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Northern Temperate Coastal Sitka Spruce Forests with Special Emphasis on Canopies: Studying Arthropods in an Unexplored Frontier

Abstract

Arthropod biodiversity is being investigated in the Carmanah Valley on Vancouver Island, British Columbia. Examination of several species, many of which are not yet described from this intact old-growth forest indicate that this structurally complex habitat acts as a reservoir for biological diversity. Nowhere is this more apparent than in the canopy, where the fauna has finely partitioned the tree, both with regard to habitat type and phenology. Resident arthropods associated with the branches in the canopy are dominated by members of the phytophagous and predator/parasitoid guilds. Microhabitats exploited by this arboreal arthropod fauna are not replicated in any of the other forest sites that we examined. Taxonomic distinctness is most pronounced in the moss mats where soil microarthropods such as oribatid mites are members of a unique arboreal community. Removal of this habitat may change the structural and functional aspects of this canopy ecosystem and initiate species extirpations. Intact northern temperate coastal old-growth forests are also important for the maintenance of biodiversity of certain ground-dwelling groups of insects such as the Staphylinidae. These beetles do not easily make the transition to altered habitats. Other insect groups such as the highly mobile spheciform wasps appear to adjust to habitat changes that are most commonly a result of forest clearing. These data indicate that old-growth forests have distinct species assemblages that are altered when forests are converted to younger stands; this is particularly evident in the resident canopy community.

Introduction

Historically very little research concerning the maintenance and conservation of biodiversity has been done on the primeval old-growth conifer forests of the Pacific Northwest. In British Columbia these forests are thought to contain much of the biodiversity of the province (Fenger and Harcombe 1989; Bunnell 1990). They often have diffuse boundaries with other ecosystems, and this temporal and spatial mosaic creates a dynamic and complex set of habitats that are utilized by a variety of species.

The elements of biodiversity associated with old-growth forests form a heterogeneous group, and nowhere is this more evident than in the arthropods. Arthropods, primarily insects, are an integral part of any old-growth system and most entomologists agree that they may comprise 80-90% of the total known species in these systems (Asquith et al. 1990). They play a primary role in the function of natural ecosystems and are now frequently mentioned as important components of diversity that need to be identified (May 1986). As Platnick (1991) states "Speaking about biodiversity is essentially equivalent to speaking about arthropods. In terms of number of species, other animal and plant groups are just a gloss on the arthropod theme." The Entomological Society of Canada also passed a resolution concerning the study of biodiversity of terrestrial arthropods in 1991.

The diversity of arthropods and ecological concepts surrounding them has the potential to bury researchers in a profusion of special cases (Hoekstra et al. 1991). Nowhere is this more obvious than with the insect fauna where species estimates ranged from 1.5-1.8 million species (Hammond 1990) to 30 million species (Erwin 1983), or even up to 80 million species (Stork 1988). The truth probably lies somewhere between these estimates e.g. approx. 10 million (Erhlich and Wilson 1991), but our knowledge of almost all insect faunas is very incomplete. This lack of knowledge certainly applies to the Canadian insect fauna where 33,755 species of insects have been described, although the estimated total number is over 66,000 (Danks 1993). In British Columbia there may be as many as 40,000 arthropod species, many of which are not yet described (Cannings 1992). Community structure of forest arthropods, therefore, is not well known and information concerning responses of these communities to forest management practices is lacking (Schowalter 1985,1986,1989; Schowalter and Crossley 1987).

Within these forest systems one of the least explored habitats is the forest canopy. Insect assemblages in forest canopies are complex in terms of diversity, species interactions, host plant associations and abiotic gradients. The role of these variables in determining community structure of forest insects in general is discussed by Strong (1974 a, b) and previous studies have concentrated on responses of individual species (Dyer 1986; Schowalter et al. 1986; Witcosky et al. 1986) rather than with interactions at the community level.

