

Forest floor microarthropod abundance and oribatid mite (Acari: Oribatida) composition following partial and clear-cut harvesting in the mixedwood boreal forest

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Abstract: The effects of partial and clear-cut harvesting on abundance and community composition of forest floor microarthropods and oribatid mites were investigated in conifer and deciduous stands of the mixedwood boreal forest. Soil samples from clearcuts, strip-cut corridors in a partial cut, green-tree retention patches in a partial cut, and uncut control sites were collected 2.5 years after harvest and microarthropods were extracted, enumerated, and identified. Densities of microarthropod suborders were lower in the strip-cut corridors of the deciduous stands and significantly lower in the suborder Oribatida (oribatid mites). Changes in microarthropod community composition, decreased relative abundance of prostigmatid mites, and increased relative abundance of mesostigmatid mites were observed in corridor and clear-cut treatments. Lowered abundances and changes in community composition are likely due to compaction of the forest floor during harvesting. Selected oribatid mite species showed significantly lower abundances in clearcuts than in uncut sites, but diversity indices for oribatid mites were generally not significantly different between uncut sites and clearcuts. Changes in oribatid mite communities following harvesting were thus more quantitative (absolute abundance) than qualitative (diversity, composition), and as a result, use of oribatid mites as biological indicators of disturbance is limited because of the lack of changes in species composition.

Résumé : Nous avons étudié les effets de coupe partielle et de la coupe à blanc sur l'abondance et la composition des microarthropodes et des acariens oribates dans la couverture morte de peuplements résineux et feuillus en forêt boréale mixte. Des échantillons de sol ont été recueillis dans des coupes à blanc, des bandes coupées dans des coupes partielles, des îlots de rétention d'arbres vivants dans une coupe partielle et des sites témoins non coupés, deux ans et demi après coupe, puis les microarthropodes en ont été extraits, dénombrés et identifiés. La densité des sous-ordres de microarthropodes était plus faible dans les bandes coupées des peuplements feuillus et significativement plus faibles pour le sous-ordre des Oribatida (acariens oribates). Des changements dans la composition des communautés, une baisse d'abondance relative des acariens prostigmatés et une hausse de l'abondance relative des acariens mésostigmatés ont été observés dans les bandes coupées et les coupes à blanc. Les baisses d'abondance et les changements dans la composition des communautés résultent probablement de la compaction de la couverture morte lors de la coupe. Bien que l'abondance de certaines espèces d'acariens oribates ait été significativement plus faible dans les coupes à blanc que dans les sites témoins, les indices de diversité des acariens oribates ne différaient généralement pas dans ces sites. Les changements dans les communautés d'acariens oribates qui ont suivi la récolte sont donc plus quantitatifs (abondance absolue) que qualitatifs (diversité et composition). L'utilité des acariens oribates comme indicateurs biologiques est donc limitée par l'absence de changements dans la composition en espèces.

[Traduit par la Rédaction]

Introduction

Litter and soil microarthropods are 0.1–2 mm in length and include primarily Acari (mites) and Collembola (spring-tails). Microarthropods play an important role in regulating rates of decomposition and nutrient cycling via interactions with the microbial community (Seastedt 1984). Microarthropods influence microbial populations by stimulating micro-

bial growth through grazing, introducing microbial propagules to new substrates, and increasing litter surface area for microbial attack through comminution of organic matter and fecal pellet deposition (Visser 1985). Microarthropods also release nutrients held within fungal standing crops and contribute to soil structure and humus formation (Wallwork 1983; Norton 1985). Although the relative contributions of microarthropods to decomposition and nutrient cycling have not been specifically quantified, reductions in microarthropod abundance may be detrimental to soil processes. For this reason, preservation of soil biodiversity should be considered an integral component of forest management practices (Marshall 2000).

Numerous studies have reported a reduction in soil microarthropods following forest clear-cutting (Vlug and Borden 1973; Huhta 1976; Abbott et al. 1980; Blair and Crossley

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1988; Marra and Edmonds 1998). However, the effect of forest harvesting at reduced intensities — such as practised in residual-leave or partial-cut systems — on forest floor microarthropods has not been studied in detail. Green tree retention within harvested sites is thought to reduce overall soil disturbance, maintain organic matter inputs and nutrient cycles, reduce nutrient losses (Dahlgren and Driscoll 1994), provide refuge for belowground organisms like mycorrhizal fungi (Barg and Edmonds 1999), and help maintain soil invertebrate communities (Siira-Pietikäinen et al. 2001). Abbott et al. (1980) observed that communities of soil microarthropods in partial-cut sites were more like those in uncut sites than those in clearcuts. Huhta et al. (1967) found that forest thinning reduced soil microarthropod abundance in a Finnish coniferous forest, but reductions were less than in clearcuts. Other research has shown that partial-cut and selective timber harvesting may have significant, long-lasting effects on the soil arthropod community (Hoekstra et al. 1995). These observations suggest that partial-cut harvesting may be less detrimental to forest floor microarthropod communities than is clear-cutting, but further research is required to confirm this.

Oribatid mites (Acari: Oribatida) are the numerically dominant microarthropods in forest systems (Wallwork 1983) and often show the greatest decrease in abundance following disturbance (Seastedt and Crossley 1981; Blair and Crossley 1988). The diversity of oribatid species is higher than that of other microarthropod groups, and changes within oribatid mite community structure may be a useful indicator of disturbance (Behan-Pelletier 1999). Oribatid mites generally have low dispersal capabilities and cannot easily escape from the stress of disturbance or recolonize disturbed habitats. Oribatid mites are considered *k*-selected organisms (being iteroparous and having low fecundity, slow developmental times and metabolic rates, and long life spans); thus, they do not recover quickly from reduced population numbers (Norton 1990). However, some families and species of oribatid mites are known to be thelytokous (parthenogenic) and may have an advantage over other species in increasing numerically following disturbance. It is suggested, then, that in disturbed soil systems, measurable changes in community composition resulting from increased dominance of thelytokous families or species will be observed (Behan-Pelletier 1999). The use of oribatids as indicators of soil disturbance is not yet a common practice. This may be the result of incomplete taxonomy of oribatid mites at the species level and (or) the result of the amount of expertise and time required to identify this group of microarthropods.

