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20

Preliminary Assessment of Selected Communities of Soil Organisms under Different Conifer Species

S.M. Berch, B. Baumbrough, J. Battigelli, P. Kroeger, N. Strub, and L. de Montigny

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ABSTRACT

This study used the second-growth plantations of Douglas-fir, western hemlock, Sitka spruce, and western redcedar of the Ministry of Forests Experimental Project 571 (species-espacement trial established in 1965–1966 on southern Vancouver Island) to take a preliminary look at the effects of different conifer species on collembolan, oribatid mite, and macrofungal species. For all three groups of soil organisms, overall frequency or abundance and diversity were noticeably less under western redcedar compared with the other conifer species. Using similarity indices, we found that the macrofungus communities (species and abundance) differed under the various conifers. The community of forest floor oribatid mites under Douglas-fir was distinct, but we could not detect differences between the other conifer species. We could not detect differences in forest floor collembolan communities between any of the conifers.

FIGURES

INTRODUCTION

British Columbia Ministry of Forests Experimental Project (EP) 571 provided an excellent opportunity to explore the effects of forest cover on the diversity of macrofungi and soil fauna. EP 571 is a species-espacement trial established at seven sites across southern Vancouver Island using pure plantations of four different conifer species: Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), Sitka spruce (*Picea sitchensis* [Bong.] Carr.), and western redcedar (*Thuja plicata* Donn ex D. Don in Lamb.) (Omule and Krumlik 1987). Conifer species differ in many ways, including foliage quality at litterfall, types and quantities of allelochemicals produced, form and pattern of root development in the soil profile, and the symbiotic fungi with which they are associated (Binkley 1995). By influencing the diversity and abundance of the soil biota, these qualities may, in turn, affect the essential processes of nutrient cycling. However, beyond the recognition that certain macrofungi are associated with certain trees, relatively little is known about the relationships between tree species and soil biota. This information gap may be partly due to the study of soil organisms being time-consuming and requiring specialized equipment and advanced training. Consequently, our current knowledge of soil faunal and fungal biodiversity is limited (Behan-Pelletier and Bissett 1992; Marshall 1993; Redhead 1997).

Springtails (Collembola) and mites (Acari) dominate the soil micro-arthropod fauna, and their grazing activities significantly affect the rate and process of decomposition (Parkinson et al. 1979; Faber and Verhoeff 1991). While the collembola are relatively well known taxonomically, with an estimated 80% of North American species described (Behan-Pelletier and Bissett 1992) and a comprehensive taxonomic key available (Christiansen and Bellinger 1980), the mites are far less known. Behan-Pelletier (1993) estimates that only 10% of the oribatid mite fauna of Canada have been described. Morphological information and data on feeding habits are available for less than 10% of known oribatid mite species, and only minimal ecological information (mainly habitat of original collection)

is available for approximately 70% of known species (Behan-Pelletier and Bissett 1992). The factors determining the diversity, distribution, and abundance of collembola and mites remain unclear (Wood 1966, 1967; Addison 1980). It may be that a combination of several factors, such as vegetative cover, soil type, moisture, temperature, nutrient status, and others, determine the faunal abundance and diversity of any particular habitat. The relative importance of each of these parameters may vary from species to species.

Fungi are another key component of the soil biological community. Fungi influence soil development by: primary weathering and the establishment of soil aggregates held together by fungal mycelia, altering the ionic exchange and water-holding capacity of a soil, and producing humic substances. Decomposer fungi may release or immobilize nutrient elements during the breakdown of wood and dead organic matter. Ectomycorrhizal fungi profoundly affect forest ecosystems by mediating nutrient and water uptake of plants, protecting roots from pathogens and environmental extremes, maintaining soil structure and forest food webs, and perhaps regulating decomposition. In addition, the recreational and commercial harvesting of fungal fruiting bodies, inspired by their edibility and production of metabolites, is increasing (de Geus 1995).

As with the soil invertebrate community, the diversity of the macrofungi, their role in forest ecosystem function, and the factors affecting their diversity and distribution are often overlooked. Redhead (1997) estimates that only 25–30% of British Columbia's macrofungi have been reported. Though ectomycorrhizal fungus diversity has been reported as 13–35 species in small stands of various conifer monocultures (Bruns 1995), little direct experimental evidence from the field indicates the role of host specificity in the biodiversity of macrofungi.

This study used the approximately 30-year-old plantations of Douglas-fir, western hemlock, Sitka spruce, and western redcedar of EP 571 to take a preliminary look at the effects of single-species conifer stands on collembolan, oribatid mite, and macrofungal species diversity and abundance or frequency.

METHODS

STUDY SITE

Sampling was conducted on the west coast of Vancouver Island, British Columbia, at the Upper Klanawa Mainline site of the Ministry of Forests Experimental Project (EP) 571 near Franklin River. The study site (Table 1) is located in the Submontane Very Wet Maritime Coastal Western Hemlock (CWHvm1) variant on the windward side of the Vancouver Island Mountains (Klinka et al. 1994). Typically cool summers and mild winters characterize this Coastal Western Hemlock variant. Mean annual temperature is about 8.2°C and mean annual precipitation is 2787 mm (Meidinger and Pojar 1991).

The study area initially supported old-growth stands of western hemlock, western redcedar, amabilis fir, and occasional

TABLE 1 *Description of study site, Upper Klanawa installation of EP 571*

Location	48°49′N, 124°47′W
Elevation (m)	75–85
Aspect	-
Slope position	valley bottom
Slope gradient (%)	-
Site association[a]	05 (moist to very moist and rich to very rich)
Soil classification	Duric Humo-Ferric–Ferro-Humic Podzol
Dominant humus form[b]	Leptomoder
Understorey shrub composition (percentage cover)[c]	*Rubus spectabilis* Pursh (18) *Polystichum munitum* (Kaulf.) K.B. Presl (4) *Tiarella trifoliata* L. (4) *Gaultheria shallon* Pursh (3)
Understorey total percentage cover[d]	Western redcedar 91 Western hemlock 68 Douglas-fir 31 Sitka spruce 13

a Site association determined by Klinka et al. (1996).
b Nomenclature according to Douglas et al. (1991).
c Herbs and shrubs covering more than 2% (Klinka et al. 1996).
d Klinka et al. (1996).

Douglas-fir and Sitka spruce (Omule and Krumlik 1987). The site was logged by 1960, slashburned in 1961, and planted in 1962 with 81 trees per plot. Randomly located, pure plots of western hemlock, western redcedar, Sitka spruce, and Douglas-fir were planted at three different planting densities with two plots per conifer species and planting density. We focused on the two denser plantings for the work on soil biota.

