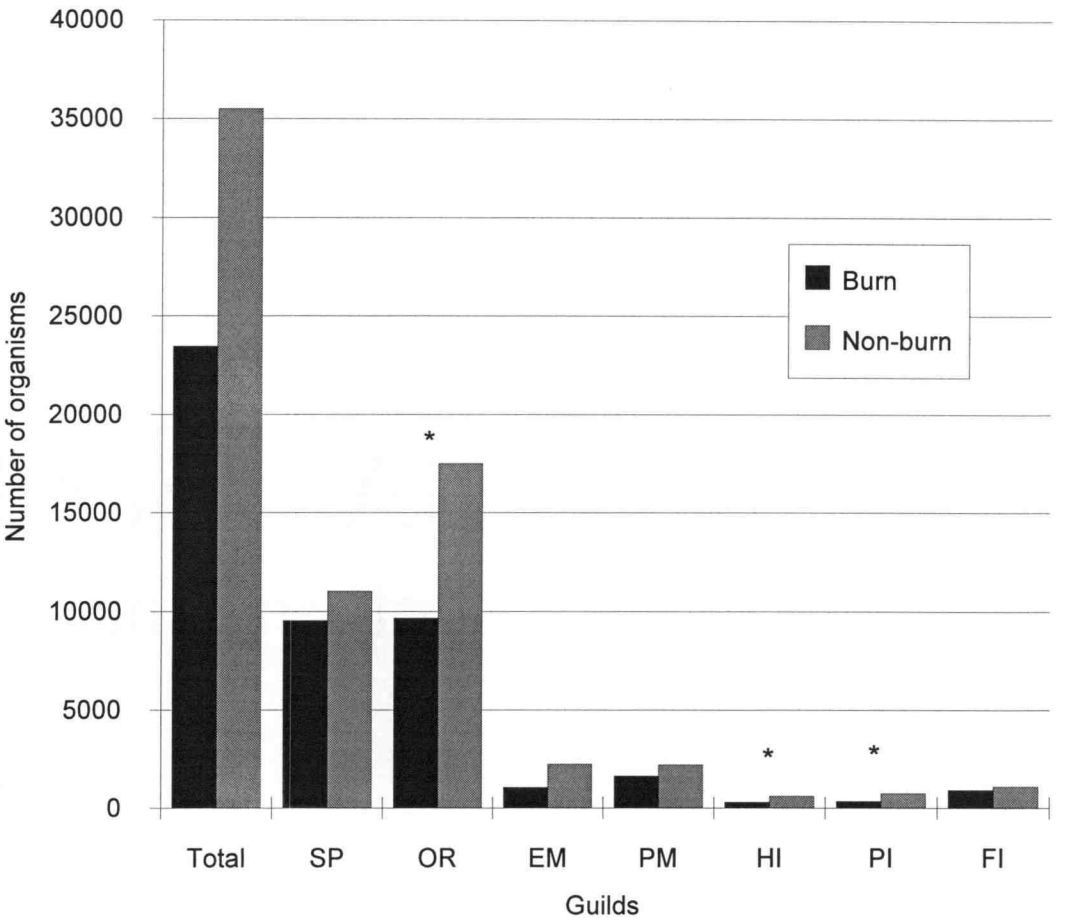


Fig. 6. Total number of organisms by guild in site 31 (SP=Collembola; OR=oribatid mites; EM=endeostigmatid mites; PM=predaceous mites; HI=herbivorous insects; PI=predaceous insects; FI=fungivorous insects).* Significant treatment effect at $p< 0.05$.

In terms of biomass, statistical differences were not found between treatments either among any of the guilds or the total in site 31 (Fig. 7). Apparent differences in predaceous and fungivorous mesoarthropods were an artifact of a few specimens of very large individual species.

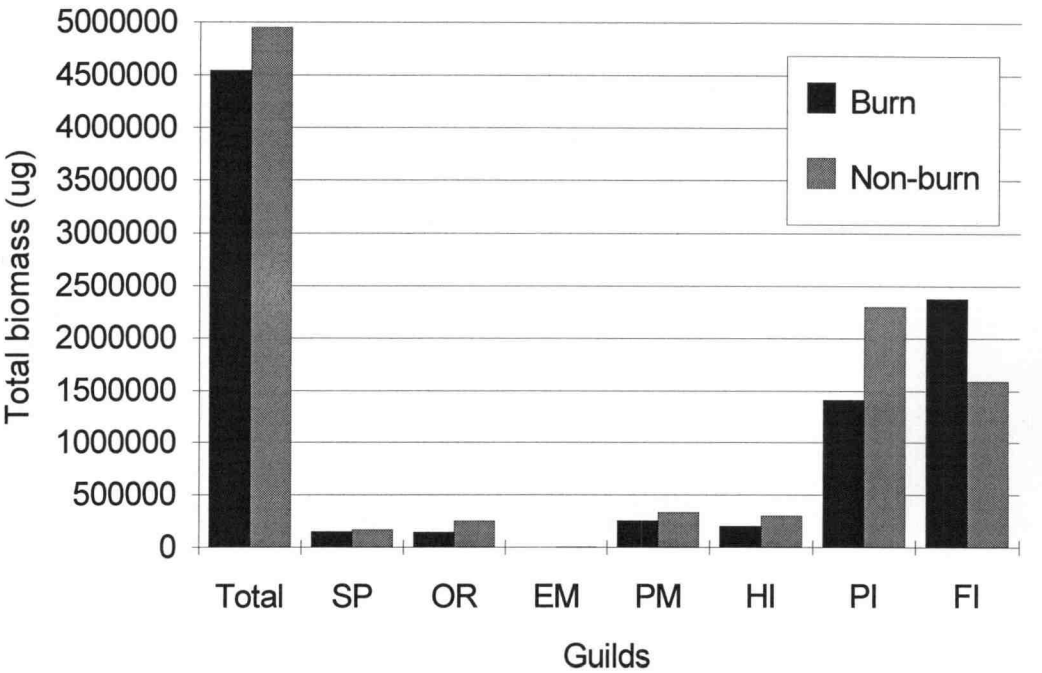


Fig. 7. Total biomass by guild in site 31 (SP=Collembola; OR=oribatid mites; EM=endeostigmatid mites (burn= 1055 μg; non-burn= 2241μg); PM=predaceous mites; HI=herbivorous insects; PI=predaceous insects; FI=fungivorous insects).* Statistically significant at $p<0.05$.

Certain individual taxa demonstrated significant treatment effects. For Collembola, the densities of *Entomobrya, Folsomia, Hypogastrura,* and *Onychiurus sp.2* increased in the non-burned control. The density of prostigmatid mites (*Nanorchestes* and *Speleorchestes*) increased in the burned treatment. The taxa of fungivorous mesoarthropods (Pauropoda, Protura, Ptiliidae), one herbivore (Symphyla) and five predators (Formicidae: *Aphaenogaster, Tapinoma*; Chelonettida: *Apochthonius*; Geolophilomorpha and Staphylinidae: *Stenus*) all increased significantly in the burned treatment. As in the other sites, oribatid mites were the dominant group and the one in

which treatment effect resolution was greatest. Seven genera increased their density under the burn treatment (*Achipteria, Brachychthonius, Caenobelba, Ceratozetes, Eporibatula, Oppiella,* and *Phthiracarus)*; in contrast, six genera showed population density increases in the non-burned (*Ceratoppia, Jacotella, Oppia, Propelops, Quadroppia,* and *Suctobelbella*).

1.3.4 Between-site comparisons

Total arthropod density did not show a consistent treatment effect. In sites 21 (significant) and 30 (not significant) there is an increase in the burn treatment, but site 31 (not significant) showed an increase in the non-burn treatment (Fig. 8).