The present study examined the effects of clear-cut and 50% partial-cut harvesting on forest floor microarthropods in coniferous- and deciduous-dominated stands of the boreal mixedwood forest. The overall objective was to determine whether a 50% partial-cut harvest had less of an impact on forest floor microarthropods than a clear-cut harvest did. In addition, oribatid diversity and community composition were assessed to evaluate the usefulness of oribatid mites as biological indicators of harvesting disturbance. We hypothesized that forest floor microarthropod abundance would be reduced by partial-cut harvesting, compared with uncut sites, but would have greater microarthropod abundance than

clearcuts. Within the partial-cut sites, we predicted that microarthropod numbers would be lower in strip-cut corridors than in retention patch areas, as strip-cut corridors have a greater degree of forest floor disturbance. Changes in the composition of oribatid mite communities, such as lower species diversity indices and shifts in the dominance or relative abundance of certain oribatid species (that is, increased thelytokous individuals), were also expected to result from harvesting disturbance.

Materials and methods

This study was conducted at the Ecosystem Management Emulating Natural Disturbance (EMEND) research site in northern Alberta, Canada (Sidders and Spence 2001). The EMEND site is located approximately 90 km northwest of Peace River (56°46'13"N, 118°22'28"W) in the Upper Boreal – Cordilleran ecoregion. This area has a mean daily temperature of -0.6 °C, and total annual precipitation is 426.5 mm (Environment Canada 2003). The elevation is 677–800 m above sea level, and soils are predominantly fine-textured lacustrine Luvisols.

The EMEND experimental design is a random block design with two stand types and four treatments. Coniferous (white spruce) and deciduous (trembling aspen) dominated, 80- to 140-year-old stands were divided at random into 10-ha clear-cut, partial-cut, or uncut sites. In the present study, the partial-cut site was divided into two treatments, the strip-cut corridors and the retention patches, because impacts on the forest floors differ between these two areas (Lindo and Visser 2003). Thus, the treatments considered in this study are clearcut, partial-cut patch (patch), partial-cut corridor (corridor), and uncut control. Harvesting occurred in the winter of 1998–1999. Conventional full-tree harvesting with direct route skidding was used in the clearcuts. A two-pass system of harvest was used in the partial-cut sites. The corridors were created with a feller–buncher–forwarder (skidder). Corridors have 100% tree removal and are 5 m wide, 20 m apart, and oriented north–south, perpendicular to the prevailing wind. The retention patches (15 m wide) were selectively harvested on the second pass at a 1:3 stem removal/total stem ratio (one of every three trees removed). All harvesting and skidding was confined to the corridors. A full description of the research site and harvesting methods is available in Sidders and Spence (2001).

Forest floor microarthropod sampling was conducted in June 2001, 2.5 years after harvest. A total of 80 forest floor cores were removed to mineral depth (~10 cm) along 50-m transects in each treatment (2 stand types (conifer, deciduous) × 2 replicate stands × 4 treatments (uncut, patch, corridor, clearcut) × 5 samples per treatment). Transects were oriented north–south to coincide with the direction of the patch and corridors, and forest floor samples were removed from the centre of the retention patches and corridors. Individual 5.5-cm diameter polyvinyl chloride soil corers were used for each sample, and samples were stored in the corer at 4 °C until just before microarthropod extraction, 3 days after sampling for conifer and 13 days after sampling for deciduous cores.

Intact forest floor cores were extruded from the plastic corers, divided into 4-cm sections, and placed in a

Macfadyen extractor (Macfadyen 1961), where a temperature and moisture gradient forced active soil fauna to move down the core into a picric acid fixative over a period of 10 days. The Macfadyen extractor is >95% effective in extracting the active fauna from these types of soils (unpublished). Microarthropods extracted from the cores were filtered from the picric acid and preserved in 70% ethanol. Average dry mass of core samples was 30 g. The total numbers of individuals within major microarthropod groups (Collembola and Acari) were evaluated with a dissecting microscope at 25× magnification. Collembola were identified to suborder (Arthropleona, Symphypleona), as were the Acari (Oribatida, Prostigmata, Astigmata, Mesostigmata). Oribatid mites from the uncut and clear-cut treatments were classified to genus and species, where possible, with a compound microscope (100–400× magnification) and keys produced by Gilyarov and Krivolutskii (1975), Balogh and Mahunka (1983), Norton (1990), (R.A. Norton, unpublished key)², and Balogh and Balogh (1992).

Microarthropod abundance, expressed as number of individuals per gram dry mass of forest floor, was used to estimate population sizes and to determine changes in absolute abundance (density) of mites and springtails between treatments. Changes in microarthropod community composition were explored by using percentage relative abundance of microarthropod suborders ((number individuals in a suborder/total number individuals) × 100). Relative abundances are useful for comparing the structure of microarthropod assemblages and for identifying suborders most impacted by forest harvest. Taxonomic groupings at the suborder level for oribatid mites and mesostigmatid mites are roughly equivalent to functional groups (organisms that share similar functional roles in the community) that are based on characteristics such as primary food source, feeding mode, reproductive rate, and defence against predators (Moore et al. 1988). Any changes in the relative abundance of microarthropod functional groups (community composition) can affect energy and nutrient pathways in the below ground foodweb (Seastedt and Crossley 1984).

Oribatid mite community composition and diversity were examined by applying nonparametric diversity indices, including species richness, diversity, evenness, and dominance (Magurran 1988). Diversity indices for uncut and clear-cut treatments were analysed separately for conifer and deciduous stands by using a two-sample *t* test. Species richness (*N*) measures the total number of species recorded for a given sampling unit. The species richness index is simple to calculate and is widely used; however, it is very sensitive to sampling effort. Thus, a cumulative species curve for oribatid mites was constructed to test whether the oribatid sampling effort was intensive enough to find all oribatid mite species present in conifer and deciduous stands of this mixedwood boreal system.