DETERMINATION OF MACROFUNGUS DIVERSITY

In four plots each of western redcedar, Douglas-fir, and Sitka spruce, the centre 10 × 10 m of each plot was divided into 16 contiguous subplots each measuring 2.5 × 2.5 m. To minimize edge effects such as in-growth of foreign roots or deposit of foreign litter, we left at least 5 m to the plot edge all around. Due to time limitations, macrofungi were not studied in the western hemlock stands. Five sampling trips were carried out from October through December 1995. At each sampling time, presence of all macrofungus species was recorded for each subplot. Voucher specimens of all species were preserved. Mushrooms were identified based on Phillips (1991), Arora (1986), and Breitenbach and Kränzlin (1984, 1986, 1991, 1995). The macrofungi were categorized by substrate or role in the forest: litter decomposers, wood decomposers, ectomycorrhizal, etc. Data were recorded as presence or absence of fruiting body by macrofungus species by subplot, plot, species, and time. From these data, total number of species per plot and per conifer species were determined, and percentage frequency of subplots containing each macrofungus by conifer species over the entire sampling period was calculated.

DETERMINATION OF SOIL FAUNA DIVERSITY

In November 1993, three randomly located (although we avoided plot edges, decaying wood, and shrubs) 4.4-cm diameter cores were removed from three plots of each of the four conifer species. Mesofauna were extracted from the top 3 cm (usually pure forest floor with occasionally a small amount of upper mineral soil) of each soil core using a high-gradient extractor (Lussenhop 1971). Following extraction, soil fauna were stored in 75% alcohol. Collembolan and oribatid mite species were sorted and counted.

Collembola were prepared for species identification by first boiling the specimens in 95% ethanol for approximately 5 minutes to destroy the fat bodies. Specimens were then cleared by immersion in lactic acid and mounted on microscopic slides using PVLG as a permanent-mounting medium. Slides were cured at 40°C for 12 hours or until mountant was dry. Keys used for identification included Christiansen and Bellinger (1980) and Fjellberg (1985). Representatives from each species were permanently mounted.

Adult oribatid mite specimens were cleared in lactic acid (85%) for 1 month at room temperature before species determination. Species were identified by temporarily mounting specimens in lactic acid in a cavity slide and examining each specimen under a compound microscope. Keys used for identification included Walker (1965), Woolley (1968), Balogh and Mahunka (1983), Marshall et al. (1987), Norton (1990), and Balogh and Balogh (1992). Representatives of each species were permanently mounted while species represented by a single specimen were stored separately in labelled ¼-dram vials of 75% ethanol.

FOREST FLOOR PROPERTIES

In October 1995, soils were sampled from each of the study plots. Forest floor and mineral soil were collected from three random locations in each plot (avoiding edges) and kept cool until returned to the lab. Samples were air-dried, picked free of coarse branches, roots, and stones, sieved through a 2 mm mesh, and ground. Forest floor and mineral soil chemicals were analyzed by the Ministry of Forests Analytical Lab. Only data on the forest floor are reported here since we studied only forest floor micro-arthropods.

DATA ANALYSES

Renkonen's Similarity Index and Morisita's Simplified Similarity Index (Morisita 1959; Wolda 1981; Krebs 1989) were used to assess the similarity of collembolan, oribatid mite, and macrofungus communities among the different conifer stands. The conifer stands most similar to each other were then grouped using average linkage clustering (SAS Institute Inc. 1989–1996).

Forest floor chemistry data were analyzed using a completely randomized one-way ANOVA (SAS Institute Inc. 1989–1996).

RESULTS

The relatively small amount of sampling limits this study since macrofungus fruiting and soil micro-arthropod communities vary both in the short term and from year to year. However, because the conifer species plots were replicated at the study site and the results were similar in the replicates, we are confident that the results indicate real differences between the conifer species.

MACROFUNGI

Although taxonomic challenges made it difficult to name all macrofungi found, 62 species or species groups were identified from the Sitka spruce, Douglas-fir, and western redcedar plots. A few other species were found; however, because they were infrequent and not found exclusively under any one of the conifers, they have been excluded from this analysis. A more detailed, multi-year and multi-site study of the macrofungi of EP 571 is in progress and will consider all species encountered. The results reported here focus on the most abundant species in the macrofungal community.

The western redcedar plots supported the fewest species of macrofungi, with only 28 recorded for all redcedar plots (Table 2). A total of 37 and 40 species were recorded under Sitka spruce and Douglas-fir, respectively. Western redcedar also had the lowest percentage frequency of macrofungi, while Sitka spruce and Douglas-fir were both much higher.

TABLE 2 *Relative frequency and diversity of most common macrofungi under second-growth conifer plantations on southern Vancouver Island, Upper Klanawa Installation of EP 571*

Conifer species	Relative frequency (%)	Diversity (no. of species)
Sitka spruce	90.75	37
Douglas-fir	95.25	40
Western redcedar	30.75	28

Therefore, not only were fewer species of macrofungi found under redcedar, but also fewer fruiting bodies.

Most species identified (Table 3) belong to one of four functional groups: ectomycorrhizal, needle decomposer, wood decomposer fungi, and general decomposer (i.e., not specific to wood or conifer needles). A few parasites and pathogens were found (e.g., *Cordyceps militaris* on insects). The wood decomposers were the most abundant fungi found under all three conifer species.

TABLE 3 *Macrofungus species under second-growth plantations of Sitka spruce (Ss), Douglas-fir (Fd), and western redcedar (Cw), on southern Vancouver Island, Upper Klanawa Installation of EP 571*

Macrofungus functional group and species	Conifer species		
	Ss	Fd	Cw
Ectomycorrhizal fungi			
Boletus piperatus Bull. ex Fr.	*	-	-
Cantharellus formosus Corner	*	*	-
Clavulina cristata (Fr.) Schroet.	-	***	*
Cortinarius cinnamomeus (Fr.) Fr.	-	*	-
Lactarius cf. *luculentus* var. *laetus* Smith & Hesler	**	***	*
Lactarius obscuratus (Lasch.) Fr.	-	*	-
Lactarius scrobiculatus (Fr.) Fr.	-	*	-
Russula fragilis (Pers. ex Fr.) Fr.	-	*	-
Tricholoma vaccinum (Pers. ex Fr.) Kummer	*	-	-
Litter decomposer fungi			
Heyderia abietis (Fr.) Link	*	-	-
Mycena aurantiidisca Murr.	***	*	*
Mycena pura (Pers. ex Fr.) Kummer	*	*	-
Mycena rorida (Fr.) Quél.	*	*	*
Mycena rosella (Fr.) Kummer	**	*	-
Mycena sanguinolenta (A. & S. ex Fr.) Kummer	*	-	-
Mycena tenax Smith	***	*	-
Wood decomposer fungi			
Bondarzewia montana (Quél.) Singer	*	-	-
Flammulaster granulosa (Lge) Watl.	-	-	*
Fomitopsis pinicola (Schwartz ex Fr.) Karsten	*	-	-
Galerina cf. *mammilata*	*	**	*
Galerina stylifera (Atk.) Smith & Singer	*	*	**
Ganoderma tsugae Murr.	*	*	-
Gymnopilus flavidellus Murr.	*	*	-
Gymnopilus picreus (Fr.) Karst.	*	*	*