The canopy of rainforest trees (particularly in the tropics) is believed by many to hold the key to the immense diversity of insects. Indeed this biotope has recently been described as "the last biological frontier" (Erwin, 1983). Although much has been learned in recent years about canopy insects (mainly species lists) in tropical rainforests, relatively little is known about northern temperate rainforests. Canopy research in these forests lag behind tropical canopy studies and only three studies of old-growth forest-canopy invertebrates in the Pacific Northwest had been completed by 1989 (Voegtlin 1982; Schowalter 1986, 1989), and these were carried out in the context of old-growth Douglas Fir-Hemlock surveys in Oregon.

Given the importance of arthropods in old-growth forests of the Pacific Northwest and the lack of taxonomic knowledge, the objective of this study is to document the arthropod fauna from an old-growth Sitka spruce forest and look at species changes along a gradient from the old- growth forest canopy to a second-growth forest. Specifically, this paper will look at guild structure and the microarthropods associated with the forest canopy. Between-habitat species composition of the Staphylinidae (Coleoptera) and the Spheciform wasps (Hymenoptera) will be used as examples to document species compositional changes associated with habitat alterations.

Methods and Materials

Study Area

The study area is located in the Upper Carmanah Valley drainage on the Southwest coast of Vancouver Island, British Columbia, Canada (Figure 1). This typical U-shaped coastal valley, approximately 6731 ha. in extent, is situated between the villages of Port Renfrew and Bamfield. The entire valley lies within the Coastal Western Hemlock Biogeoclimatic Zone with the exception of two high-elevation areas (Meidinger and Pojar 1991). The dominant conifers in the Carmanah drainage are Sitka spruce (*Picea sitchensis*) (Bong.) Carr., western hemlock (*Tsuga heterophylla*) (Rafn.) Sarg., western red cedar (*Thuja plicata*) D. Don and Pacific silver fir (*Abies amabilis*) (Dougl.) Forb.

The sample area in the Upper Carmanah Valley (UTM: 10U CJ 801991) includes 6 study sites: old-growth canopy (UTM: 10U CJ 801991), old-growth forest floor (UTM: 10U CJ 802998; both old growth sites are approximately 300-500 years old), transition zone (edge between old-growth and clear-cut; UTM: 10U CJ 803006), clear-cut (UTM: 10U CK 803005), second-growth 1 (UTM: 10U CK 803000) approximately 10 years old and second-growth 2 approximately 60 years old. All study sites except the 60 year old site were located adjacent to one another along an approximately 4 km transect. This watershed represents an intact ancient forest that has been evolving since the Wisconsin glaciation. In 1985 the clear-cut site, (approx. 4 hectares) was harvested and is the only area in the entire Carmanah watershed to be logged. The 60 year old site located along the Rosander mainline, is not contained in the Carmanah Valley watershed and lies 30 km to the southeast from the Upper Carmanah Valley.

Canopy Access

Five Sitka spruce trees were randomly chosen to be incorporated into the access system. Access to the Sitka spruce canopy is by means of a 2:1 mechanical advantage pulley system. Strapped into a harness and attached to a series of climbing lines, we are able to sample five adjacent Sitka spruce trees. Four wooden platforms strapped onto the branches and trunk of the main tree give us consistent heights (31 to 67 metres) from which to sample. A series of burma bridges enables us to access four other Sitka spruce trees, complete with platforms. This entire system, the first of its kind in North America, has become a springboard for documenting old-growth forest arthropods. At the time of study this station was the only permanent access system of this type available to do long-term canopy work in Northern temperate rainforests.