The diversity index, inverse of Simpson's, was calculated using the formula $1/D = 1/\sum p_i^2$ where *D* is Simpson's index and p_i is the proportion of individuals found in the *i*th species. Simpson's index has low sensitivity to sample size and is widely used (Magurran 1988).

The Shannon–Wiener index of evenness was calculated using the formula $H' = -\sum p_i \ln p_i$ where *H'* is Shannon's index and p_i is the proportion of individuals found in the *i*th species. The Shannon–Wiener index has average discrimination ability, is widely used, but is moderately sensitive to sampling effort (Magurran 1988).

The Berger–Parker index is calculated as the inverse of $d = N_{\max}/N$ where *d* is inverse dominance, N_{\max} is the number of individuals in the most abundant species, and *N* is the total number of individuals. This index is not as widely used as others, but it provides a simple calculation of the inverse dominance of a community independent of species richness (Magurran 1988).

The general linear model for randomized block designs in SYSTAT 7.0 was used to analyse the abundance data (SYSTAT Inc. 1997). A two-factor analysis of variance (ANOVA) was performed to test for stand and overall treatment effects on absolute and relative abundance means for each suborder. Results were considered significant when $p < 0.05$. Within each of the conifer and deciduous stand types, additional one-way ANOVAs with Tukey's honestly significant difference tests were performed to assess the effects of harvesting treatments on microarthropod suborder abundance. Microarthropod suborder and oribatid species abundances were log transformed (\log_{10}) to normalize the data and to minimize the effects of rare species and aggregated population distributions (Krebs 1989). Hierarchical cluster analysis was used to group the most similar treatments in each stand type on the basis of the absolute abundance of microarthropod suborders. Where possible, oribatid species from uncut and clear-cut treatments in each stand type were compared by using a two-sample Student's *t* test.

Results

Effect of forest harvesting on microarthropods

There were no significant treatment differences in mite or Collembola abundances observed within the conifer stands as a result of high variability between sites (Fig. 1). In the deciduous stands, oribatid mite numbers were significantly lower in the strip-cut corridors than in the uncut control treatment ($df = 3, f = 13.976, p = 0.029$). Numbers of prostigmatid mites, astigmatid mites, mesostigmatid mites, arthropleonid Collembola, and symphypleonid Collembola in corridors of the deciduous stands were also lower than in other treatments but not significantly.

Hierarchical cluster analyses (Fig. 2) showed that patterns of absolute abundance (density) within the microarthropod suborders in the conifer stands were similar between the strip-cut corridors and the clear-cut treatments, whereas abundances of suborders in the retention patches were more similar to those in the uncut control forest. In the deciduous stands, the numbers and types of microarthropods in the retention patches and the clearcuts were most similar and resembled the pattern in the strip-cut corridors. The uncut control treatment was dissimilar to the patch, corridor, and clear-cut treatments in the deciduous stands.

²R.A. Norton. n.d. An unpublished key to the genera of lower oribatid mites of the United States and Canada and to genera of the Brachyline oribatid mites of North America. Ohio State University, summer acarology course book.

Fig. 1. Absolute abundance of (a) oribatid mites, (b) prostigmatid mites, (c) astigmatid mites, (d) mesostigmatid mites, (e) arthropleonid Collembola, and (f) symphypleonid Collembola in forest floors of uncut, partial-cut patch, partial-cut corridor, and clear-cut sites in conifer and deciduous stands. Values are means ± SE. Values with the same letters within each forest stand type are not significantly different.

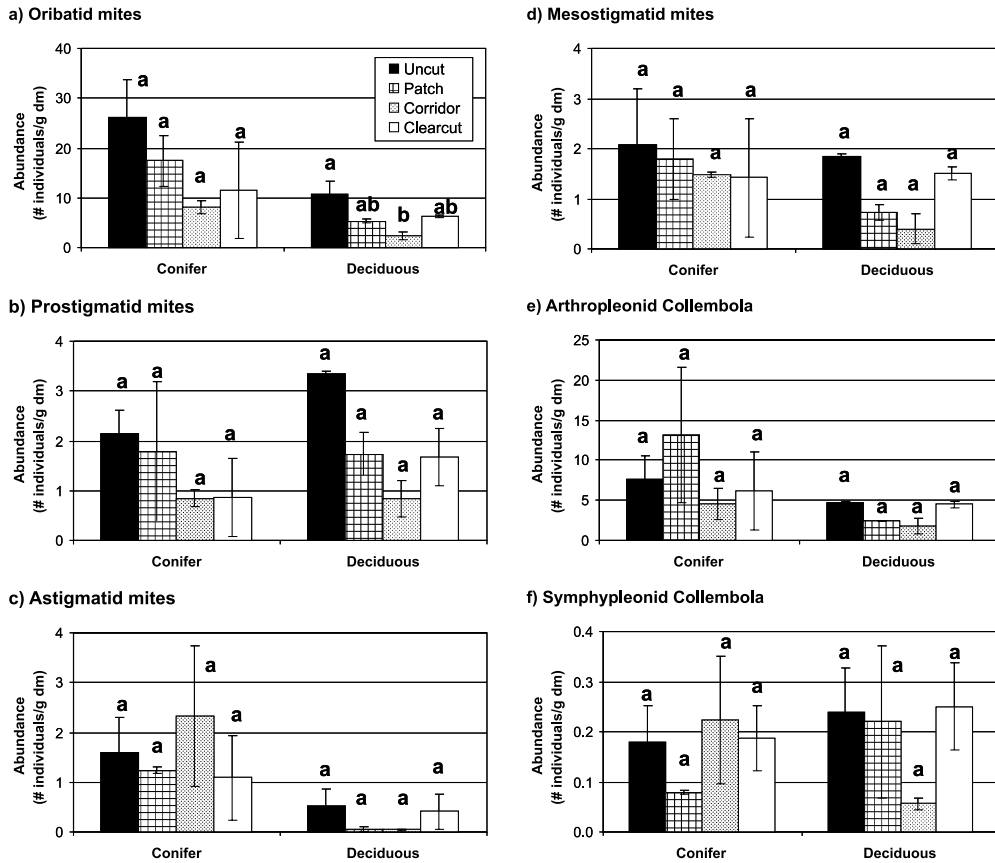


Table 1. Relative abundance (percentage of total abundance) of forest floor microarthropod suborders in uncut, partial-cut patch, partial-cut corridors, and clear-cut treatments of conifer and deciduous stands.