table 3 *Continued*

Macrofungus functional group and species	Conifer species Ss	Fd	Cw
Hypholoma capnoides (Fr. ex Fr.) Kummer	-	-	*
Hypholoma dispersum (Fr.) Quél.	-	-	*
Hypholoma fasciculare (Huds. ex Fr.) Kummer	-	*	*
Laetiporus sulphureus (Fr.) Murr.	*	-	-
Mycena haematopus (Pers. ex Fr.) Kummer	*	*	*
Mycena cf. *rugulosiceps* (Kauff.) Smith	-	*	-
Panellus mitis (Pers. ex Fr.) Singer	-	*	-
Pholiota flavida (Fr.) Singer	*	-	*
Pholiota malicola (Kauffman) Smith	*	*	*
Pleurocybella porrigens (Pers. ex Fr.) Singer	-	-	*
Pluteus cervinus (Fr.) Kummer	*	*	-
Polyporus elegans Fr.	*	*	*
Pseudohydnum gelatinosum (Scop. ex Fr.) Karsten	*	*	-
Xeromphalina campanella (Bat. ex Fr.) Kühner & Maire		*	*
General decomposer fungi			
Baeospora myosurus (Fr. ex Fr.) Singer	*	*	-
Calocera viscosa (Fr.) Fr.	*	*	-
Clavaria vermicularis Micheli ex Fr.	*	-	-
Clavulina ornatipes Peck	*	*	-
Collybia dryophila (Bull. ex Fr.) Kummer	-	*	-
Cystoderma granulosum (Fr.) Fayod	*	-	-
Guepiniopsis alpina (Tracy & Earle) Bres.	-	*	-
Marasmius candidus (Bolt.) Fr.	-	-	*
Melanotus textilis Redhead & Kroeger	-	-	*
Mycena alcalina (Fr.) Kummer	*	*	**
Mycena amabilissima (Pk.) Singer	-	*	-
Mycena amicta (Fr.) Quél.	*	*	*
Mycena epipterygia (Fr.) S.F. Gray	*	*	*
Mycena cf. *galericulata* (Scop. ex Fr.) S.F. Gray	-	*	-
Mycena galopus (Pers. ex Fr.) Kummer	**	*	-
Nidula candida (Pk.) White	-	-	*
Panellus longinquus Libonetti-Barnes & Redhead	*	*	**
Pholiota scamba (Fr.) Moser	*	**	*
Other fungi			
Cordyceps militaris (L. ex St. Amans) Link	*	-	-
Galerina cf. *hypnorum* (Schrank ex Fr.) Kuehn.	-	-	*
Omphalina ericetorum (Fr.) Lange	-	*	*
Tremella deliquescens (Mérat) Duby	-	-	*

- = absent, * = uncommon, ** = common, *** = abundant.

The Renkonen Index measures the percentage similarity between two samples and ranges from 0 (no similarity) to 100 (complete similarity). Values calculated for macrofungi data ranged from 4 to 76 (Table 4). The macrofungus community under plots of the same conifer species supported a similar (high index value) macrofungus community; conversely, plots under different conifer species were consistently dissimilar (low index values). The macrofungus community under western redcedar was less distinct than those under Douglas-fir and Sitka spruce. Average linkage cluster analysis of these data illustrates this finding (Figure 1). The Simplified Morisita's Index ranges from 0 (no similarity) to 1 (complete similarity). The indices calculated using values of relative abundance of fungi ranged from as low as 0.02 to as high as 1.00. Average linkage cluster analysis resulted in a similar pattern as that generated using the Renkonen Indices of Similarity.

ORIBATID MITES

The Sitka spruce stands supported the greatest average number of species (10) and the highest average density of mites (approximately 21 000 individuals/m^2). Western hemlock

TABLE 4 *Renkonen Similarity Indices (0 = no similarity, 100 = complete similarity) for mushroom communities under second-growth conifer plantations on southern Vancouver Island, Upper Klanawa Installation of EP 571 (Cw = western redcedar, Fd = Douglas-fir, Ss = Sitka spruce)*

	Cw A	Cw B	Cw C	Cw D	Fd A	Fd B	Fd C	Fd D	Ss A	Ss B	Ss C	Ss D
Cw A	100	-	-	-	-	-	-	-	-	-	-	-
Cw B	22	100	-	-	-	-	-	-	-	-	-	-
Cw C	27	27	100	-	-	-	-	-	-	-	-	-
Cw D	51	28	31	100	-	-	-	-	-	-	-	-
Fd A	14	27	19	12	100	-	-	-	-	-	-	-
Fd B	6	20	14	9	72	100	-	-	-	-	-	-
Fd C	10	30	21	13	60	54	100	-	-	-	-	-
Fd D	21	24	20	16	76	67	58	100	-	-	-	-
Ss A	17	15	10	8	13	11	13	14	100	-	-	-
Ss B	15	24	8	4	22	23	25	22	70	100	-	-
Ss C	23	15	7	7	16	12	17	19	70	69	100	-
Ss D	25	12	10	14	15	8	15	22	55	56	67	100

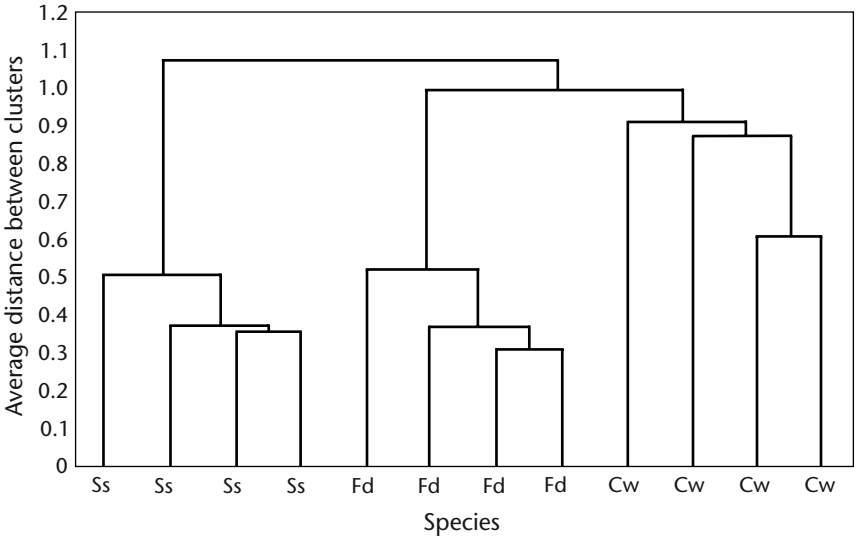

FIGURE 1 *Tree diagram resulting from average linkage cluster analysis showing similarity of mushroom communities under four stands each of Sitka spruce (Ss), Douglas-fir (Fd), and western redcedar (Cw).*

stands followed closely with nine species and about 20 000 individuals/m^2 (Table 5). The Douglas-fir and western redcedar plots supported a noticeably lower abundance (approximately 8 500 and 8 000 individuals/m^2, respectively) along with a lower average number of species (seven and six, respectively).