A second permanent access station was completed in March, 1994, near Victoria, B.C. allowing

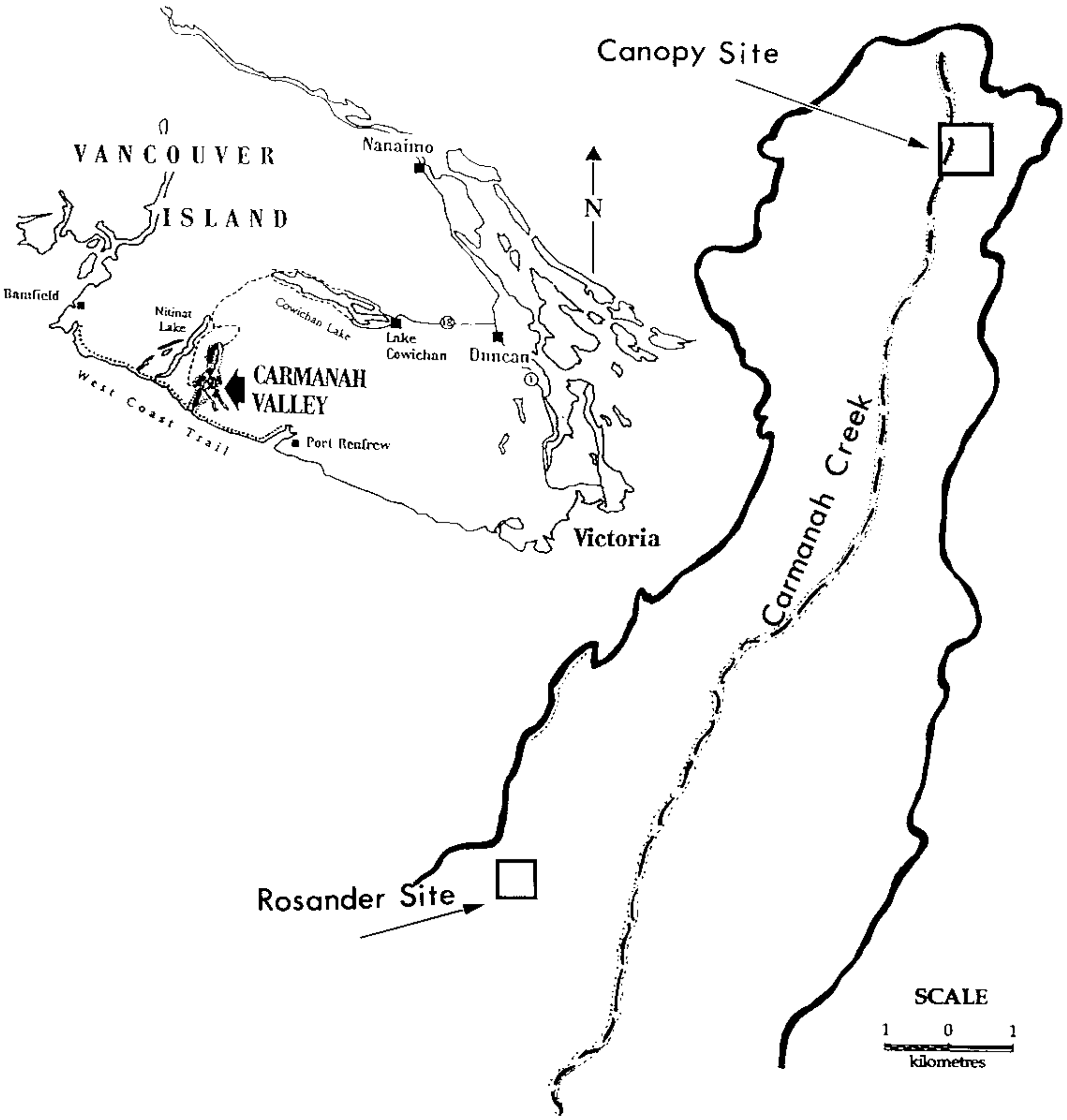

Figure 1. Map location of the study sites in the Carmanah Valley, Vancouver Island, British Columbia, Canada.

access to a dry coastal old-growth Douglas fir forest, and a third has been completed recently (May, 1994) in old-growth western red cedar at Bamfield Marine Station, B.C.