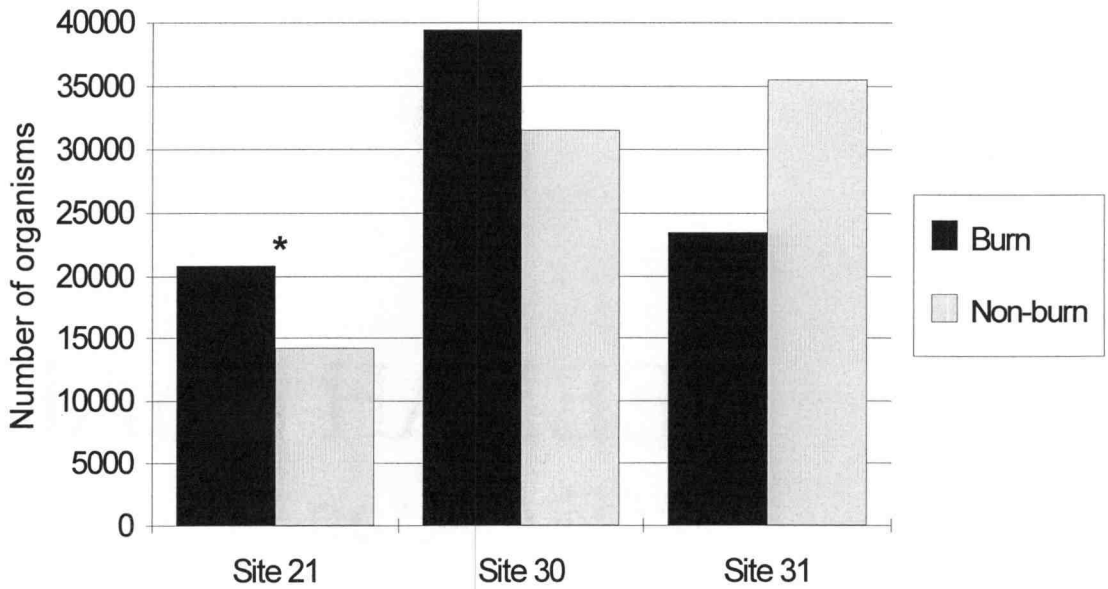


Fig 8. Between-site comparison of population count of total arthropods.
*** Significant treatment effect at $p < 0.05$.**

Figure 9 reveals that population biomass estimates following the burn treatment are consistently lower that the non-burn (never significant). It is logical to assume that the burning has effectively removed resources, that still have not been replaced after 40 years. Site 21, with the most severe treatment effect, has the most noticeable comparative decrease.

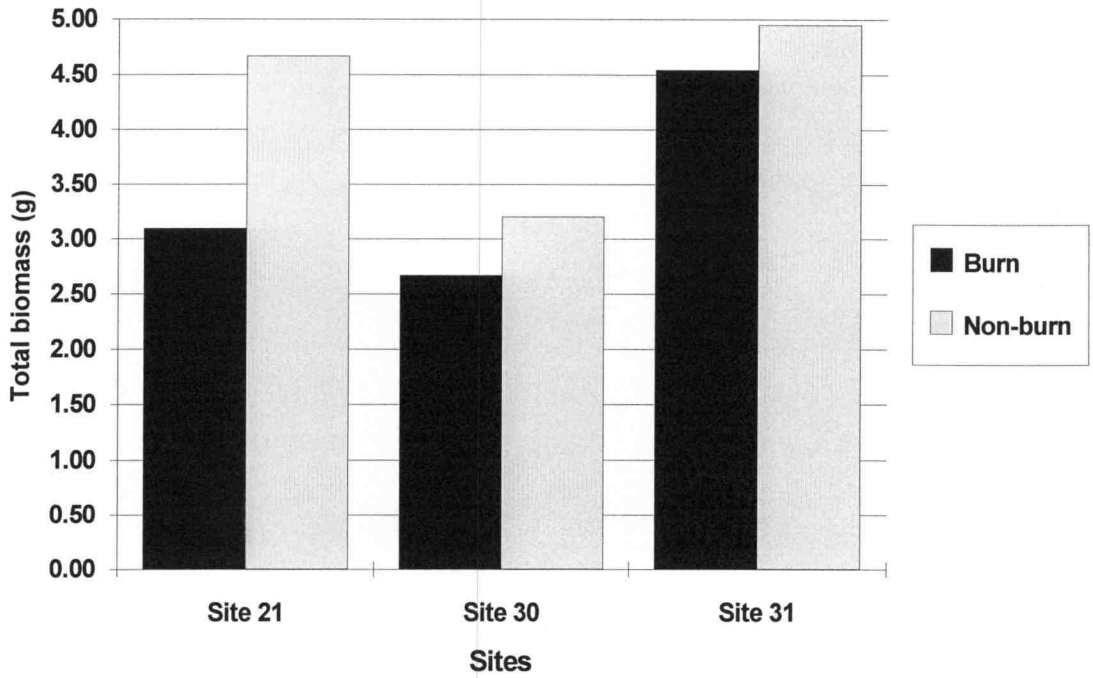


Fig. 9. Between-site comparison of biomass of total arthropods (No significant differences).

1.4 DISCUSSION

There are numerous comparative studies of the arthropod fauna of mature forest and adjacent clear-cuts accompanied by broadcast burning (Shawn *et al.,* 1991). The contrasting faunas are very different, both in terms of total arthropod density and arthropod species composition. The flora, annual photosynthetic product and microclimate are very dissimilar in such a comparison; resultant differences in the arthropod assemblages are therefore not surprising. However, several decades after canopy cover has been reestablished, differences in flora, annual litter production and microclimate diminish. By the time the regenerating trees are more than 15 m tall, most forest ecologists would assume that any differences between paired sites which had, or had not, been burned would be minimal. Regenerating trees of this size would have been adding fresh litter substrate for more than 20 years. The only expected difference might be in the rate of decay of large downed logs if the site preparation fire had been severe enough to remove most of the coarse woody debris in the treated location.

It is significant, then, that there was no consistent trend in either the total arthropod densities (Fig. 8) or densities of individual guilds at the three sites. As a generality, though, population densities of nearly all the groups were higher in the burn for sites 21 and 30, but higher in the non-burn for site 31. Likewise there was no consistent significant biomass response at the sum total or individual guild-level of analysis. As a generality, biomass of all groups at all sites was higher in the unburned treatment (except for endeostigmatid mites). The only site where the total density of invertebrates was significantly different was the site 21, that was most severely treated.

However, equally significant is the fact that 28-30 of the commonest individual taxa at each site showed strong treatment effects (Table 3). The tendency of a number of species (40% of the commonest species) to demonstrate the same treatment effect at two or three sites provides additional reinforcement that these species-specific responses are real, and not statistical anomalies.

The fungivorous oribatid mites (*Achipteria, Brachychthonius, Caenobelba, Carabodes, Ceratozetes, Eporibatula and Oppiella*), the

fungivorous endeostigmatid mites (*Nanorchestes* and *Speleorchestes*), and the fungivorous Protura all consistently increased following the burn. The fungivorous springtails (*Entomobrya triangularis,* and *Onychiurus* sp. 2), the fungivorous oribatid mites (*Ceratoppia* and *Jacotella*), and the predaceous Geophilomorpha all consistently decreased relative to the burned plots.

Discussion with numerous members of the College of Forestry has failed to elicit suitable hypotheses that might account for this exceptional degree of specificity in the distribution of forest floor fauna. Since the landscape-level pattern of forestry practice within the Willamette National Forest has resulted in small isolated plots that have NOT been burned within an extensive matrix of burning, the emphasis must be on why the non-burned plots are not overwhelmed over several decades by immigration from the surrounding burned regions.

Companion studies at three additional paired sites by Moldenke, Miller and Boyle (unpublished data) reveal that the species assemblages of both the burned and non-burned sites are more similar to one another, than either is to the remaining old-growth. Therefore, I must conclude (along with Moldenke *et al.*) that canopy removal (with resultant soil compaction, etc.) has had an enormous effect on the soil fauna, an effect that persisted for at least three and one-half decades. Secondary to the cutting effect is a burning effect that is detectable in the relative species abundance of nearly half the commonest species after 35 years.

The fauna appears to respond to differences in the environment that are undetectable to the wide range of tests employed by foresters to assess changes in "forest health" and succession. These results may represent a wake-up call for land managers, that perhaps the criteria they now measure are not the appropriate ones.

1.5 CONCLUSION

The soil fauna can serve as a biological indicator of forest ecosystem structural changes resulting from site-preparation burning. Overall faunal measurements (total density, total diversity, total biomass) are similar 35 years after burning. However, a majority of the commonest species in most of the different functional ecological guilds reveal strong treatment effects at the individual species level. The surprising magnitude of these differences may imply significantly different successional trajectories with profound implications on long-term productivity.

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Chapter 2

Biology of some Oribatid Mites from the Pacific Northwest

2.1 Introduction

The oribatid mite fauna of the Pacific Northwest is not well known, although species lists for the region are included in works by Behan and Hill (1978), Topic (1982), Moldenke and Fichter (1988), Schowalter and Filip (1991), and Moldenke and Thies (unpublished). Despite their biological importance in decomposition processes of forest soils, the biology and life cycles of most oribatid mite species are poorly understood. In addition to the study of the effects of burning on forest soil arthropods, I decided to study the life cycles and biologies of common species present in the study area. In order to achieve this, the establishment of cultures in laboratory conditions was necessary.

Several different methods of rearing mites have been employed. One of the original methods for rearing mites was that devised by Michael (1884). He used a glass ring on a slide roofed with a cover slip. A piece of paper towel was used to maintain humidity in the chamber. With some modifications, this method was used by Jacot (1937) and others. Subsequently, different kinds of containers were used, but any container with a closed sealed bottom creates a moisture problem, especially if the top is closed as well. Small vials or Stender dishes with filter paper or other absorbent material on the bottom were used by Sengbush (1954) for culturing oribatids. Lipovsky (1953) was the first to utilize the plaster-charcoal method for rearing mites. This method was previously used for other soil arthropods by Searls (1928). Huber (1958) found that the relative humidity produced in culture tubes at least 2 cm in depth utilizing plaster-charcoal, was stable at most laboratory temperatures.