Twenty-nine species of oribatid mite were identified from the adults collected in this study (Table 6). Of these, 11 species are new records for British Columbia (Marshall et al. 1987; Behan-Pelletier 1993). *Liacarus bidentatus*, the most abundant

TABLE 5 *Comparison of forest floor micro-arthropod density (individuals/m^2) and diversity (number of species) under second-growth conifer plantations on southern Vancouver Island, Upper Klanawa Installation of EP 571*

	Collembola		Oribatid mites	
Conifer species	**Density**	**Diversity**	**Density**	**Diversity**
Sitka spruce	31 712	30	20 607	10
Western hemlock	20 240	29	19 651	9
Douglas-fir	30 031	31	8 412	7
Western redcedar	9 643	22	7 885	6

TABLE 6 *Forest floor oribatid mite species under second-growth plantations of western hemlock (Hw), Sitka spruce (Ss), Douglas-fir (Fd), and western redcedar (Cw) on southern Vancouver Island, Upper Klanawa Installation of EP 571*

Oribatid mite family and species	Conifer species			
	Hw	Ss	Fd	Cw
Achipteriidae				
Achipteria sp.	*	-	-	-
Dentachipteria sp.	-	*	-	-
Atopochthoniidae				
Atopochthonius artiodactylus Grandjean, 1948†	*	*	-	-
Camisiidae				
Platynothrus peltifer (C.L. Koch, 1839)†	-	*	-	-
Carabodidae				
Carabodes hoh Reeves and Behan-Pelletier 1998	-	*	-	-
Ceratozetidae				
Sphaerozetes sp.	-	*	-	*
Damaeidae				
Belbodamaeus sp.	*	-	-	-
Epilohmanniidae				
Epilohmannia sp. nr. *Spathulata*†	-	*	**	-
Eulohmanniidae				
Eulohmannia ribagai (Berlese, 1910)†	**	***	-	-
Euphthiracaridae				
Euphthiracus monyx Walker, 1965†	*	-	*	-
Rhysotritia scotti Walker, 1965†	-	*	-	-
Hypochthoniidae				
Hypochthonius sp.	*	-	-	-
Kodiakellidae				
Kodiakella lutea Hammer, 1967†	-	*	***	-
Liacaridae				
Dorycranosus sp.	*	-	-	-
Liacarus bidentatus Ewing, 1918	***	***	***	***
Liacarus detosus Woolley, 1968†	-	-	*	-
Rhaphidosus sp.	-	**	*	*
Nanhermanniidae				
Nanhermannia elegantula Berlese, 1913†	*	-	-	*
Nothridae				
Nothrus silvestris Nicolet, 1855†	***	-	-	**
Oppiidae				
Oppeilla nova (Oudemans, 1902)	**	**	***	*
Quadroppia sp.	-	-	-	*
Peloppiidae				
Ceratoppia sp.	-	**	-	-
Phenopelopidae				
Eupelops sp.	**	**	*	-
Phthiracaridae				
Phthiracarus (Archiphthiracarus) sp.	**	***	***	-

TABLE 6 *Continued*

Oribatid mite family and species	Conifer species			
	Hw	Ss	Fd	Cw
Scheloribatidae				
Scheloribates sp.	**	-	-	-
Suctobelbidae				
Suctobelbella sp.1	-	**	-	-
Suctobelbella sp.2	-	-	-	*
Synichotritiidae				
Synichotritia spinulosa Walker, 1965	*	*	*	**
Tectocepheidae				
Tectocepheus velatus (Micheal, 1880)†	**	***	**	**

- = absent, * = uncommon, ** = common, *** = abundant.
† = New record for British Columbia.

species recorded, occurred under all four forest covers. *Oppiella nova*, *Tectocephus velatus*, and *Synichotritia spinulosa* were also found under all four tree species but at lower abundance.

Renkonen Indices calculated for mite species data ranged from 5 to 64 (Table 7). The pattern of mite species distribution in conifer stands is much less clear than that of the macrofungi. Average linkage cluster analysis (Figure 2) illustrates that the three Douglas-fir plots sampled had similar fauna, but all

TABLE 7 *Renkonen Similarity Indices (0 = no similarity, 100 = complete similarity) for oribatid mite communities under second-growth conifer plantations on southern Vancouver Island, Upper Klanawa Installation of EP 571*

	Cw A	Cw B	Cw C	Ss A	Ss B	Ss C	Fd A	Fd B	Fd C	Hw A	Hw B	Hw C
Cw A	100	-	-	-	-	-	-	-	-	-	-	-
Cw B	42	100	-	-	-	-	-	-	-	-	-	-
Cw C	42	57	100	-	-	-	-	-	-	-	-	-
Ss A	43	61	44	100	-	-	-	-	-	-	-	-
Ss B	60	29	33	50	100	-	-	-	-	-	-	-
Ss C	14	14	14	36	37	100	-	-	-	-	-	-
Fd A	46	27	23	32	43	24	100	-	-	-	-	-
Fd B	45	22	22	44	56	25	60	100	-	-	-	-
Fd C	40	32	35	60	47	44	54	64	100	-	-	-
Hw A	14	21	27	14	14	10	14	14	14	100	-	-
Hw B	36	38	39	34	39	24	36	27	31	22	100	-
Hw C	45	12	7	20	36	11	31	28	16	5	17	100

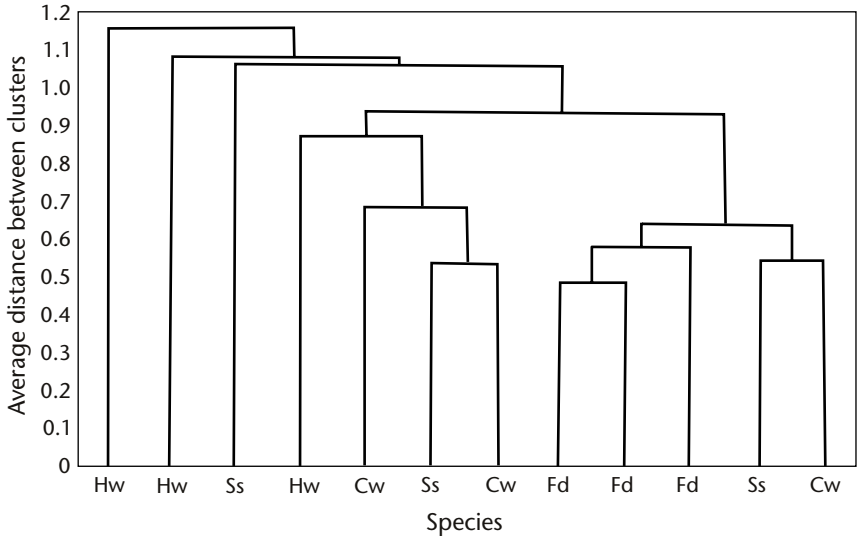

FIGURE 2 *Tree diagram resulting from average linkage cluster analysis showing similarity of oribatid mite communities under three stands each of western hemlock (Hw), Sitka spruce (Ss), Douglas-fir (Fd), and western redcedar (Cw).*

other conifer species showed little correlation between conifer species and mite community. Morisita's Indices for mite species data ranged from 0.03 to 0.91. Average linkage cluster analysis resulted in a similar pattern as that seen using the Renkonen Indices.