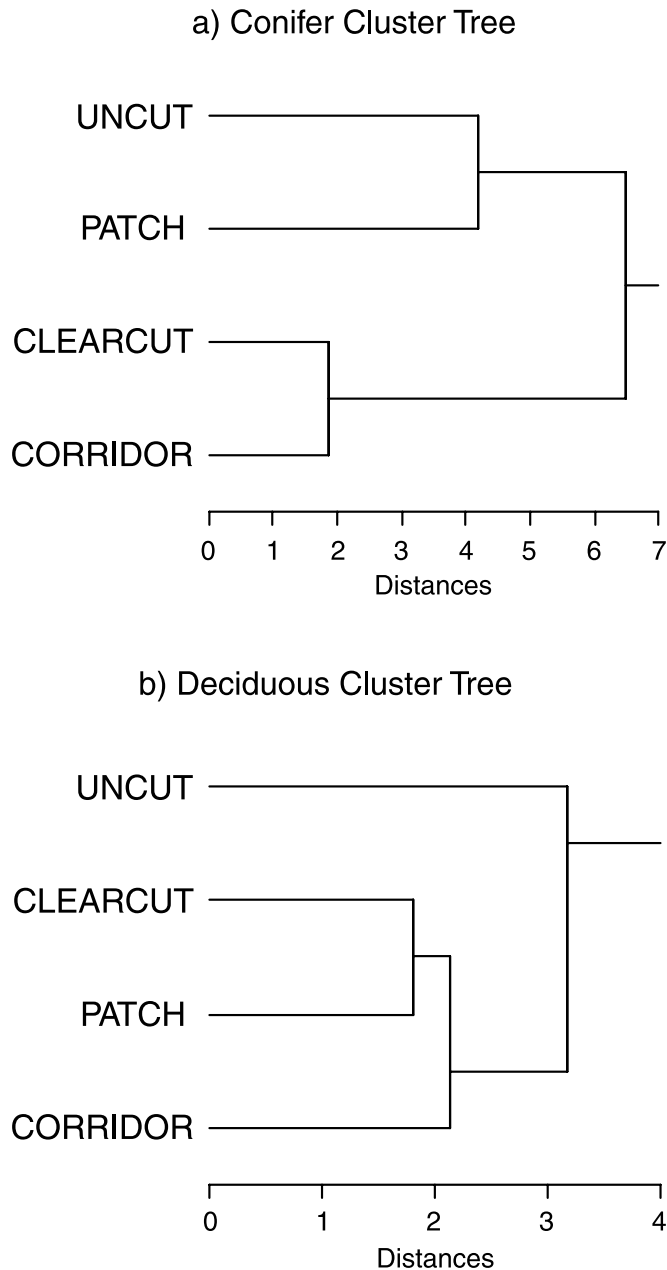
	Uncut (%)	Patch (%)	Corridor (%)	Clearcut (%)
Conifer (n = 2)				
Oribatida	67.82 (3.45)a	52.22 (6.10)a	46.43 (3.76)a	46.28 (8.47)a
Prostigmata	5.16 (0.39)a	4.35 (2.09)a	5.18 (0.14)a	3.00 (1.53)a
Astigmata	3.35 (1.38)a	5.99 (3.15)a	9.45 (2.69)a	6.59 (0.91)a
Mesostigmata	4.40 (1.10)b	4.71 (0.67)b	8.24 (1.91)a	5.84 (1.25)a
Arthropleona	17.93 (1.49)a	29.75 (5.97)a	23.82 (4.12)a	30.35 (3.65)a
Symphypleona	0.46 (0.04)a	0.30 (0.15)a	1.18 (0.39)a	1.48 (0.88)a
Deciduous (n = 2)				
Oribatida	48.86 (4.80)a	48.12 (1.06)a	46.21 (8.81)a	36.76 (1.54)a
Prostigmata	17.64 (0.44)a	15.98 (1.06)ab	13.59 (1.02)ab	9.87 (1.48)b
Astigmata	2.12 (0.90)a	0.47 (0.47)a	0.77 (0.54)a	2.42 (2.05)a
Mesostigmata	8.43 (1.84)a	6.06 (0.72)a	5.01 (2.08)a	10.01 (0.74)a
Arthropleona	20.28 (2.01)a	24.17 (0.99)a	25.34 (5.71)a	34.56 (4.22)a
Symphypleona	0.99 (0.58)a	2.02 (1.20)a	1.39 (0.49)a	2.81 (0.36)a

Note: Values are means, with SE given in parentheses. Within each row, values followed by the same letter are not significantly different, based on one-way analysis of variance and Tukey's test ($p < 0.05$).

Relative abundance (percentage of total) of oribatid mites in both stand types was lower in harvested sites, but this was not significant (Table 1). Prostigmatid mite relative abundance was significantly lower in clearcuts of deciduous

stands than in the uncut control treatment ($df = 3, f = 9.352, p = 0.049$), and the relative abundance of mesostigmatid mites was significantly greater in the strip-cut corridors of the conifer stands than in the uncut and patch treatments

Fig. 2. Hierarchical cluster analysis of forest harvest treatments based on absolute abundances of forest floor microarthropods for (a) coniferous and (b) deciduous stands. Treatments joined at a low distance index are more similar than those with higher distance indices. Groupings are based on percentage similarity of treatments.



($df = 3$, $f = 11.472$, $p = 0.038$). Arthropleonid Collembola had higher relative abundance in harvested treatments in both forest stand types, but differences in relative abundances were not significant. Astigmatid mites and symphypleonid Collembola showed no significant shifts in relative abundance as a result of harvesting disturbance and were consistently lower in relative abundance than the other groups of microarthropods.