2.2 Rearing Methods

2.2.1 Chamber specifications:

The volume of the chamber is critical in regulating the humidity of the culture. A rearing chamber with too small a moisture reserve easily dehydrates if not kept inside an additional chamber to regulate humidity. Conversely, a chamber regulated to excessively high humidity level increases the possibility of food spoilage and mold problems. Some oribatid species require high humidity levels (i.e., *Atropacarus* sp. and *Euphthiracarus* sp.). Fungi thrive in humid conditions and are not easy to control without also adversely affecting the mites. Mite feeding often does not keep pace with fungal growth when mite populations are low. Under these conditions mites may become trapped in fungal growth and die; if they continue to develop they do not feed well and observations on the length of the life cycle may be erroneous. The larva and protonymph are especially susceptible to these conditions. Removing the fungi manually can sometimes be effective. Springtails may be used in these cultures to keep the fungi under control. Since springtails have a higher metabolic rate and consume hyphae more rapidly than oribatid mites, small numbers of springtails can control the fungi without interfering with the mites.

The chamber shape is also an important concern, especially during microscopic observations. A pot narrower at the bottom than the top ensures full observation of the walls and allows unobstructed observation of the base. It is important to have good visual access to all the areas in the culture, because some mites deposit spermatophores on the smooth surface of the walls. From a dorsal view, many critical aspects of behavior cannot be observed because the mite's body is opaque; a slanted container wall allows lateral views and good observation of what happens ventrally.

It is important to provide heterogeneity in the chamber and the larger the chamber, the easier this becomes. Heterogeneity should provide shelter for the adults, as well as locations for egg deposition. Larger, more

heterogeneous, chambers are, however, progressively more difficult to monitor. This is especially important if one needs to locate a specific place in the culture to observe a specific event, such spermatophore deposition.

2.2.2 Rearing techniques:

In order to study the biology of some common oribatid mites of the Pacific Northwest, a series of soil samples was taken from different areas in the states of Washington and Oregon. Sample sites were located within the conifer zone dominated by Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) (Table 4). Soil samples taken at each site were placed into plastic bags and subsequently carried to the laboratory in a cooler with ice.

Living mites were extracted using a Berlese funnel; the mites were deposited into a pint jar equipped with a base of moistened plaster-of-Paris. Some blended dried vegetable material was added to the plaster to provide extra food, water-holding capacity and substrate for fungi. The vegetable amendment was a mixture of maple, Douglas-fir and oak leaves. The cover-lid of the jar was screwed on tightly to prevent mites from escaping and a small perforation in the lid was covered with a 10μ mesh fabric to provide some ventilation. The jars were held at room temperature (15-17^{0}C), and kept moist by adding a few drops of water every few days as necessary. An assortment of pine needles, maple leaves, pollen, yeast, and fresh material (such as lettuce and orange peel) was offered to the mites to determine their specific requirements.

Table 4. Study species of oribatid mites from the Pacific Northwest.

Species studied	**Source**
Ceratozetes pacificus	Matlock, Mason Co., Washington
Caenobelba sp.	Andrews Experimental Forest, Linn Co., Oregon
Pilogalumna sp.	Andrews Experimental Forest, Linn Co., Oregon
Liacarus sp.	Mary's Peak, Benton Co., Oregon
Ommatocepheus sp.	Mary's Peak, Benton Co., Oregon
Epilohmannia sp.	20 mi E Sweet Home, Linn Co., Oregon
Atropacarus sp.	Matlock, Mason Co., Washington
Euphthiracarus sp.	Matlock, Mason Co., Washington

After the cultures were established, observations were made at least 2-3 times a week from November, 1993, to March, 1994. Specific biological processes required daily observations of several hours (Table 5). For example, sperm deposition occured 3-5 days after the adults emerged; during this period longer observations were required in order to document the entire process.

Table 5. Biological processes studied.

Species	Process
Ceratozetes pacificus	Moulting, reproduction, sperm deposition
Caenobelba sp.	Moulting, reproduction, sperm deposition, aging
Pilogalumna sp.	Moulting, tanning, reproduction, sperm transfer
Liacarus sp.	Moulting, aparity
Ommatocepheus sp.	Moulting
Epilohmannia sp.	Moulting
Atropacarus sp.	Moulting, egg deposition
Euphthiracarus sp.	Moulting

2.2.3 Archiving documentation:

Behavioral observations were made with a zoom Zeiss stereo microscope 475057 connected to a Sony DXC-102 camera and VCR. The tape-recording apparatus was always readied prior to every observation to permit documentation of unexpected mite behavior. Still pictures were taken with a stereo microscope setup. SEM photographs were obtained at the Electron Microscope Facility microscope at Oregon State University. To study the aging process of *Caenobelba*, adults of various ages and immatures were killed (ethyl acetate), mounted on glue, coated with gold and compared under a scanning electron microscope.

2.3 RESULTS

2.3.1 *Ceratozetes pacificus* Behan-Pelletier 1984.

In order to study the biology of this species, some individuals were collected on October 20, 1993, from near Matlock on the Olympic Peninsula, WA. The site was a clear-cut with a 2% south facing slope (latitude 47^0 14' N and longitude 123^0 25' W) with an elevation of 125 m. This culture started out as a mixture of several species. After the culture was established and the mites were reproducing, *C. pacificus* were transferred to a separate chamber.

Four separate cultures of *Ceratozetes pacificus,* all from the same initial collection, have been maintained in the laboratory for 18 months. Differing diets have been used to test for food preferences. The food types tested included: orange peel, lettuce, yeast and some fungi that appeared naturally in the culture. Orange peel has been shown to be an adequate source of food for these mites and some cultures have been kept exclusively on this diet for several generations. The fresh white inner peel is utilized by the mites, and as mites continued to remove the exposed layers the peel remained in good condition for several days. The mites did not feed upon the peel either when it became covered with fungi or when it became desiccated.

I have observed *Ceratozetes pacificus* feeding on dying T*yrophagus putrescentiae* and an undetermined gamasid that were present in some cultures. *Ceratozetes pacificus* imbibed liquids from the wounds of dying mites.

Fresh lettuce was consumed by both immature and adult mites. A culture was kept on this diet for several months and grew well using the lettuce and some occasional fungi that grew in the culture dish. The mites did not eat the lettuce when the lettuce was decomposed or dried.

Adults and immatures both seem to accept the same diet. Several days prior to death, the adults became lethargic and did not eat. After a few days, they fell over on their backs, helplessly moving their legs while dying.

Life cycle from larva to adult is 59-64 days approximately (Table 6.). The adult stage is preceded by a 3-5 day teneral period after the mite has emerged from tritonymphal stage.

Table 6. Life cycle of *Ceratozetes pacificus* Behan-Pelletier.

Stage of development	**Duration (days)**
NO EGG	
LARVA	10 DAYS
QUIESCENT	2-3 DAYS
PROTONYMPH	13 DAYS
QUIESCENT	3-4 DAYS
DEUTONYMPH	12 DAYS
QUIESCENT	2-4 DAYS
TRITONYMPH	14 DAYS
QUIESCENT	3-4 DAYS
ADULT	6-8 MONTHS

Ceratozetes pacificus was larviparous. No eggs or egg chorion were observed in the cultures. When the immatures emerged from the female, they looked shrunken, but after feeding for a few days the immatures swelled and outwardly appeared smooth. Usually *C. pacificus* fed on the shed skin after molting.

Ceratozetes pacificus males produce a stalked spermatophore which has a drop of sperm surrounded by a thin envelope at the top. Males deposit spermatophores on the plaster surface and detritus, but never on the culture walls. The spermatophores blend with the plaster surface making it difficult to find them. Females were observed to inseminate themselves within 25 -35 minutes of the males depositing the spermatophores, so that spermatophores usually remained only temporarily in the culture.

Survival of immatures was high. Only about 5 mites had problems during the moulting process or died as result of mold overgrowth.

The average life span of adults was between 6-8 months in these laboratory conditions.

2.3.2 *Caenobelba* sp.

Stock for study of the biology of this species was collected at the Andrews Experimental Forest, Oregon, on October 20, 1993.

The diet used to maintain this species was yeast, pollen of *Pinus contorta*, and orange peel (used indirectly as substrate for endemic fungi within the cultures). A bright green fungus (probably *Cladosporium* sp.) was observed growing in the culture. This fungus appears to have been introduced into the culture by the mite, because it occurred in the culture dishes only subsequent to inoculation of the mites. When the mites fed on this fungus, their bodies became covered with spores which adhere to the waxy secretions covering their bodies.

Adults and immatures fed on the same three types of food described earlier, with no differences in preference being observed.