COLLEMBOLA

Sitka spruce had the greatest average abundance of collembola (about 32 000 individuals/m^2) and a high average number of species (30), while western redcedar had the lowest average number of individuals (approximately 10 000 individuals/m^2) and lowest average number of species (22) (Table 5). Douglas-fir had a density (30 000 individuals/m^2) and diversity (31) of collembolan species similar to the Sitka spruce stands, while western hemlock supported a moderate density of about 20 000 individuals/m^2 and an average of 29 species.

Forty-seven collembolan species were identified from the samples collected for this study (Table 8). Of these, *Anurophorus* (*Pseudanurophorus*) *binoculatus* is a new record for Canada (Battigelli and Marshall 1993; Setala and Marshall

TABLE 8 *Forest floor collembolan species under second-growth plantations of western hemlock (Hw), Sitka spruce (Ss), Douglas-fir (Fd), and western redcedar (Cw) on southern Vancouver Island, Upper Klanawa Installation of EP 571*

Collembola family and species	Conifer species			
	Hw	Ss	Fd	Cw
Entomobryidae				
Harlomillsia oculata (Mills, 1937)	**	*	**	-
Sinella nr. *sexoculata* (Schött, 1896)	-	*	*	-
Tomocerus (Pogonognathellus) ? dubius Christiansen, 1965	-	*	-	-
Tomocerus (Pogonognathellus) flavescens Tullberg, 1871	-	**	-	-
Tomocerus (Tomolonus) reductus (Mills, 1949)		**	**	*
Hypogastruridae				
Hypogastrura (Mitchellania) horrida Yosii, 1960	*	*	*	-
Hypogastrura (Mitchellania) krafti (Scott, 1962)	***	***	**	-
Hypogastrura (Mitchellania) virga Christiansen & Bellinger, 1980	**	***	**	**
Hypogastrura (Mitchellania) wallmoi Fjellberg, 1985	**	*	***	-
Hypogastrura (Mitchellania) sp.1	*	-	**	*
Hypogastrura (Mitchellania) sp.2	**	-	*	-
Microgastrura minutissima (Mills, 1934)	-	-	*	-
Neanura (Deutonura) frigida Yosii, 1969	*	-	-	-
Odontella (Odontella) biloba Christiansen and Bellinger, 1980	-	***	**	-
Paranura colorata Mills, 1934	*	**	*	***
Willemia denisi Mills, 1932	-	*	*	-
Isotomidae				
Anurophorus (Pseudanurophorus) binoculatus (Kseneman, 1934)	*	***	***	*
Folsomia macroseta Ford, 1962	**	*	**	*
Folsomia ozeana Yosii, 1954	*	-	-	*
Folsomia nr. *stella* Christiansen and Tucker, 1977	*	*	*	*
Isotoma (Desoria) ekmani Fjellberg, 1977	*	***	*	*
Isotoma (Desoria) notabilis Schäffer, 1896	**	***	***	***
Isotoma (Desoria) uniens Christiansen and Bellinger, 1980	**	***	**	***
Isotoma (Pseudisotoma) monochaeta Kos, 1942	-	-	*	*
Micrisotoma achromata Bellinger, 1952	*	*	***	**
Neelidae				
Neelus (Megalothorax) minimus (Willem, 1900)	***	***	***	***

TABLE 8 *Continued*

Collembola family and species	Conifer species			
	Hw	Ss	Fd	Cw
Onychiuridae				
Lophognathella choreutes Börner, 1908	*	-	*	*
Onychiurus (Onychiurus) flavescens Kinoshita, 1916	***	***	***	***
Onychiurus (Onychiurus) lusus Christiansen and Bellinger, 1980	*	-	-	-
Onychiurus (Onychiurus) nr. *reluctus* Christiansen, 1961	*	**	*	**
Onychiurus (Protaphorura) cocklei (Folsom, 1908)	-	*	*	-
Onychiurus (Protaphorura) sibiricus (Tullberg, 1876)	*	-	-	-
Onychiurus (Protaphorura) nr. *sibiricus* (Tullberg, 1876)	**	***	***	*
Onychiurus (Protaphorura) similis (Folsom, 1917)	*	*	**	*
Sensiphorura marshalli Rusek, 1976	**	***	***	***
Tullbergia (Tullbergia) vancouverica (Rusek, 1976)	-	-	-	*
Tullbergia (Tullbergia) yosii (Rusek, 1967)	*	***	*	-
Sminthuridae				
Arrhopalites amarus Christiansen 1966	-	*	-	-
Arrhopalites benitus (Folsom, 1896)	*	*	-	-
Dicyrtoma (Ptenothrix) maculosa (Schött, 1891)	**	*	*	-

- = absent, * = uncommon, ** = common, *** = abundant

1994; Rusek and Marshall 1995; Skidmore 1995). Of the collembolan species identified, 16 were common, being found under at least one of the plots of all four conifer species. *Onychiurus* (*Onychiurus*) nr *flavescens*, *Neelus* (*Megalothorax*) *minimus*, *Hypogastrura* (*Mitchellania*) *virga*?, *Isotoma* (*Desoria*) *notabilis*, and *Sensiphorura marshalli* were found in virtually all plots of all conifer species. These five species accounted for about 50% of the total abundance of collembola found under all four conifer species.

Renkonen Similarity Indices calculated using collembolan species data ranged from 27 to 70 (Table 9). Average linkage cluster analysis using these indices showed that no correlation existed between the collembolan community and conifer species (Figure 3). Similar results were obtained using

TABLE 9 *Renkonen Similarity Indices (0 = no similarity, 100 = complete similarity) for collembolan communities under second-growth conifer plantations on southern Vancouver Island, Upper Klanawa Installation of EP 571*

	Hw A	Hw B	Hw C	Ss A	Ss B	Ss C	Cw A	Cw B	Cw C	Fd A	Fd B	Fd C
Hw A	100	-	-	-	-	-	-	-	-	-	-	-
Hw B	31	100	-	-	-	-	-	-	-	-	-	-
Hw C	45	36	100	-	-	-	-	-	-	-	-	-
Ss A	36	50	38	100	-	-	-	-	-	-	-	-
Ss B	35	52	34	57	100	-	-	-	-	-	-	-
Ss C	47	43	40	57	65	100	-	-	-	-	-	-
Cw A	27	51	49	36	38	40	100	-	-	-	-	-
Cw B	37	50	45	52	49	53	46	100	-	-	-	-
Cw C	34	46	30	52	69	57	30	50	100	-	-	-
Fd A	37	45	33	48	60	49	38	55	49	100	-	-
Fd B	39	51	34	58	64	70	44	64	56	58	100	-
Fd C	61	41	56	47	41	45	39	46	35	40	46	100