Effect of clear-cut harvest on oribatid mites

More than 3900 adult oribatid mites from 19 families

were identified to species from the uncut and clear-cut treatments (Table 2). Individuals from the family Oppiidae (2 species) were the most abundant, followed by Suctobelbidae (4 species) and Brachychthoniidae (11 species). Individuals from these three families accounted for >85% of all oribatid mites observed in these two treatments. A total of 39 species of oribatid mites were identified in this study: 33 species inhabited the conifer forest floor, 25 species occurred in the deciduous forest floor, and 19 species were common to both stand types. The most abundant species in both conifer and deciduous stands was *Oppiella nova* (Oudemans).

The absolute abundance of *O. nova* was much lower in the clearcuts of both stand types than in the uncut control treatments, but results were only significant in the deciduous stands ($df = 2$, $t = -4.283$, $p = 0.050$). Numbers of *Suctobelbella* sp. 1 were lower in clearcuts of deciduous stands than in the uncut deciduous stands ($df = 2$, $t = -5.077$, $p = 0.037$), and numbers of *Liochthonius* nr. *muscorum* Forsslund in the conifer stands were lower in clear-cut sites than in the uncut sites ($df = 2$, $t = -5.668$, $p = 0.030$). No other oribatid species showed significant changes in abundance as a result of forest-harvesting disturbance.

An average of 22.5 and 20.5 species were identified in the uncut and clear-cut treatments, respectively, in the conifer stands. In the deciduous stands the species richness was 13.5 in the uncut sites and 14.0 in the clearcut sites (Table 3). Differences in species richness were not significant between treatments in either forest stand type. Shannon–Wiener, inverse Simpson's, and Berger–Parker indices were all higher in conifer stands than in deciduous stands, and all indices were higher in clear-cut treatments than in uncut treatments. However, only the Shannon–Wiener index in the conifer stands showed a significant result ($df = 2$, $t = 8.187$, $p = 0.015$). A cumulative species curve constructed for oribatid mites from both stand types showed that the number of mite species may be slightly underestimated, as the cumulative number of species did not attain a plateau with the maximum number of samples processed (Fig. 3). Additional sampling is suggested to obtain a more comprehensive inventory of oribatid mite species for this region.

Some species showed a preference for one stand type over another. *Quadroppia quadricarinata* (Michael) and *Suctobelbella* sp. 2 were more abundant in the deciduous stands, whereas *Suctobelbella* nr. *acutidens* (Forsslund), *Suctobelbella* sp. 1, *Moritzoppia clavigera* (Hammer), and members of the genus *Liochthonius* were more abundant in the conifer stands.

Discussion

Lower microarthropod abundances in harvested treatments at the suborder level in this study were mostly non-significant, and where significantly lower abundances occurred, as in the oribatid mites of the deciduous stands, it was within the strip-cut corridor treatment, in contrast to the uncut control treatment. High variability and differences between sites within stands is thought to contribute to the overall lack of significant results.

Reductions in forest floor microarthropods following forest harvest have been attributed to decreases in organic mat-

Table 2. Mean forest floor densities of oribatid species found in uncut and clear-cut treatments of conifer and deciduous stands.

	Conifer (no. individuals per gram dry mass)		Deciduous (no. individuals per gram dry mass)	
	Uncut	Clearcut	Uncut	Clearcut
Family Brachychthoniidae				
<i>Brachychthonius</i> nr. <i>berlesei</i> Willmann	0	0	0	0.01 (0.01)
<i>Liochthonius sellnicki</i> (Thor)	0.09 (0.08)	0.12 (0.09)	0	0
<i>Liochthonius</i> nr. <i>brevis</i> (Michael)	1.02 (0.94)	0.90 (0.82)	0.06 (0.04)	0.01 (0.01)
<i>Liochthonius</i> nr. <i>clavatus</i> (Forsslund)	0.01 (0.01)	0.01 (0.01)	0	0
<i>Liochthonius</i> nr. <i>muscorum</i> Forsslund	0.13 (0.04) ^a	0.02 (0.00) ^b	0	0.01 (0.01)
<i>Liochthonius</i> nr. <i>simplex</i> (Forsslund)	0.73 (0.56)	0.41 (0.39)	0	0
<i>Mixochthonius</i> nr. <i>concaus</i> (Chinone)	0.08 (0.06)	0.03 (0.03)	0	0
<i>Paraliochthonius</i> nr. <i>occultus</i> (Niedbala)	0.01 (0.01)	(0.01)	0	0
<i>Poecilochthonius</i> nr. <i>spiciger</i> (Berlese)	0	0	0	0.01 (0.01)
<i>Sellnickochthonius rostratus</i> (Jacot)	0.01 (0.01)	0	0	0
<i>Sellnickochthonius suecica</i> Forsslund	0.86 (0.80)	0.02 (0.00)	0	0.01 (0.01)
Family Pterochthoniidae				
<i>Pterochthonius angelus</i> (Berlese)	0	0	0	0.01 (0.01)
Family Phthiracaridae				
<i>Phthiracarus</i> nr. <i>borealis</i> (Trägårdh)	0	0	0.01 (0.01)	0
Family Oribotritiidae				
<i>Protoribotritia</i> sp.	0	0	0.01 (0.01)	0
Family Camisiidae				
<i>Heminothrus minor</i> Aoki	0.01 (0.01)	0.02 (0.01)	0	0
<i>Platynothrus peltifer</i> (C.L. Koch)	0	0.01 (0.01)	0	0
Family Trhypochthoniidae				
<i>Trhypochthonius tectorum</i> (Berlese)	0.01 (0.01)	0.12 (0.12)	0.01 (0.01)	0
Family Damaeidae				
<i>Epidamaeus</i> sp. 1	0.06 (0.04)	0.02 (0.02)	0.01 (0.01)	0.01 (0.01)
<i>Epidamaeus</i> sp. 2	0.01 (0.01)	0	0	0
<i>Epidamaeus</i> sp. 3	0.01 (0.01)	0.01 (0.01)	0	0.05 (0.03)
Family Cepheidae				
<i>Cepheus corae</i> Jacot	0.03 (0.00)	0	0	0
<i>Cepheus latus</i> C.L. Koch	0.01 (0.01)	0	0	0
Family Eremaeidae				
<i>Eremaeus translamellatus</i> Hammer	0.01 (0.01)	0.01 (0.01)	0	0.01 (0.01)
<i>Eueremaes marshalli</i> Behan-Pelletier	0	0.01 (0.01)	0	0
Family Astegistidae				
<i>Astegistes</i> sp.	0	0	0.01 (0.01)	0.01 (0.01)
Family Peloppiidae				
<i>Ceratoppia quadridentata</i> (arctica) Hammer	0.01 (0.00)	0	0.01 (0.01)	0.01 (0.01)
Family Tectocephidae				
<i>Tectocephus velatus</i> (Michael)	0.03 (0.03)	0.10 (0.00)	0.03 (0.02)	0.09 (0.06)
Family Oppiidae				
<i>Moritzoppia clavigera</i> (Hammer)	0.38 (0.13)	0.05 (0.05)	0.03 (0.02)	0
<i>Oppiella nova</i> (Oudemans)	7.20 (3.41)	1.77 (1.60)	2.03 (0.54) ^a	0.35 (0.11) ^b
Family Quadropiidae				
<i>Quadropia quadricarinata</i> (Michael)	0.11 (0.03)	0.09 (0.07)	0.32 (0.01)	0.20 (0.04)
Family Suctobelbidae				
<i>Suctobelba</i> sp.	0	0.02 (0.02)	0	0.01 (0.01)
<i>Suctobelbella</i> nr. <i>acutidens</i> (Forsslund)	0.80 (0.25)	0.74 (0.58)	0.26 (0.17)	0.24 (0.02)
<i>Suctobelbella</i> sp. 1	1.61 (0.14)	0.90 (0.77)	0.63 (0.07) ^a	0.30 (0.02) ^b
<i>Suctobelbella</i> sp. 2	0.16 (0.04)	0.15 (0.13)	0.36 (0.01)	1.25 (0.31)
Family Protoribatidae				
<i>Liebstadia</i> nr. <i>similis</i> (Michael)	0	0.01 (0.01)	0	0
Family Ceratozetidae				
<i>Ceratozetes gracilis</i> (Michael)	0.37 (0.12)	0.06 (0.06)	0.03 (0.02)	0