The life cycle span of *Caenobelba* sp. was approximately 63-67 days from egg to adult (Table 7).

A few days after adult maturation, numerous stalked spermatophores were observed on both the plaster and the walls of the culture. Males and females were continually active; males continually deposited spermatophores. After the female encountered a spermatophore deposited by the male she positioned herself above it. She opened her genital valves and lowered herself, taking the sperm capsule into her genital vestibule. She then closed the valves and straightened her legs, breaking the capsule away from the spermatophore stalk. The whole process took just a few seconds. Adults fed on the spermatophores when searching for food, destroying a significant percentage of them. The survivorship of immatures and adults was high. A subsequent batch of eggs was found in the culture a month after the adults emerged.

Table 7. Life cycle of *Caenobelba* sp.

Stage of development	Duration (days)
EGG	10 DAYS
LARVA	6 DAYS
QUIESCENT	3-4 DAYS
PROTONYMPH	13 DAYS
QUIESCENT	3-4 DAYS
DEUTONYMPH	10 DAYS
QUIESCENT	4-5 DAYS
TRITONYMPH	16 DAYS
QUIESCENT	4-5 DAYS
ADULT	6-8 MONTHS

Moulting apparently occurred during the night, as it was never observed during the day, even with a great deal of searching. All immature mites carry old skins from all the previous stages. For example, the tritonymph carries the larval, protonymphal and deutonymphal cast skins. Some of the adults carry all the old skins from previous stages attached to the long strong setae on the notogaster (but just for a short period of time). These setae are present as well during all the immature stages.

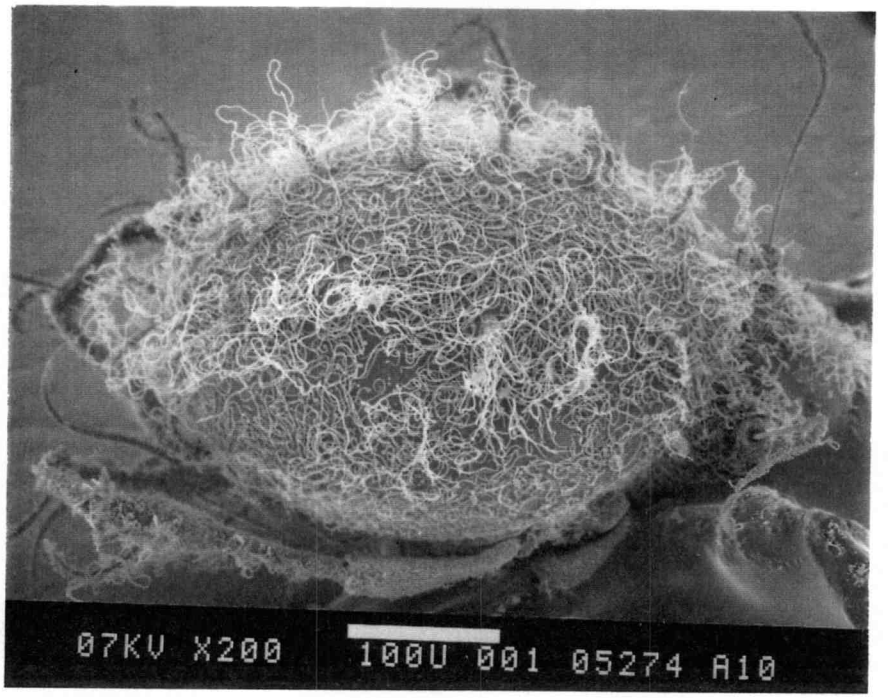
During the 2-3 day tritonymphal period of quiescence before the adult emerges, a large amount of wax was secreted as the new integument is forming. When the adult emerged the whole body is covered with wax. This wax looks like curled "spaghetti" and it adhered to the body surface with a head-shaped attachment (Fig. 10). These wax strands were also attached to the setae over the body surfaces. Initially during the tritonymphal quiescent stage, the entire body appeared pale white due to the nymphal wax coating, but after a couple of days it turned gray. As the adult wax was produced the mite again appeared white, so that when the adult had emerged it looked completely white, even though the cuticle had hardened and subsequently tanned.

When the adult had emerged, the body was covered with a dense net of wax and two rows of long and prominent setae on the notogaster. After 1-2 months the integument lost the wax and subsequently the setae on the back were broken off near their insertions. This pattern had been observed both in culture and field conditions. After the aging process was completed, the adults appeared so different that one could mistake them for a different genus. The older adults were dark brown, had no wax or notogastral setae, and did not carry the nymphal cast skins.

Through observation of aged adult mites, and as confirmed by using SEM (Fig. 10), it was found that the notogastral setae were completely lost on older individuals, as well as the wax from most of the body, although some remaining wax was observed on the venter and around the base of the legs. During the aging process, the notogastral setae were progressively broken at different levels until they were completely gone. The notogastral setae and the wax were present during all the immature stages.

The wax showed sticky properties which appeared to allow the mites to carry material like pebbles, pieces of food, eggs, and fungal spores attached to their backs. Occasionally some hyphae were observed growing on the body surfaces of the mites, probably using the wax as a primary carbon source. Many of the mites appeared green, as the result of the growth of the fungus.

Most aspects of behavior did not differ with increasing age. Adults started to lay eggs 30 days after moulting. Adults fed continuously until just a few days before they died.



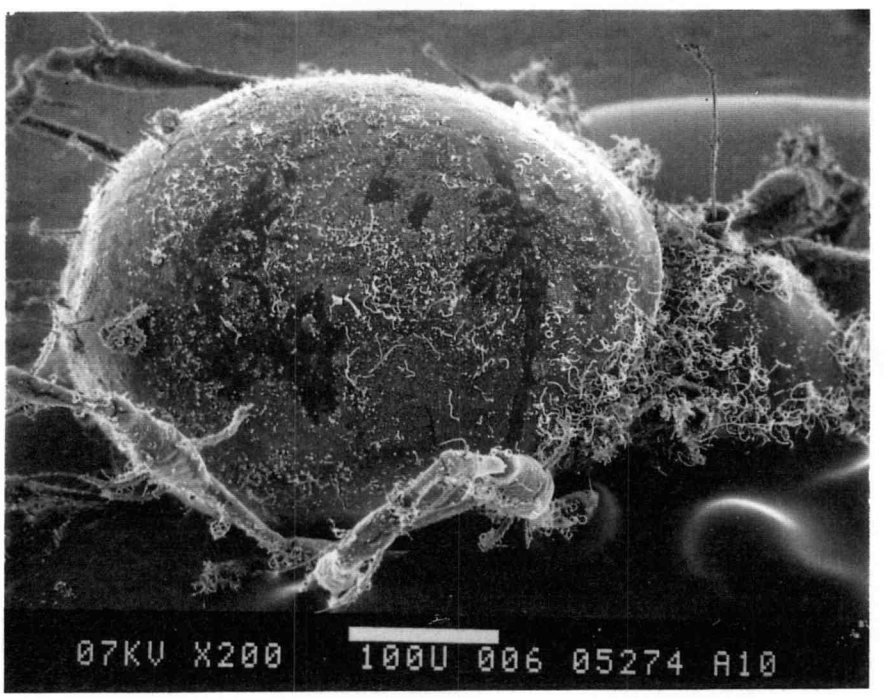


Fig. 10. *Caenobelba* SEM.

2.3.3 *Pilogalumna* sp.

The original inoculum of this species was collected from the Andrews Forest. Living material was extracted and the culture was started on November 18, 1993, with a mixture of species. After the death of all other species during a period of a couple of months, the culture was found to contain only *Pilogalumna*.

The conditions of the culture were basically the same as for the other species used in this study. *Pilogalumna* was offered diets of orange peel, carrots, dried and fresh mushroom, and pine needles. None of these items were used by *Pilogalumna* sp., although the pine needles were used for shelter. Occasionally, they plucked fungi off the surface of the pine needles.

The diets that worked best for *Pilogalumna* were lichen (*Usnea* sp.), pollen (*Pinus contorta*), and yeast. *Pilogalumna* were observed feeding on these diets throughout of their life cycle. In the case of the lichen, mites were observed to ingest pieces of both the fresh material and decomposed lichen. Although some granules of pollen were ingested completely and observed in fecal pellets, the mites usually broke the pollen apart and fed on the internal content.

Different kinds of yeast were consumed, but the mites preferred brewer's yeast, either when added to the culture in the form of dried flakes or after a couple of days of growth in the culture.

Both immatures and adults were observed feeding voraciously on dying *Tyrophagus* sp. and an undetermined gamasid present in the culture. *Pilogalumna* evinced a preference for feeding on the other mites even when normal diet items were present in the culture.

The life cycle is approximately 64-78 days. Adults persist in teneral condition for 3-5 days (Table 8).

Table 8. Life cycle of *Pilogalumna* sp.