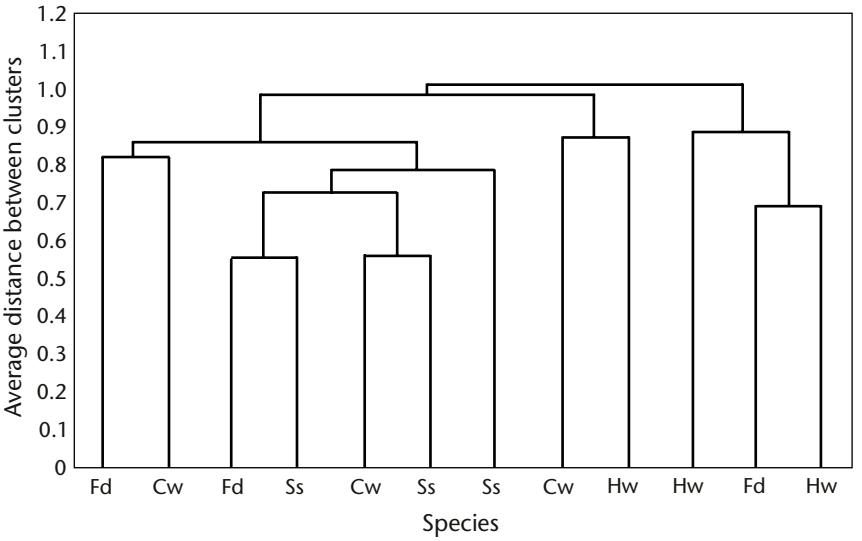

FIGURE 3 *Tree diagram resulting from average linkage cluster analysis showing similarity of collembolan communities under three stands each of western hemlock (Hw), Sitka spruce (Ss), Douglas-fir (Fd), and western redcedar (Cw).*

Morisita's Similarity Indices, though the indices of similarity ranged from 0.41 to 0.94.

forest floor properties

Only the concentration of forest floor K differed between conifer species (Table 10), being higher under Sitka spruce than under western redcedar and Douglas-fir.

DISCUSSION

Cluster analysis of the macrofungus data showed that the fungal communities found under the three different forest covers (Sitka spruce, western redcedar, and Douglas-fir) were distinct from each other. Generally, the macrofungus community in the four western redcedar plots clustered less tightly than those under Sitka spruce or Douglas-fir, indicating lower similarity of the macrofungal communities among the western redcedar stands than among the stands of the other two conifer species. The similarity of the Douglas-fir stands was largely based on two fungi, *Clavulina cristata* and *Lactarius* cf. *luculentus* var. *laetus*, that occurred frequently and consistently throughout the sampling period. The Sitka spruce stands all produced

table 10 *Forest floor chemistry data under second-growth conifer plantations on southern Vancouver Island, Upper Klanawa Installation of EP 571*

	Western redcedar		Douglas-fir		Sitka spruce	
	Mean	*s*[a]	Mean	*s*	Mean	*s*
pH/$CaCl_2$	4.16	0.13	4.44	0.18	4.12	0.36
Loss on ignition (%)	65	9	58	15	57	13
Total C (%)	39	6	35	10	35	8
Total N (%)	1.10	0.15	0.91	0.14	0.99	0.15
C/N	37	2	38	5	35	4
P (%)	0.087	0.008	0.088	0.017	0.093	0.003
K (%)	0.043	0.002	0.055	0.015	0.075	0.011
Ca (%)	0.65	0.03	0.60	0.16	0.57	0.17
Mg (%)	0.129	0.052	0.153	0.009	0.131	0.027
S (%)	0.107	0.018	0.092	0.017	0.095	0.018

a *s* = standard deviation.

troupes of needle decomposer *Mycena* species, which accounts for their similarity. In the western redcedar stands, no macrofungal species were consistent or frequent. Clearly, host specificity can be an important factor in determining macrofungal diversity and abundance, at least at this installation of EP 571 during the fall of 1995.

Host specificity can also be vitally important to recreational and commercial mushroom pickers; anyone seeking to harvest the ectomycorrhizal chanterelles should avoid pure western redcedar stands. The occasional presence of a few ectomycorrhizal fungal species under the western redcedar was unexpected, as this conifer forms vesicular-arbuscular mycorrhizae (Berch et al. 1991, 1992), but can be accounted for by the few volunteer ectomycorrhiza-forming western hemlock in the understorey. This example illustrates the value of mixed-species plantations for mycorrhizal fungus diversity—the presence of even a few young western hemlocks in a western redcedar stand was enough to make a few ectomycorrhizal fungi appear.

The lower frequency and fewer species of macrofungi under western redcedar than under Sitka spruce and Douglas-fir cannot be entirely explained by the fact that western redcedar does not develop ectomycorrhizae. Fewer needle decomposers and general decomposers were found under redcedar than under Sitka spruce or Douglas-fir. Wood decomposers were about as numerous and abundant under western redcedar as under the other two conifers. The wood being decomposed on these second-growth plots comes primarily from the pre-existing stand and has therefore not been directly affected by species differences among the planted conifers. This observation suggests that something about the leafy and twiggy substrates produced by western redcedar affects the fruiting of macrofungi.

Since plots of the three conifer species are intermixed at the same location, it is unlikely that differential inoculum availability would account for the patterns we observed. Microclimate and edaphic factors affect mushroom production and we cannot exclude the possibility that microclimate differences under the three conifer canopies varied enough to account for the disparity in mushroom production. However, the forest floors were similar among conifers at this rich and moist valley-bottom location. The patterns of mushroom

diversity and abundance that we observed under the three conifer species might also have resulted from different resource availability or quality. For instance, western redcedar wood is well known to resist fungal decay (e.g., Kelsey and Harmon 1989). Perhaps the rest of this plant is equally able to discourage fungal growth. To determine which of these factors is most important would require more work at other similar installations but under different climatic and edaphic regimes.

Several studies have found no direct relationship between plant species and collembolan species (Wood 1967; Curry 1978; Addison 1980). Other studies suggest that vegetation type, soil type, moisture, temperature, locality, and plant growth forms contribute to the overall composition of collembolan fauna (Hagvar 1982; Berg and Pawluk 1984). The results of our cluster analysis using the Renkonen's and Morisita's Similarity Indices for collembolan species data suggest that forest cover has little effect on the structure of collembolan species community even though the overall density of soil collembola under western redcedar is lower than under Douglas-fir and Sitka spruce. Our results should be interpreted cautiously since the distribution of soil micro-arthropods like mites and collembola tends to be strongly structured spatially with distinctive areas of high density and others of low (Klironomos et al. 1999). This distribution pattern results in high variability between samples and relatively low analytical power for the number of samples we examined.

The widespread and abundant collembolan species from this study are well-known and common species for British Columbia (Battigelli and Marshall 1993; Rusek and Marshall 1995; Setala and Marshall 1994). Five species were common to all plots and accounted for half of the total abundance of collembola. This finding is typical of other collembolan population studies (Hale 1966; Setala and Marshall 1994). Hale (1966) found that the rare species were the better indicators of variations between moorland habitats than the more common species. Unfortunately, these rare species tend to occur in insufficient numbers to allow for detailed analysis of their distribution.