Table 2 (concluded).

	Conifer (no. individuals per gram dry mass)		Deciduous (no. individuals per gram dry mass)	
	Uncut	Clearcut	Uncut	Clearcut
Family Mycobatidae				
<i>Mycobates conitus</i> Hammer	0.15 (0.15)	0.01 (0.01)	0	0
<i>Mycobates incurvatus</i> Hammer	0.03 (0.00)	0.01 (0.00)	0.05 (0.00)	0.06 (0.04)
Family Galumnidae				
<i>Pilagalumna</i> sp.	0	0.03 (0.03)	0.01 (0.01)	0.01 (0.01)
Average total adult oribatids	13.93 (5.49)	5.64 (4.85)	3.86 (0.67)	2.66 (0.51)

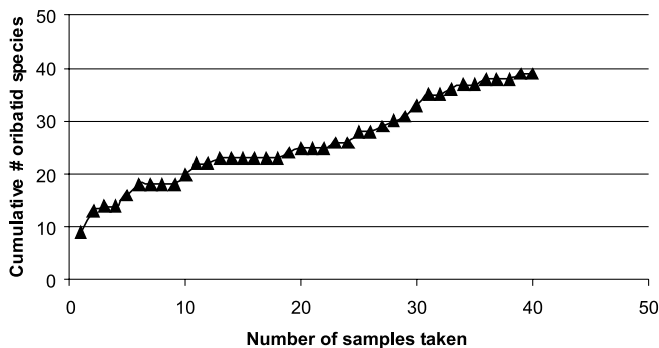
Note: Values are means, with SE given in parentheses. Within each row, within each stand type, values followed by different letters are significantly different, based on two-sample Student's *t* test ($p < 0.05$).

Table 3. Species diversity indices calculated for forest floor oribatid communities in uncut and clear-cut treatments of conifer and deciduous stands.

Indices	Conifer ($n = 2$)		Deciduous ($n = 2$)	
	Uncut	Clearcut	Uncut	Clearcut
Species richness	22.5 (2.5)	20.5 (6.5)	13.5 (0.5)	14.0 (2.0)
Shannon–Wiener	1.74 (0.03)b	2.13 (0.04)a	1.53 (0.04)	1.75 (0.09)
Inverse Simpson's	3.39 (0.35)	6.27 (0.70)	3.10 (0.31)	3.76 (0.31)
Inverse Berger–Parker	2.03 (0.20)	3.86 (0.75)	1.95 (0.19)	2.15 (0.13)

Note: Values are means, with SE given in parentheses. Within each row, within each stand type, values followed by different letters are significantly different, based on two-sample Student's *t* test ($p < 0.05$).

Fig. 3. Cumulative number of forest floor oribatid species collected with increasing number of samples taken from uncut and clear-cut treatment sites in conifer and deciduous stands at the Ecosystem Management Emulating Natural Disturbance research area.



ter, litter input, microbial biomass (Huhta et al. 1967; Bird and Chatarpaul 1986; Marra and Edmonds 1998), and soil pore space (Vlug and Borden 1973; Battigelli 2000) and to changes in microclimate (Abbott et al. 1980; Seastedt and Crossley 1981; Marra and Edmonds 1998) that occur following harvesting disturbance. In the present study, the slight reduction in forest floor microarthropods and the alteration of microarthropod community structure are probably a result of some, or all, of these factors. Total Acari and total Collembola abundances have correlated positively with microbial and fine-root biomass in both stand types (Lindo and Visser 2003), supporting the idea that microarthropod densities are related to food availability and that any alterations in these food sources will have repercussions on the microarthropod communities.

Lower abundances of microarthropods following harvesting in the corridors may be related to compaction of the forest floor. Compaction associated with the harvesting process can significantly increase soil bulk density and reduce the soil pore space that is inhabited by microarthropods (Startsev et al. 1998). Battigelli (2000) found that heavy compaction (4 cm) of the forest floor associated with stem-only and whole-tree harvesting significantly reduced total microarthropod density by 50% or more in comparison with uncut forests in sites in British Columbia. Compaction was apparent in the corridors and clear-cut treatments in this study, where a decrease in forest floor depth and an increase in soil bulk density were observed, and Pearson's correlation coefficients showed a significant negative relationship between microarthropod abundance and soil bulk density (Lindo and Visser 2003).