Stage of development	Duration (days)
EGG	10-12 DAYS
LARVA	11-12 DAYS
QUIESCENT	2-3 DAYS
PROTONYMPH	10-12 DAYS
QUIESCENT	3-4 DAYS
DEUTONYMPH	11-13 DAYS
QUIESCENT	3-4 DAYS
TRITONYMPH	1-13 DAYS
QUIESCENT	3-4 DAYS
ADULTS	6-8 MONTHS

High survival was generally observed for both immatures and adults. Only a few died, due mainly to increased fungal presence in the growth chambers.

In this species, no spermatophores were observed in the culture chamber, but the population increased nonetheless. More observations were made and a novel method of sperm transfer was observed (Fig. 11). Males were observed following and pushing teneral females 2-3 days after the females emerged. Males shoved the lateral portion of the female to overturn and position her venter-to-venter. After the female had been positioned, the male deposited a stalkless spermatophore on the anterior region of the genital plates. The spermatophore remained attached to the cuticle as the females were observed walking around. The spermatophore measured about 40 % of the female body length, and was 2.4 times longer than broad. Subsequently, females were observed to remove the spermatophore and deposit it into their genital aperture using their first pair of legs while lying immobilized on their backs.

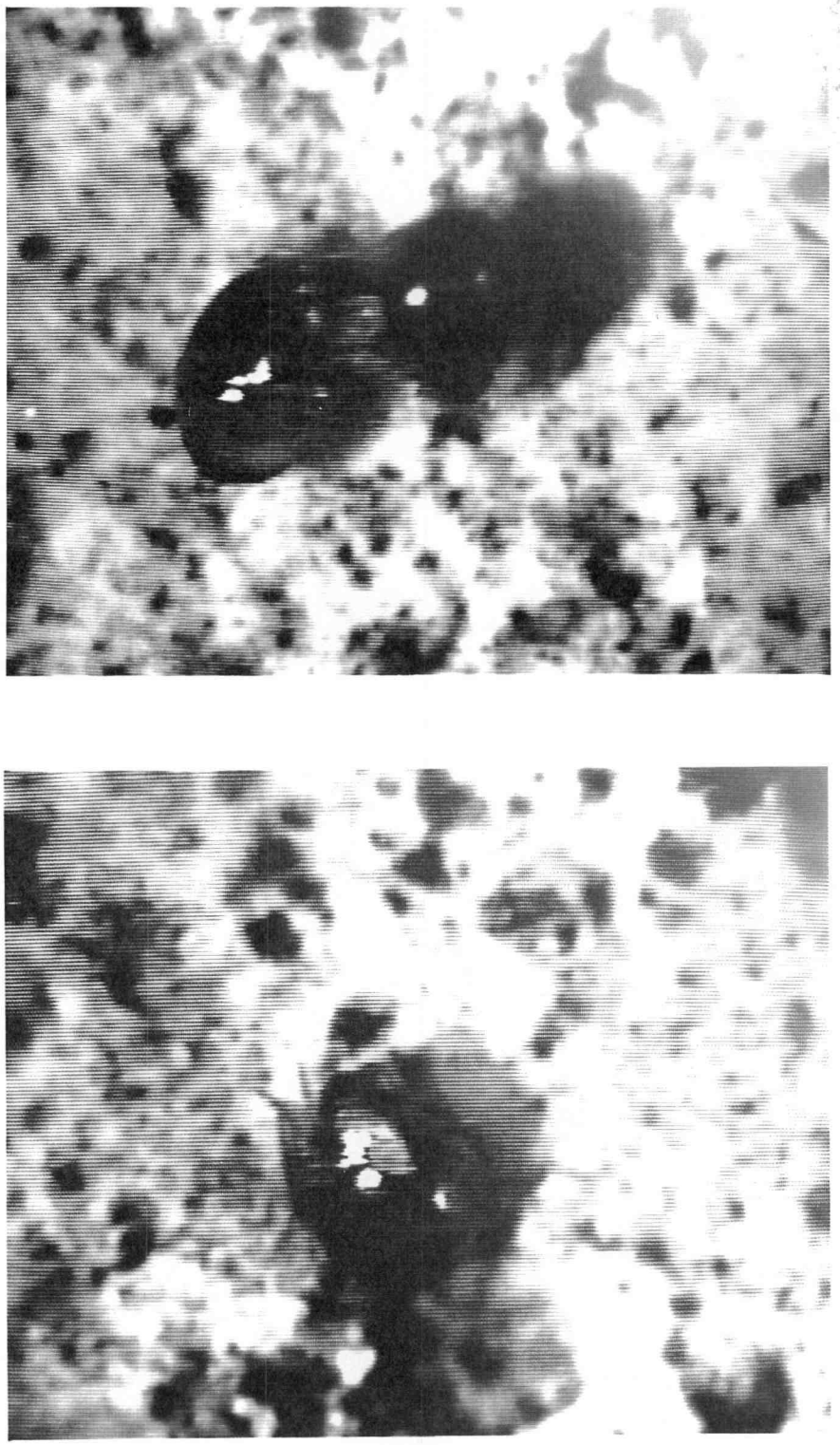


Fig. 11. Sperm transfer photographs of *Pilogalumna* sp.

2.3.4 *Liacarus* sp.

The material in this case came from Mary's Peak, Oregon, on November 4, 1993, in an area dominated by mature Douglas-fir. The samples were taken from litter and the upper centimeters of soil. Berlese-Tullgren funnels were used to extract the mites from the soil samples.

The culture was maintained with a mix of mites including *Odontodamaeus veriornatus*, *Caenobelba* sp., *Ommatocepheus* sp. and *Cepheus* sp.

The standard diet included pollen (*Pinus contorta*), fresh yeast, lichen (*Usnea* sp.), pine needles, fresh lettuce and orange peel. The mites were also observed to feed on both fermented yeast and some of the fungi growing in the culture.

The total elapsed time spent from oviposition through tritonymph was approximately 276-303 days (Table 9).

Table 9. Life cycle of *Liacarus* sp. (observations still in progress).

Stage of development	Duration (days)
EGG	12-17 DAYS
PRELARVA	13-15 DAYS
LARVA	45-50 DAYS
QUIESCENT	8-10 DAYS
PROTONYMPH	52-56 DAYS
QUIESCENT	8-10 DAYS
DEUTONYMPH	115-120 DAYS
QUIESCENT	8-10 DAYS
TRITONYMPH	AT LEAST 15 DAYS (maturation not observed yet)

The females attached their eggs to the ground substrate, pine needles or lichen. The eggs changed in color during development from light yellow to light orange. The egg chorion looked coarse and thick, and was probably covered with a protective substance which also cemented it to the substrate.

The eggs hatched after approximately 2 weeks. As the egg chorion was broken, the mouth parts and leg primordia of the prelarva stage could be observed through the aperture. The prelarval instar is a calyptostase that is fully retained within the egg chorion until ecdysis and hatching of the larva. The prelarva was observed to turn around inside the egg shield only to avoid intense illumination during photography.

Aparity (defined as birth without the egg-laying of a living mother) was observed in the culture 4 months after the culture was established (Fig. 12). In the case of aparity, females died while pregnant with fertile eggs. These eggs and prelarvae continued their development even after the mother was dead. After a period of time (about 2-3 weeks), larvae were observed coming out through the region of the mother's mouth parts. Emerging larvae contained dark-colored food boluses, presumably the result of ingesting some parts of the female's body.

The majority of immatures have been observed boring into pieces of wood where they spent extended time. Sometimes they remained outside the wood, and also were observed molting outside the wood.

One observation of a quiescent larva moving its mouth parts and legs may be significant. This behavior was not seen before in any other of the species cultured in this study. The larva flexed its appendages for several minutes then stopped. Subsequent stimulation and touch did not elicit further movement. The movements may help the larva during its moulting process.