Survey Design

Arthropods (mainly insect, mites and spiders) have several biological features that predispose them to diversity in response to environmental heterogeneity (Southwood 1978). The ability of insects to exploit a variety of habitats coupled with their diversified behaviour means that few, if any, traps are equally efficient in capturing different groups. Owing to the diverse nature of the taxa involved in an arthropod biodiversity study coupled with their varied habits and life cycles, no single survey method or sampling technique can be used for a complete study. A variety of techniques must be employed and the sampling techniques that are most easily used, and the relevant taxa that

TABLE 1. Community ecology of the insect/arthropod fauna from an old-growth forest: with special emphasis on the canopy fauna. An overview of the site designations and sampling techniques.

METHOD	SITE					
	Canopy	Forest floor	Trans-ition zone	Clear-cut	Second growth 1	Second growth 2
Pan/Window	NO	YES	YES	YES	YES	NO
Malaise	YES	YES	YES	YES	YES	NO
Moss cores	YES	YES	YES	YES	NO	NO
Branch clip	YES	NO	NO	NO	NO	YES
General collect	YES	YES	YES	YES	YES	YES

can be collected by each method, have been summarized by Winchester and Scudder (1993) and the Biological Survey of Canada (1994). The methodologies used in this study at each site are presented in Table 1 and were run for 5 months (June-October) in 1991 and for 7 months (May-November) in 1992. Elaboration of the 1991 sampling design is given below. The 1992 component of this project is in the initial stages of specimen preparation and will not be included in this paper.

Branch Clippings

The branch clipping program was conducted in the five Sitka spruce trees contained in the fixed-access canopy system. The sampling procedure was modified after Schowalter (1989). In each tree three samples were taken at each of three heights (33, 45, and 54 metres). A total of 45 branches were collected for each of six sample periods. Samples were collected in one-month intervals from May-October, 1991. All insects were removed from each sample and prepared for identification. Immature individuals were reared to maturity. Single branches from each tree and level were run through Tullgren funnels to extract Collembola and Acari. After sorting, all branches were dried, and then total branch weight and needle weight were recorded. Various other measurements were taken from the branches but are not relevant to the present analysis and will be reported in later papers.

Malaise Traps

Five Malaise traps (Townes 1962), randomly placed along a linear transect, were run at each of 4 sites (Table 1). Arthropods were collected into 70% ethyl alcohol to which 6 drops of ethylene glycol had been added. Traps were cleared at two-week intervals from May-October. A total of 245 trap samples were collected. Arthropods from each trap were sorted and enumerated. These samples are in the process of being prepared for sending to taxonomic experts for identification.

Window/Pan traps

Five window/pan traps were run at each ground sample site (Table 1). Pans (23 X 15 X 5 cm) were buried with rims flush at ground level. They were randomly placed along a 50 m linear transect. A clear glass window (0.5 by 0.5 m) was placed above each pan trap. A saturated salt solution was used as a preservative with a few drops of detergent added as a wetting agent. A total of 120 trap samples were collected. All arthropods were washed in water and stored in 75% ethyl alcohol. Specimens of the families of interest were then removed and prepared for shipment to taxonomic experts for identification.

Moss Cores

A hand held moss/soil corer (approx. 3 cm X 5 cm) was used to collect 5 moss/soil cores at random from each sample site (Table 1) once a month from May-October. A total of 120 cores were collected. In the laboratory each core was extracted through a Tullgren funnel for forty-eight hours. Samples were preserved in 75% ethyl alcohol. Volume displacement and dry weight were recorded for each core sample.

Results

In total, an estimated 800,000 arthropod individuals were captured during the 1991 sample season. Only a small proportion of these samples (approx.

40,000 individuals) have been identified and from this data set only selected examples will be used in this paper.

An informative view of canopy arthropods can be gained by placing them in guilds. The guilds used in this study are structured after work done by Root (1967, 1973). We recognize six guilds: phytophages, which feed on living plant material; the epiphytic fauna, which live on and are associated with the surface of plants; scavengers; predators; parasitoids and tourists. The tourist guild is composed of those individuals which represent non-resident fauna that are dispersing between habitat types. Further elaboration of these guilds is given by Moran and Southwood, (1982). Guild structure, expressed as mean biomass per kg. of dry plant material for all arthropods from the 1991 branch clipping program (Figure 2), indicates that phytophagous and predator guilds occur in the highest proportions and these proportions are approximately equal.