Clearcuts within the deciduous stands demonstrated extensive regeneration of aspen suckers 2.5 years following clear-cutting; these suckers were approximately 4 ft high at the time of sampling. Aspen regeneration was not observed in the deciduous partial-cut patch or corridors, and conifer clearcuts and corridors also remained without any intact overstory vegetation during this time. This aspen regeneration in deciduous clearcuts may have mitigated any reductions in microarthropod numbers occurring immediately following clear-cutting in this stand type. The rapid reestablishment of overstory vegetation in the deciduous clearcuts may have also mitigated the compaction of these sites and stabilized the forest floor microclimate and litter inputs more quickly.

Overall trends in microarthropod abundance were reflected in the cluster analyses. A cluster analysis clearly showed that harvesting disturbance in the corridors and clearcuts of the conifer stands caused similar reductions in

microarthropod densities at the suborder level, whereas densities in the retention patches were less altered and not significantly different from those in the conifer control. The cluster analysis pattern was different in the deciduous stands, where microarthropod suborder densities were most reduced in the corridors. Microarthropod suborder densities in the deciduous patch and clear-cut treatments also showed decreases, but these decreases in abundance were not significant, compared with the uncut control treatment.

Decreased relative abundance of prostigmatid and oribatid mites, combined with increased relative abundance of mesostigmatid mites and arthropleonid Collembola in corridor and clear-cut treatments, shows that community composition was different in harvested sites. Physical disturbance of the forest floor, in the form of compaction or mixing of organic and mineral soils during harvesting, may have increased mesostigmatid and decreased prostigmatids relative abundances. Many prostigmatid mites inhabit the upper organic horizon of the soil profile (Kethley 1990), whereas a substantial proportion of mesostigmatid mites occur in mineral soils beneath the litter-humus layers (Krantz and Ainscough 1990). Changes in relative abundances among suborders of microarthropods also have been attributed to life history traits of the different groups. Oribatid mites are considered *k*-selected organisms — with low fecundity, slow metabolism, and slow generation turnover rates — and thus are expected to show impacts of disturbance for longer periods (Norton 1990). Collembolans, in contrast, are considered *r*-selected organisms — with high fecundity, rapid development, and fast generation turnover rates, which allow Collembola populations to recover quickly from disturbance (Marshall 2000). Increases in the relative abundance of arthropleonid Collembola corroborate results found in other studies (Bird and Chatarpaul 1986; Blair and Crossley 1988).

Oribatid mites have long been identified as the microarthropod group most sensitive to forest harvest (Seastedt and Crossley 1981; Bird and Chatarpaul 1986). This is supported by the present study: oribatid mites were the only suborder to show significantly lower densities in a harvested treatment (deciduous corridors). Most oribatids are fungivorous and (or) detritivorous. Corridor and clear-cut treatments reduced microbial biomass, fine-root biomass, and annual litter input in both stand types (Lindo and Visser 2003), thereby decreasing resource availability and contributing to a decline in forest floor oribatids.

Disturbance did not increase the abundance of thelytokous parthenogenic oribatids in this study. *Trhypochthonius tectorum* and *Suctobelbella* sp. 2, both suspected to be parthenogenic species, increased slightly in abundance, but other species known to be parthenogenic, such as *O. nova*, did not, and actually showed significantly lower abundance in clearcuts.

Diversity indices of oribatid mites were higher in clearcuts of both stand types than in the uncut sites. This contradicts Marra and Edmonds (1998), who found that oribatid mites in undisturbed sites had higher species richness and diversity than they did in clearcuts. Diversity indices are a measure of community structure, being based on the number and relative abundance of species within the community. The increase in diversity indices in clearcuts in this study is

likely related to the relative abundance of the most dominant species (*O. nova*). The reduction of *O. nova* in clearcuts was proportionally greater than that of any other oribatid mite species, thus leading to greater evenness of species within the oribatid community and a reduction in the dominance of any particular oribatid species in clearcuts.

Changes in the oribatid mite community following partial and clear-cut forest harvest were more quantitative (absolute abundance) than qualitative (diversity, community composition). Oribatid mites may be useful as biological indicators of disturbance, as they are sensitive to changes in their environment and show measurable decreases in abundance when their habitat is disturbed; however, support for their use as biological indicators is limited because of a lack of changes in community composition.

Conclusion

Most forest floor microarthropod suborder densities were lower in corridors of deciduous sites; however, only oribatid mite populations showed significantly lower absolute abundances in the strip-cut corridors of the deciduous stands. A reduction in forest floor microarthropods following harvesting is likely due to a combination of factors, including a decrease in food availability (organic matter, microbial biomass) and compaction. Changes in microarthropod community composition, seen in the decreased relative abundance of prostigmatid mites and the increased relative abundance of mesostigmatid mites in corridor and clear-cut treatments, may be due to physical disturbance to the forest floor in the form of compaction or mixing of organic and mineral soils during harvesting. Selected oribatid mite species showed significantly lower abundances in clearcuts than in uncut sites, but diversity indices of oribatid mite species were generally not significantly different between uncut sites and clearcuts. Oribatid mites may be useful as biological indicators in terms of absolute abundances of species; however, this study showed no support for shifts in species composition.

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References

- Abbott, D.T., Seastedt, T.R., and Crossley, D.A., Jr. 1980. Abundance, distribution and effects of clearcutting on Cryptostigmata in the southern Appalachians. *Environ. Entomol.* **9**: 618–623.