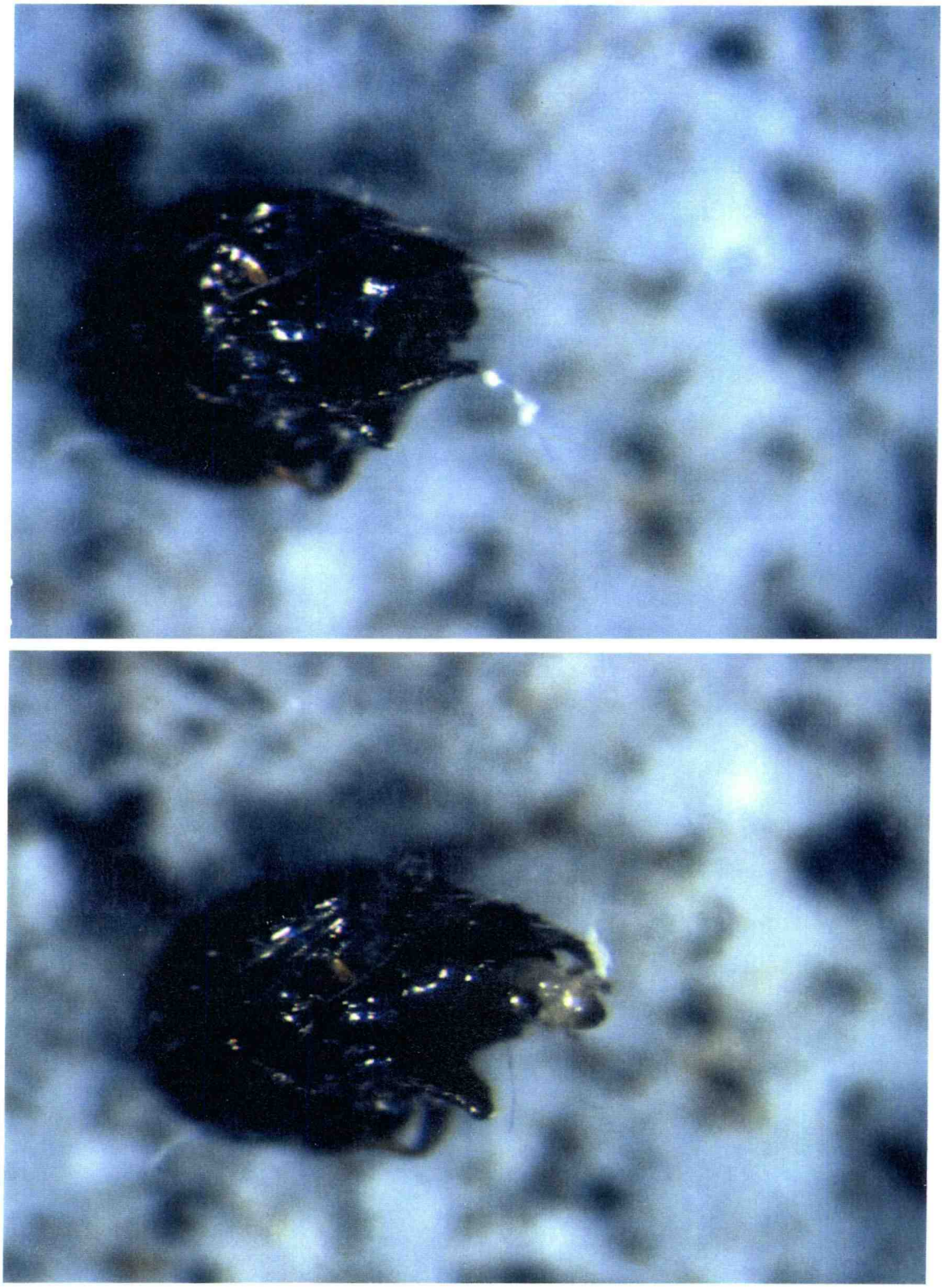


Figure 12. Aparity in *Liacarus* sp.

2.3.5 *Ommatocepheus* sp.

The material for this culture was obtained from Mary's Peak, Or., on November 4, 1993. The culture conditions for this species were the same as for *Liacarus* sp., because they were cultured in the same culture pot.

Even though the same spectrum of food was offered to *Ommatocepheus*, only the protonymphs were found feeding on pollen and yeast. All immatures were characterized by having dark food boluses most of the time, probably from ingesting pine needles where they resided. The dark content could also possibly have come from the decomposed maple leaves blended in the plaster of Paris.

Immatures carry cast skin from previous stages on their backs. All looked very similar in shape.

No egg information was obtained, but the first larva was observed in the culture approximately 80 days after the culture was initiated (Table 10).

Table 10. Life cycle of *Ommatocepheus* sp. (incomplete).

Stage of development	**Duration (days)**
EGG	NO INFORMATION
LARVA	25-29 DAYS
QUIESCENT	8-11 DAYS
PROTONYMPH	50-55 DAYS
QUIESCENT	10-13 DAYS
DEUTONYMPH	47 DAYS NOT COMPLETED

The morphology of this species was remarkable, and was characterized by the appearance of modified leaf-like dorsal setae, during the immature stages.

2.3.6 *Epilohmannia* sp.

The material used to establish this culture was collected on March 11, 1994, at Long Bow Campground, 20 miles east of Sweet Home, Or. The mites first resided in a mixed culture and, after approximately a week, they were moved to a new jar and maintained as a single species.

The food offered to *Epilohmannia* was basically the same as for the other species. The preferred diet consisted of pieces of decayed wood, pine needles and wood chips extracted from a woodpecker nest. The mites preferred structurally sound plant material, but in an advanced stage of microbial colonization.

The eggs were found on the ground among feces or under pine needles. They were deposited on the surface and no cement was observed. The eggs were ovoid and quite transparent. The larvae and nymphs were transparent, with only the mouth parts tanned as the adult's color (bright red).

This species feigned death when disturbed and stayed in this condition for several minutes.

The life cycle of *Epilohmannia* has not been completed because all the protonymphs have died even though they look active and search for food. Probably in this case this species required some conditions (temperature, humidity and different diet) to allow them to continue their development that they could not find in the culture (Table 11).

Active adults have continued in the culture, but no new eggs have been found.

Table 11. Life cycle of *Epilohmannia* sp. (incomplete).

Stage of development	**Duration (days)**
EGG	15-18 DAYS
LARVA	20-27 DAYS
QUIESCENT	8-10 DAYS
PROTONYMPH	INCOMPLETE

2.3.7 *Atropacarus* sp.

The material used to study this species was obtained near Matlock on, the Olympic Peninsula, Washington, on October 20, I993.

Atropacarus was maintained in a mixed culture with *Euphthiracarus cernus* and a species of springtail (*Isotoma* sp.). Springtails were successfully used in the culture to reduce the mold problems due to the high humidity levels required to culture this species.

The diet consisted of decayed material like pine needles, pieces of wood, pieces of maple leaves and "shredded" wood from a woodpecker nest. The material offered to the mites had to be moist and thoroughly decayed, for example by keeping the material (especially pine needles and leaves) submerged in water in a sealed jar to maintain the correct conditions of decay and humidity. Under these conditions, when the material was offered to the mites, they accepted it immediately.

Females were observed laying each egg in a tiny hole which they made previously on the surface of pine needles and wood. The shape and size of this tiny pit was the same as the egg. After they laid the egg, saliva and dust from the pine needle hole was used to cement the egg into the pit. The females went around and around the egg many times, cementing the egg and checking that it was well covered. The cementing process took about 45 minutes. A few eggs were removed and prelarvae were found inside them. When the larva hatched, it moved directly into the pine needle or wood instead of remaining on the surface. They fed immediately after emerging. Subsequently, they moved deep into the wood and the implanted egg chorion became filled with feces.

Information about the larval and protonymphal stages was recorded, but the other immature stages were not possible to observe because they moved completely into the wood or pine needle. If the wood or pine needles were opened, the mites did not subsequently find the appropriate conditions and died.

After the mites reach the adult stage (approximately 3 months), they leave the needles and wood and may be found on the surface.

The study of *Atropacarus* was complicated due to its secretive habits. The mites spent most of their life cycle inside wood or pine needles, such that observations were difficult (Table 12).

Table 12. Life cycle of *Atropacarus* sp. (incomplete).

Stage of development	**Duration (days)**
PRELARVA	1-13 DAYS
LARVA	15-17 DAYS
QUIESCENT	3-4 DAYS
PROTONYMPH	16-17 DAYS
QUIESCENT	3-4 DAYS

2.3.8 *Euphthiracarus cernus*

The material used to study this species was collected near Matlock, Olympic Peninsula, Washington on October 20, 1993.

Euphthiracarus cernus has been maintained in a mixed culture with *Atropacarus* sp. The diet used was the same as were the feeding habits.

Observations on this species were likewise complicated because they burrowed directly into the pine needle or wood. In this species, the females did not cement their eggs and eggs were found on the ground or barely hidden in depressions or tiny holes. Consequently, free-living larvae were encountered on exposed surfaces. Subsequently they burrowed into a pine needle or wood until they reached the adult stage.

E. cernus reaches the adult stage after approximately 4 months (Table 13). The population of this species has been consistently low. The number of organisms has not increased since the cultures were started.

Table 13. Life cycle of *Euphthiracarus cernus* (incomplete).

Stage of development	**Duration (days)**
PRELARVA	11-14 DAYS
LARVA	15-18 DAYS
QUIESCENT	4-6 DAYS
PROTONYMPH	17-20 DAYS
QUIESCENT	4-6 DAYS

In order to determine preference of oribatid mites for different stages of decayed pine needles, three different decay stages were examined: (1) pine needles that just had dropped from the tree; (2) pine needles that had stayed on the ground several months but were only slightly decomposed; and (3) pine needles that had been on the ground for a long period of time (at least one year) and in which the level of decomposition was high.