Based on oribatid mite distributions provided by Marshall et al. (1987) and Behan-Pelletier (1993), close to half of the mite species identified in this study are new records for Canada or British Columbia, or are presently undescribed. Many

individuals in this survey could only be identified to genus. For example, the *Suctobelbella* were identified as species 1 and 2, as no working keys exist for this genus. This example indicates the currently limited and incomplete knowledge of British Columbia's oribatid mite fauna and the need for further taxonomic study at the species level.

The results of the cluster analysis using the Renkonen and Morisita Similarity Indices for oribatid species data suggest that forest cover sometimes affects the pattern of mite species distribution. For instance, although all Douglas-fir plots supported a similar fauna, the distribution of oribatid mite species among plots under hemlock, redcedar, and Sitka spruce had no clear pattern. Given the rather limited amount of sampling and the variability of the data, the reliability of these results is difficult to predict. It is possible that Douglas-fir is in some way different from the other conifers; the macrofungus data tell us so. That the plots were laid out randomly indicates that the Douglas-fir plots were probably not inherently different originally from the others and that, if the difference is real, it is an effect of the Douglas-fir itself.

Results of other studies examining the effect of vegetation type on mite distribution suggest something similar. While several studies conclude that vegetation type has a significant effect on mite species (Curry 1978; Hagvar 1984), others have found little correlation between mite distribution and vegetation type (Wood 1966; Walter 1985). Some studies have also found significant correlations between oribatid mites and organic matter (Mitchell 1978; Schenker 1984) or soil chemical properties (Hagvar 1984). In this study, although the oribatid mite community under Douglas-fir appears to differ from the rest, we found no significant differences in the forest floors that would account for this result. Wood (1966) suggested that the environment of soil micro-arthropods, defined by a network of soil cavities and a "jungle" of root hairs and fungal hyphae, cannot be adequately described by soil type, vegetation, or quantitative measurements of soil properties such as pore space and organic matter. As Klironomos et al. (1999) demonstrated, soil organisms do not all function at similar scales. Nor do they all use the same food resources. Although oribatid mites as a group generally feed on soil micro-organisms and decaying plant material, the degree of food specificity varies,

with some being rather strictly fungivorous, others restricted to decaying plant material, and still others being more generalized feeders (Norton 1990). Clearly, one could expect that species of oribatid mite that eat only decayed plant material would respond more directly to plant species than species that are generalized feeders.

One of the obvious limitations of this study is the one-time nature of the sampling. Many studies indicate that collembola and mites vary seasonally (e.g., Hale 1966; Luxton 1981) as do macrofungi (e.g., Arora 1986). Nonetheless, despite its various limitations, results of this study suggest that forest cover influences micro-arthropod populations. Collembolan abundance and diversity were noticeably less under western redcedar compared with the other forest types sampled. Oribatid mite populations were least abundant and diverse under redcedar. The community of oribatid mites under Douglas-fir appears to be different from that under the other conifer species.

Many collembola and oribatid mites feed on fungal hyphae (Anderson and Healey 1972; Luxton 1972). Because of this, fungi influence population dynamics (fecundity, survival, etc.) and community structure (distribution, species abundance) of these micro-arthropods. Since ectomycorrhizal fungi can form more hyphae in the soil than can vesicular-arbuscular mycorrhizal fungi (Jones et al. 1998), it is likely that western redcedar plots have less mycorrhizal fungus hyphal biomass in the soil. In addition, the lower diversity and abundance of general decomposer fungi under western redcedar suggest that the hyphal biomass of decomposer fungus is also less. Less fungal biomass in the soil may contribute to the lower diversity and abundance of micro-arthropods under western redcedar than under Douglas-fir and Sitka spruce.

This preliminary work suggests that species of conifer has more effect on macrofungus community than on forest floor mite or collembolan communities. Detailed studies of the macrofungi and the collembola collected over 2 years on replicated sites of EP 571 are in progress. These studies will provide more information on these two groups of soil organisms, allow us to test the findings of this preliminary study, and examine the relationships between conifer species and the less common species of macrofungi and collembola.

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LITERATURE CITED

Addison, J. A. 1980. Influence of individual plant species on the distribution of Arctic collembola. In Soil biology as related to land use practices. Proc. 7th International Soil Zoology Colloquium of the International Society of Soil Science. D.L. Dindal (editor). Environ. Protection Agency, Office of Pesticide and Toxic Substances, Washington, D.C., pp. 704–15.

Anderson, J.M. and I.N. Healey. 1972. Seasonal and inter-specific variation in major components of the gut contents of some woodland collembola. J. Anim. Ecol. 41:359–68.

Arora, D. 1986. Mushrooms demystified. 2nd ed. Ten Speed Press, Berkeley, Calif.

Balogh, J. and P. Balogh. 1992. The Oribatid mites genera of the world. Vol. 1 and 2. Hungarian Natural History Museum Press, Budapest, Hungary.

Balogh, J. and S. Mahunka. 1983. The soil mites of the world. Vol. 1: Primitive Oribatids of the Palearctic region. Academiai Kiada, Budapest, Hungary.

Battigelli, J.P. and V.G. Marshall. 1993. Relationships between soil fauna and soil pollutants. *In* Proc. Forest Ecosystem Dynamics Workshop. XXX. V.G. Marshall (editor). For. Can. and B.C. Min. For., Victoria, B.C. FRDA Rep. 210, pp. 31–4.

Behan-Pelletier, V.M. 1993. Diversity of soil arthropods in Canada: systematic and ecological problems. Mem. Entomol. Soc. Canada. 165:11–50.

Behan-Pelletier, V.M. and B. Bissett. 1992. Biodiversity of Nearctic soil arthropods. Can. Biodiversity 2(3):5–14.

Berch, S.M., E. Deom, A. Roth, and W.J. Beese. 1992. Vesicular-arbuscular mycorrhizae of western redcedar in container nurseries and on field sites after slash burning. Tree Planters' Notes 44:33–7.

Berch, S.M., E. Deom, and T. Willingdon. 1991. Western redcedar growth and vesicular-arbuscular mycorrhizal colonization in fumigated and nonfumigated nursery beds. Tree Planters' Notes 42:14–6.Berg, N.W., and S. Pawluck. 1984. Soil mesofaunal studies under different vegetative regimes in north central Alberta. Can. J. Soil Sci. 64:209-23.

Binkley, D. 1995. Species influence on forest soils - processes and patterns. In Proc. Trees and Soils Workshop. D.J. Mead and I.S. Cornforth (editors). Lincoln Univ., Canterbury, N.Z., Feb. 28–Mar. 2, 1994. Agron. Soc. N.Z., Spec. Publ. No. 10, pp. 1–33.

Breitenbach, J. and F. Kränzlin (editors). 1984. Fungi of Switzerland. Vol. 1. Ascomycetes. Verlag Mykologia, Luzern, Switzerland.