- Balogh, J., and Balogh, P. 1992. The oribatid mites genera of the world (2 vols.). Hungarian National Museum Press, Budapest, Hungary.
- Balogh, J., and Mahunka, S. 1983. The soil mites of the world. Vol. 1. Primitive oribatids of the Palaearctic region. Elsevier, New York.
- Barg, A.K., and Edmonds, R.L. 1999. Influence of partial cutting on site microclimate, soil nitrogen dynamics, and microbial biomass in Douglas-fir stands in western Washington. *Can. J. For. Res.* **29**: 705–713.
- Battigelli, J.P. 2000. Impacts of soil compaction and organic matter removal on soil fauna in the sub-boreal spruce zone of central British Columbia. Ph.D. thesis, University of Alberta, Edmonton, Alta.
- Behan-Pelletier, V.M. 1999. Oribatid mite biodiversity in agroecosystems: role for bioindication. *Agric. Ecosyst. Environ.* **74**: 411–423.
- Bird, G.A., and Chatarpaul, L. 1986. Effect of whole-tree and conventional forest harvest on soil microarthropods. *Can. J. Zool.* **64**: 1986–1993.
- Blair, J.M., and Crossley, D.A., Jr. 1988. Litter decomposition, nitrogen dynamics and litter microarthropods in a southern Appalachian hardwood forest 8 years following clearcutting. *J. Appl. Ecol.* **25**: 683–698.
- Dahlgren, R.A., and Driscoll, C.T. 1994. The effects of whole-tree clear-cutting on soil processes at the Hubbard Brook Experimental Forest, New Hampshire, USA. *Plant Soil.* **158**: 239–262.
- Environment Canada. 2003. Canadian climate normals, Eureka River, Alberta. Environment Canada, Ottawa, ON. Available from http://www.climate.weatheroffice.ec.gc.ca/climate_normals/index_e.html [cited 24 September 2003].
- Gilyarov, M.S., and Krivolutskii, D.A. 1975. A key to the soil-inhabiting mites. Sarcopiformes. USSR Academy of Sciences, A.N. Servertsov Institute of Evolutionary Morphology and Ecology of Animals, Zoological Institute, Moscow.
- Hoekstra, J.M., Bell, R.T., Launer, A.E., and Murphy, D.D. 1995. Soil arthropod abundance in coast redwood forest: effect of selective timber harvest. *Environ. Entomol.* **24**: 246–252.
- Huhta, V. 1976. Effects of clear-cutting on numbers, biomass and community respiration of soil invertebrates. *Ann. Zool. Fenn.* **13**: 63–80.
- Huhta, V., Karppinen, E., Nurminen, M., and Valpas, A. 1967. Effect of silvicultural practices upon arthropod, annelid and nematode populations in coniferous forest soil. *Ann. Zool. Fenn.* **4**: 87–143.
- Kethley, J. 1990. Acarina: Prostigmata (Actinedida). *In* Soil biology guide. *Edited by* D.L. Dindal. John Wiley & Sons, Inc., Toronto, Ont. pp. 667–756.
- Krantz, G.W., and Ainscough, B.D. 1990. Acarina: Mesostigmata (Gamasida). *In* Soil biology guide. *Edited by* D.L. Dindal. John Wiley & Sons, Inc., Toronto, Ont. pp. 583–665.
- Krebs, C.J. 1989. Ecological methodology. Harper & Row Publishers, New York.
- Lindo, Z., and Visser, S. 2003. Microbial biomass, nitrogen and phosphorus mineralization and mesofauna in boreal conifer and deciduous forest floors following partial and clear-cut harvest. *Can. J. For. Res.* **33**: 1610–1620.
- Macfadyen, A. 1961. Improved funnel-type extractors for soil arthropods. *J. Anim. Ecol.* **30**: 171–184.
- Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, N.J.
- Marra, J.L., and Edmonds, R.L. 1998. Effects of coarse woody debris and soil depth on the density and diversity of soil invertebrates on clearcut and forested sites on the Olympic Peninsula, Washington. *Environ. Entomol.* **27**: 1111–1124.
- Marshall, V.G. 2000. Impacts of forest harvesting on biological processes in northern forest soils. *For. Ecol. Manage.* **133**: 43–60.
- Norton, R.A. 1985. Aspects of the biology and systematics of soil arachnids, particularly saprophagous and mycophagous mites. *Quaest. Entomol.* **21**: 523–541.
- Norton, R.A. 1990. Acarina: Oribatida. *In* Soil biology guide. *Edited by* D.L. Dindal. John Wiley & Sons, Inc., Toronto, Ont. pp. 779–803.
- Seastedt, T.R. 1984. The role of microarthropods in decomposition and mineralization processes. *Annu. Rev. Entomol.* **29**: 25–46.
- Seastedt, T.R., and Crossley, D.A., Jr. 1981. Microarthropod response following cable logging and clear-cutting in the southern Appalachians. *Ecology* **62**: 126–135.
- Sidders, D., and Spence, J.R. 2001. EMEND: Ecosystem Management Emulating Natural Disturbance. Research study and field guide. Canadian Forest Service, Northern Forestry Centre, Edmonton, Alta. Available from <http://www.biology.ualberta.ca/emend/> [cited 24 September 2003].
- Siira-Pietikäinen, A., Pietikäinen, J., Fritze, H., and Haimi, J. 2001. Short-term responses of soil decomposer communities to forest management: clear felling versus alternative forest harvesting methods. *Can. J. For. Res.* **31**: 88–99.
- Startsev, N.A., McNabb, D.H., and Startsev, A.D. 1998. Soil biological activity in recent clearcuts in west-central Alberta. *Can. J. Soil Sci.* **78**: 69–76.
- SYSTAT Inc. 1997. SYSTAT for Windows: statistics. Version 7.0 ed. [computer program]. SYSTAT Inc., Chicago, Ill.
- Visser, S. 1985. Role of the soil invertebrates in determining the composition of soil microbial communities. *In* Ecological interactions in soil: plants, microbes and animals. *Edited by* A.H. Fitter, D. Atkinson, D.J. Read, and M.B. Usher. Blackwell Scientific, Oxford, UK. pp. 297–317.
- Vlug, H., and Borden, J.H. 1973. Soil Acari and Collembola populations affected by logging and slash burning in a coastal British Columbia coniferous forest. *Environ. Entomol.* **2**: 1016–1023.
- Wallwork, J.A. 1983. Oribatids in forest ecosystems. *Annu. Rev. Entomol.* **28**: 109–130.