In the case of the newly fallen needles, I found that *Liacarus* sp. thoroughly investigated them but did not remain. Other species, i.e., *Caenobelba* sp., and *Pilogalumna* sp., remained with the new needles for shelter and occasionally fed on fungi growing on the surfaces. *Liacarus* preferred the second option, as did *Oribotritia*. Unlike *Oribotritia* which feeds solitary, *Liacarus* fed in communal groups until individual pieces of the food were completely consumed. *Liacarus* would reside under the needles in option 3, feeding sporadically on surface-growing fungi.

2.4 DISCUSSION

Studying the biology of any organism is always fascinating; certainly the case of oribatid mites is not an exception. Sometimes an understanding of behavior is difficult to attain, but after seemingly endless attempts I feel that I have partially succeeded. The Oribatida have received considerable research attention because of their role in nutrient cycling and decomposition processes. However, many aspects of their biology and behavior are still unknown. Continuing research will allow us to better understand their role in natural ecosystems. The present study was focused on only a few species from the Pacific Northwest; nevertheless, a number of interesting things were documented.

Feeding habits were documented in eight species of oribatid mites. Many researchers believe that oribatids are limited in the types of food resources they can utilize. Careful rearing revealed a diversity of palates, some restricted and others broad. Some of the oribatids studied fed on fresh vegetable, animals (i.e., *Tyrophagus putrescentiae* and gamasid), and feces as found by other authors (Woodring, 1965; Rocket, 1980, Behan-Pelletier and Hill, 1983, and Evans, 1992). Strict fungivory and plant detritivory also was observed, as expected.

Life cycle length varied between the different species. In this study the variation extends from 2 months to more than one year, in laboratory conditions. For *Ceratozetes pacificus* and *Euphthiracarus cernus*, no information on life cycle was available before this study (Behan-Pelletier and Norton personal communication). The immatures of *C. pacificus* were described, but the larva had not been found (Behan-Pelletier, 1984).

Stages of development in oribatid mites are egg, prelarva, larva, protonymph, deutonymph, tritonymph and adult (Norton, 1994). During this study *C. pacificus* was found to be a larviparous species; in the case of *Atropacarus,* females lay prelarva inside the egg chorion. In the case of *Liacarus,* eggs and prelarva develop inside the female when aparity occurs. *Caenobelba* shows variation during the developing stages, all immatures have soft body and carry the old cast skin that some researches believe is use for protection (Pauly, 1956). The adults *Caenobelba* not only did not carry the old

cast skin, but also lost the notogastral setae that are presumable used to carry the cast skins. Probably adults did not need the old kind for protection because they have hard body.

Reproduction in oribatid mites was seen to be indirect, occurring through the employment of stalked spermatophores which are deposited by the male on different substrates; the spermatophores are picked up subsequently by the female (Fernandez *et al*, 1991). In the present study, the observed behavior of *Pilogalumna* was completely novel and unexpected. In this species, the male deposits a stalkless spermatophore on the body surface of the female. This might be considered as an intermediate step between indirect reproduction through spermatophores and direct insemination of the sperm into the female's body. The structure of the *Pilogalumna* spermatophore is definitely different than those found in other oribatid mites (Alberti *et al*, 1991), and further study of its unique structure in *Pilogalumna* could enhance our knowledge regarding the evolution of mating behaviors.

Aging in oribatid mites, is signaled through discoloration, increased shininess, loss of setae, slowing of locomotory movements and decreased feeding. This can commonly be found throughout the Oribatida, but in *Caenobelba* the changes appear more dramatically. In this case, when the adults emerge from the last molt their appearance changes radically to the point where they appear generically dissimilar. Aging individuals first lose nearly all their covering of curly wax filaments, then the two rows of immense notogastral setae. Careful SEM analysis revealed these changes were part of normal ontogeny, both in the laboratory and in the field. Previous to these observations, misidentification of field-collected samples was frequent.

Aparity is another unique aspect of oribatid biology that was independently observed. This process was first mentioned many years ago (Michael, 1883); however, its biological significance remains a mystery. Some authors (Grandjean, 1956; Norton, 1994) believe that aparity is merely an abnormal occasional aberration of the common practice of prolonged egg retention prior to deposition (when a suitable place to lay their eggs has not yet been found). If the female happens to die with the developing eggs inside, the eggs may hatch by default. Other authors think that aparity may be part of a special reproductive strategy (Jacot, 1933; Krantz, 1978), which the female uses to provide her eggs with extra protection during an especially stressful

period while providing the right conditions for them to develop. More studies need to be done in this regard to clarify this phenomenon.

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Chapter 3

GENERAL DISCUSSION

Oribatid mites, *Caenobelba* and *Ceratozetes,* both showed prominent increases in population density on the burn treatment. Moldenke and Fichter (1988) noted that both genera were characteristic either of very disturbed conditions or tolerated a wide range of habitat types.

In the specific case of *Caenobelba* and *Ceratozetes*, both species reproduced and increased continuously when reared under what are undoubtedly stressful laboratory conditions. Both used a variety of resources for food in the laboratory, which implies an ability to survive under a spectrum of different natural conditions. In general, both have short life cycles for oribatid mites; which may be an additional strategy that may help them compete successfully under a variety of environmental conditions.

Continued study of the biology of the organisms in the soil will help us to better understand their role in natural ecosystems. This knowledge will provide a key to interpret field results, which are in some cases (if not ALL cases) rather complicated.

Chapter 4

SUMMARY

Prescribed fire has been used as common silvicultural practice in the Pacific Northwest. Prescribed burning drastically affects the soil fauna by killing the organisms, and by removing the substrate as source of food. The objectives of this study were to determine which effects persist after 40 years of treatment and to study the biology of some common oribatid mites central to the regions fauna.

The study was divided in two parts. First, three sites were chosen in the Willamette National Forest. At each site, pairs of samples were taken in two contrasting plots, one that was clear-cut and the other was clear-cut and burned. Soil fauna was extracted, identified and counted. A total of 204 taxa were found in the three sites. To facilitate comprehension, the organisms were divided into functional feeding guilds. The total arthropod population densities differed significantly in only one of the three sites (# 21; higher densities in burn). Several individual guilds showed significant treatment effects at each site, but none were consistent at all three sites. Many of the commonest individuals taxa demonstrated significant treatment effects, approximately a dozen were consistent throughout the three sites.

In the second part, some aspects of the biology and behavior of eight species of oribatid mites from the Pacific Northwest were studied. Investigations were performed on the life cycle *Ceratozetes pacificus, Caenobelba* sp, *Pilogalumna* sp., *Liacarus* sp., *Ommatocepheus* sp., *Epilohmannia* sp., *Atropacarus* sp., and *Euphthiracarus cernus* in laboratory conditions. Biological aspects of feeding behavior, moulting, reproduction, aparity and aging were studied. A unique method of sperm transfer was found for the first time in oribatid mites.

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APPENDIX

Appendix

List of arthropods and their total number of individuals by location and treatment (cm^2).

TAXON	21 Burn	21 Non-burn	30 Burn	30 Non-burn	31 Burn	31 Non-burn
			COLLEMBOLA			
Entomobrya	3	72 *	168	179	348	536 *
Folsomia	44	25	179	106	339	1464 *
Hypogastrura sp.1	737 *	580	2661 *	586	446	1056 *
Hypogastrura sp.2	0	0	0	4	2	5
Isotoma sp. 1	279	145	425	454	722	445
Isotoma sp. 2	0	0	32	123	59	3
Metisotoma	0	0	0	1	0	2
Neanura	6	1	29	49	11	14
Neelus	0	4	3	0	0	2
Onychiurus sp. 2	40	302 *	77	1015 *	31	317 *
Onychiurus sp. 1	1755 *	578	2198	6648 *	6922	6511
Pseudachorentes	10	55	0	0	0	0
Ptenothrix	10	5	1	1	1	2
Tetracanthella	0	0	0	0	0	40
Tomocerus	308	333	398	282	661	687
			ORIBATIDS			
Achipteria	308 *	139	268 *	17	195 *	136
Anachipteria	0	13	2	0	0	2
Belba	0	0	12	0	0	0
Brachychthonius	109 *	5	25 *	6	123 *	56
Caenobelba	305 *	165	511 *	238	970 *	652
Camisia	2	0	1	4	0	4
Carabodes sp. 1	834 *	84	286 *	121	22	9
Carabodes sp. 2	12	2	1	1	1	1
Ceratoppia sp. 2	0	12	0	0	0	16
Ceratoppia sp. 1	247	336 *	11	62 *	3	58 *