_____. 1986. Fungi of Switzerland. Vol. 2. Non gilled fungi. Verlag Mykologia, Luzern, Switzerland.

_____. 1991. Fungi of Switzerland. Vol. 3. Boletes and agarics. 1st Part. Verlag Mykologia, Luzern, Switzerland.

_____. 1995. Fungi of Switzerland. Vol. 4. Agarics. 2nd Part. Verlag Mykologia, Luzern, Switzerland.

Bruns, T. 1995. Thoughts on the processes that maintain local species diversity of ectomycorrhizal fungi. Plant and Soil 170:63–73.

Christiansen, K. and P. Bellinger. 1980. The Collembola of North America north of the Rio Grande. Grinnell Coll., Grinnell, Iowa.

Curry, J.P. 1978. Relationships between microarthropod communities and soil and vegetational types. Proc. Roy. Dub. Soc. Ser. A 6(11):131–41.

de Geus, N. 1995. Botanical forest products in British Columbia: an overview. B.C. Min. For., Integrated Resour. Policy Br., Victoria, B.C.

Douglas, G.W., G.B. Straley, and D. Meidinger. 1991. The vascular plants of British Columbia. Part 3 – Dicotyledons (Primulaceae through Zygophyllaceae) and Pteridophytes. B.C. Min. For., Victoria, B.C. Spec. Rep. Ser. No. 3.

Faber, J.H. and H.A. Verhoeff. 1991. Functional differences between closely-related soil arthropods with respect to decomposition processes in the presence or absence of pine tree roots. Soil Biol. Biochem. 23(1):15–23.

Fjellberg, A. 1985. Arctic Collembola I - Alaskan Collembola of the families Poduridae, Hypogastruridae, Odontellidae, Brachystomellidae and Neanuridae. Entomol. Scandinavica Suppl. No. 21.

Hagvar, S. 1984. Six common mite species (Acari) in Norwegian coniferous forest soils: relations to vegetation types and soil characteristics. Pedobiologia 27:355–64.

Hale, W.G. 1966. A population study of moorland Collembola. Pedobiologia 6:65–99.

Jones, M.D., D.M. Durall, and P.B. Tinker. 1998. A comparison of arbuscular and ectomycorrhizal *Eucalyptus coccifera*: growth response, phosphorus uptake efficiency and external hyphal production. New Phytol. 140:125–34.

Kelsey, R.G. and M.E. Harmon. 1989. Distribution and variation of extractable total phenols and tannins in the logs of four conifers after 1 year on the ground. Can. J. For. Res. 19:1030–6.

Klinka, K., H.Y.H. Chen, Q. Wang, and L. de Montigny. 1996. Forest canopies and their influence on understorey vegetation in early-seral stands on west Vancouver Island. Northwest Sci. 70:193-200.

Klinka, K., Q. Wang, B. Sivak, G.G. Wang, and D. Elstone. 1994. Ecological and supplementary height growth analyses for experimental projects 368 and 571. Contract rep. to B.C. Min. For., Res. Br., Victoria, B.C.

Klironomos, J.N., M.C. Rillig, and M.F. Allen. 1999. Designing belowground experiments with the help of semi-variance and power analyses. Appl. Soil Ecol. 12:227–38.

Krebs, C.J. 1989. Ecological methodology. Harper & Row, New York, N.Y.

Lussenhop, J. 1971. A simplified canister-type soil arthropod extractor. Pedobiologia 11:40–5.

Luxton, M. 1972. Studies of oribatid mites of a Danish beech wood soil. I. Nutritional biology. Pedobiologia 12:434–63.

_____. 1981. Studies on the oribatid mites of a Danish beech wood soil. VI. Seasonal population changes. Pedobiologia 21:387–409.

Marshall, V.G. 1993. Sustainable forestry and soil fauna diversity. *In* Our Living Legacy: proc. symp. on biological diversity. M.A. Fenger, E.H. Miller, J.A. Johnson, and E.J.R. Williams (editors). Royal B.C. Museum, Victoria, B.C., pp. 239–48.

Marshall, V.G., R.M. Reeves, and R.A. Norton. 1987. A catalogue of the Oribatida (Acari) of Continental United States and Canada. Mem. Entomol. Soc. Can. No. 139.

Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia. B.C. Min. For., Victoria, B.C. Spec. Rep. Ser. No. 6.

Mitchell, M.J. 1978. Vertical and horizontal distributions of oribatid mites (Acari: Cryptostigmata) in an aspen woodland soil. Ecology 59(3):516–25.

Morisita, M. 1959. Measuring interspecific association and similarity between communities. Mem. Fac. Sci. Kyushu Univ., Fukuoka, Japan. Ser. E (Biol.) 3:65–80.

Norton, R.A. 1990. Acarina; Oribatida. *In* Soil biology guide. D.L. Dindal (editor). John Wiley & Sons, Toronto, Ont., pp. 779–803.

Omule, S.A.Y. and G.J. Krumlik. 1987. Juvenile height growth of four species on four sites in the CWHb1 variant. For. Can. and B.C. Min. For., Victoria, B.C. FRDA Rep. 007.

Parkinson, D., S. Visser, and J.B. Whittaker. 1979. Effects of Collembolan grazing on fungal colonization of leaf litter. Soil Biol. Biochem. 11:529–35.

Phillips, R. 1991. Mushrooms of North America. Little, Brown and Co., Boston, Mass.

Redhead, S. 1997. Macrofungi of British Columbia: requirements for inventory. B.C. Min. For., Res. Br. and B.C. Min. Environ., Lands and Parks, Wildl. Br., Victoria, B.C. Work. Pap. 28/1997.

Rusek, J. and V.G. Marshall. 1995. Long-term changes of collembolan communities in forest soils. Bull. Entomol. Pologne 64:159–71.

SAS Institute Inc. 1989–1996. The SAS System for Windows. Cary, N.C.

Schenker, R. 1984. Spatial and seasonal distribution patterns of oribatid mites (Acari: Oribatei) in a forest soil ecosystem. Pedobiologia 27:133–49.

Setala, H. and V.G. Marshall. 1994. Stumps as a habitat for Collembola during succession from clear-cuts to old-growth Douglas-fir forests. Pedobiologia 38:307–26.

Skidmore, R.E. 1995. Checklist of collembola (Insecta: Apterygota) of Canada and Alaska. Proc. Entomol. Soc. Ont. 126:45–76.

Walker, N.A. 1965. Euphthiracaroidea of California Sequoia litter: with reclassification of the families and genera of the world (Acarina: Oribatei). Fort Hays Studies - New Series, Sci. Ser. No. 3 [1964].

Walter, D.E. 1985. The effects of litter type and elevation on colonization of mixed coniferous litterbags by oribatid mites. Pedobiologia 28:383–7.

Wolda, H. 1981. Similarity indices, sample size and diversity. Oecologia 50:296–302.

Wood, T.G. 1966. The fauna of grassland soils with special reference to Acari and Collembola. N.Z. Ecol. Soc. Proc. 13:79–85.

_____. 1967. Acari and Collembola of moorland soils from Yorkshire, England. III. The micro-arthropod communities. Oikos 18:277–92.

Woolley, T.A. 1968. North American Licaraidae. III. Liacarus (Acari: Cryptostigmata). J. Kan. Entomol. Soc. 41(3):350–66.