Ceratozetes sp. 1	569 *	265	2695	2578	1099 *	122
Ceratozetes sp. 2	0	0	8	0	0	5
Cultroributula	0	25	41	32	47	11
Epidamaeus	5	7	5	7	30	12
Epilohmannia	73	172 *	0	1	0	1
Eporibatula sp. 1	0	8	328 *	70	728 *	128
Eporibatula sp. 2	0	0	0	6	0	0
Eremaeus	15	0	163	486 *	303	457
Eupelops	62 *	20	29	17	1	7
Euphthiracarus	31	30	101 *	30	74	89
Eupterogaeus	1	1	0	0	0	0
Furcoribates	6	0	9	1	6	13
Galumna	0	11	23	207 *	1	3
Gymnodama	0	0	32	39	0	0
Gustavia	9	21	3	0	0	7
Hermannia	93 *	22	0	0	0	0
Hermaniella sp. 1	0	0	225	196	126	350
Hermaniella sp. 2	8	8	0	0	0	1
Hypochthoniella	6	106 *	16	0	1	0
Jacotella	0	0	17	96 *	12	123 *
Liacarus sp. 1	25	25	111	204	26	55
Liacarus sp. 2	67	130 *	50	36	63	56
Maerkelotritia	0	0	3	2	7	0
Microtritia	4	1	21	3	149	81
Metrioppia	6	52	52	12	23	24
Nanhermannia	357	344	1177 *	105	97	122
Nothrus	2	104 *	43	0	0	39
Oppia	268	304	1838 *	809	198	639 *
Oppiella	5473 *	2813	13005 *	5847	7672 *	4673
Oribatula	170	130	219 *	82	453	336
Oribatella sp. 1	0	0	0	96	11	16
Oribatella sp. 2	0	21	0	0	295	120
Oribatella sp. 3	0	34	0	0	0	0
Oribotritia	8	0	0	0	0	15
Peltenuiala	16	25	3	5	0	7
Perlohmannia	4	54	0	0	2	0
Phthiracarus sp. 1	1635 *	1239	904	1542 *	1717 *	646
Phthiracarus sp. 2	0	115	139	149	1	2
Plesiotritia	2	4	22	26	24	67
Propelops	2	11	71	190 *	44	193 *

Quadroppia	1191	966	578 *	325	308	671 *
Rhinosuctobelba	9	76 *	113 *	14	20	22
Scheloribates sp. 1	185	408 *	94	46	141	167
Scheloribates sp. 2	0	0	672 *	0	0	4
Sphodrocepheus	13	7	1	3	2	2
Suctobelba	607	723	904	934	129	719 *
Tectocepheus	23	71	18	4	38	22
Tegoribates	1	17	0	0	1	2
Tenuiala	6	0	0	0	0	0
Xenillus	0	1	1	5	1	15
Zachvatkinella	0	0	1	0	0	0
Zygoribatula	124	110	5	6	0	0
Undeterm. immature	103	103	1572	1844	920	112
			PROSTIGMATA			
Nanorchestidae	2081 *	118	3045 *	1737	2269 *	1055
Bdellidae	21	3	17	0	9	14
Labidostomatidae	0	1	4	0	1	17
Rhagidiidae	1	13	3	0	10	7
Trombidiidae	1	0	1	3	3	1
			MESOSTIGMATA			
	495	350	1218	1972 *	1554	1055
Uropodidae sp. 1	1	13	9	0	23	21
Uropodidae sp. 2	1	4	38	11	3	0
Uropodidae sp. 3	0	1	1	0	0	0
Traychetes sp. 1	0	0	1	3	1	0
Traychetes sp. 2	0	32 *	0	0	45	24
Thaychetes sp. 3	8	0	33	5	3	2
Uropodidae sp. B	0	9	0	0	0	0
Uropodidae sp. F	0	8	0	0	16	0
Zerconidae	85	235 *	144	274 *	579	477
		Other	**Arthropod**	**Taxa**		
Acalypta	0	0	0	0	1	1
Acroceridae	0	0	0	0	3	0
Agulla	0	0	0	3	10	4
Aleocharinae	0	0	0	1	0	8

Antrodiaetus	0	1	3	1	3	1
Aphenogaster	30	13	42	4	8	130 *
Aphid	1	0	0	0	0	0
Aphodius	0	0	1	0	1	0
Apochthonius	263	304	72	75	110	251 *
Aradidae	0	0	0	0	0	1
Arrhopalites	0	0	0	0	0	1
Asilidae	0	0	6	0	0	0
Bdellzonium	0	0	0	0	0	5
Beetle ?	1	1	0	0	0	0
Bollmanella	0	4	0	1	0	2
Byrrhidae	0	1	1	0	1	0
Campodeidae	226 *	66	353	206	108	201
Cantharidae	7	69 *	11	6	19	11
Carabidae	9	14	41	37	4	18
Caseya	32	24	15	6	4	6
Caterpillar	0	0	0	0	1	0
Catopocerus	2	1	1	0	9	0
Cecidomyiidae (adult)	6	14	9	9	22	24
Cecidomyiidae (immat.)	9	31	9	6	27	25
Ceraphronidae	10	20	29	24	56	18
Ceratolasma	0	0	0	1	0	0
Chironomidae (adult)	6	17	7	5	1	7
Chironomidae (immat.)	0	3	27	38	13	23
Chrysomelidae	8	7	0	0	0	0
Ctenicera	0	1	0	0	1	0
Curculionidae	3	5	3	4	11	16
Cybaeus	3	27	3	0	7	1
Dendrolasma	1	2	11	0	3	1
Dermestidae	0	0	0	2	0	0
Diabrotica	0	1	0	0	0	0
Dyslobus	0	1	0	0	0	1
Elateridae	17	42	24	44	52	38
Eupteridae	0	0	0	0	1	0
Fenderia	13	19	0	0	0	3
Flea	0	0	0	0	1	0
Fly ?	2	0	0	0	0	6
Geodercodes	2	2	0	0	0	0
Geophilomorpha	21	66 *	35	51	86	125 *
Gnaphosidae	0	0	1	0	0	4
Harpaphe	23	12	0	0	1	8
Hesperonemastoma	1	0	0	0	0	0
Cicadellidae	1	2	0	0	5	2
Ichneumonidae	0	0	1	2	1	1
Ixodes	1	0	0	0	0	0
Larva (undet)	112 *	40	280	208	192	320 *
Lampyridae	0	1	0	0	0	0
Lathridiidae	0	0	0	0	3	0
Leiodidae	0	1	1	0	34	2

Leptotyphlinae	3	0	1	0	0	0
Leuronychus	0	0	3	0	0	0
Liposcelis	0	0	1	10	8	35
Lithobidae	30	58	9	8	10	22
Lophioderus	1	0	0	0	0	0
Lygaeidae	0	0	1	0	5	1
Lygidium	9	18	0	0	0	0
Lysiopetalidae	18	18	0	0	0	0
Metanonychus	5	5	10	5	1	4
Micropterigidae	0	0	1	0	1	0
Microcreagis	23	15	18	3	0	3
Micryphantidae	20	59	87	46	17	49
Miridae	0	0	1	0	0	2
Mormoniella	0	0	0	0	0	1
Moth	1	0	1	3	4	2
Nearctodesmus	4	5	3	0	0	5
Notiophilus	0	1	0	0	0	0
Omaliinae	0	0	0	1	0	0
Orthezia	1	3	2	2	1	9
Pauropod sp. 1	336 *	102	14	4	45	196 *
Pauropod sp. 2	0	1	0	11	2	31
Pauropod sp. 3	0	0	0	0	2	0
Pellenes	0	0	0	0	0	1
Pentatomidae	0	0	0	0	1	0
Phoridae	0	0	0	0	1	1
Polyxenus	0	0	6	14	19	0
Pristocenthophilus	0	0	0	1	0	0
Protura	469	410	148 *	33	230 *	179
Pselaphidae	16	8	26	11	1	21
Psychodidae (adult)	1	6	9	6	3	3
Psychodidae (immat.)	7	2	3	1	0	3
Psyllobora	0	0	1	0	0	0
Pterostichus	1	1	0	0	1	2
Ptiliidae	1	10	88 *	4	8	32 *
Scarabaeidae	0	0	16	1	11	0
Sciaridae (adult)	0	26	0	2	0	4
Sciaridae (immat.)	0	0	1	45 *	1	7
Scydmaenidae	3	14	0	0	1	0
Scytonotus	4	2	0	2	0	0
Ariolimax	0	0	1	0	0	0
Vespericola	5	5	0	4	2	0
Sphecidae	0	0	0	0	0	1
Staphylinidae	0	0	0	0	1	0
Stenus	0	1	0	0	0	32 *
Steremnius	1	1	2	0	0	0
Symphyla	110	76	534 *	180	128	334 *

Tapinoma	0	0	0	1	0	69 *
Taracus	3	0	0	0	1	0
Eriococcidae	0	0	3	0	19	0
Tenebrionidae	1	2	4	2	8	6
Tachinus	0	2	1	0	0	5
Thysanoptera	0	0	3	2	4	2
Tipulidae	54	87	50	39	142	116
Coleophoridae	0	0	0	0	0	1
Usechomorpha	0	0	0	0	2	0
Worm	22	20	2	2	86 *	9
Xysticus	0	0	1	2	6	0