The data for staphylinid beetle species rank and abundance are plotted in Figure 3. The forest floor and transition zone exhibit a pattern appearing most similar to the log series model (Fisher et al. 1943), while the canopy and clear-cut zones exhibit no apparent patterns when compared to the geometric, log series, log normal or broken stick models. Numerical relationships between staphylinid species and study sites (Figure 4) indicate that the transition zone had the greatest number of species (49) while the canopy had the least number of species (6). The forest interior and transition zone had the most species in common (20) while the number of species shared in common between the forest interior and clear-cut is low

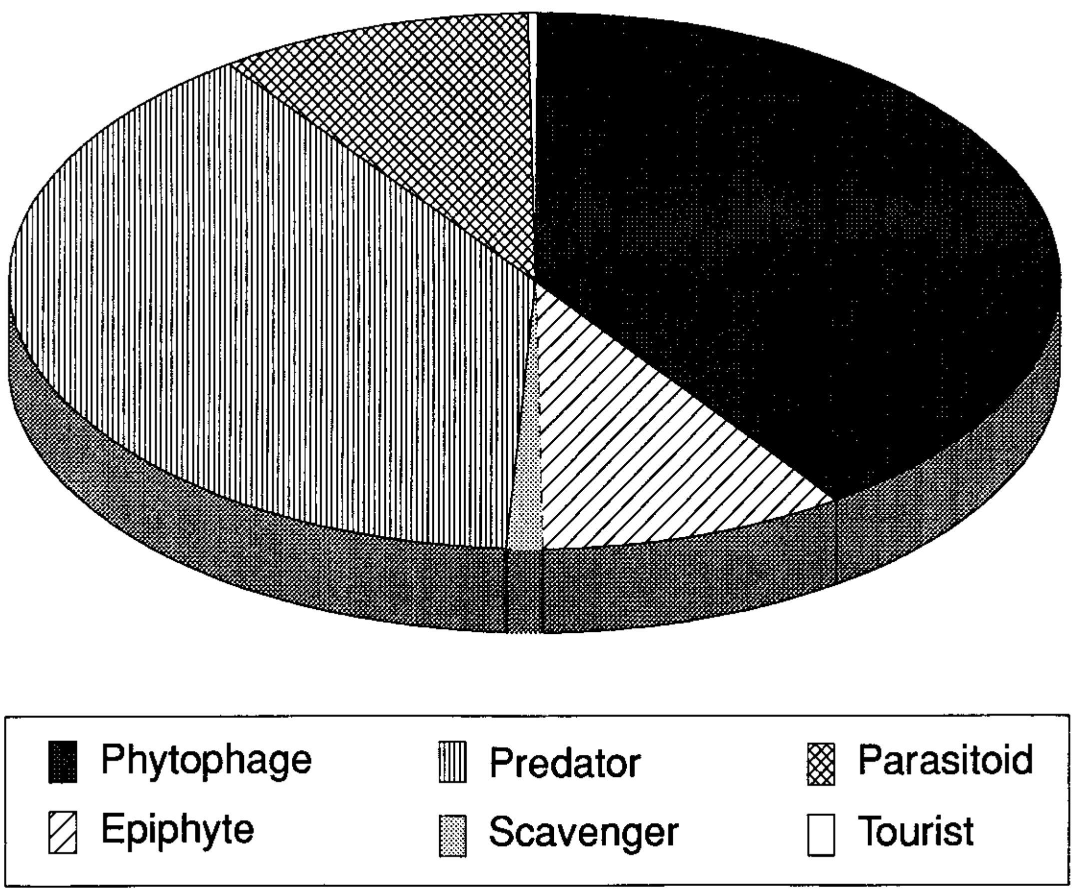

Figure 2. Guild structure of the arthropod fauna from all trees expressed as mean biomass per kg. of dry plant material. All samples are from the branch clipping program.

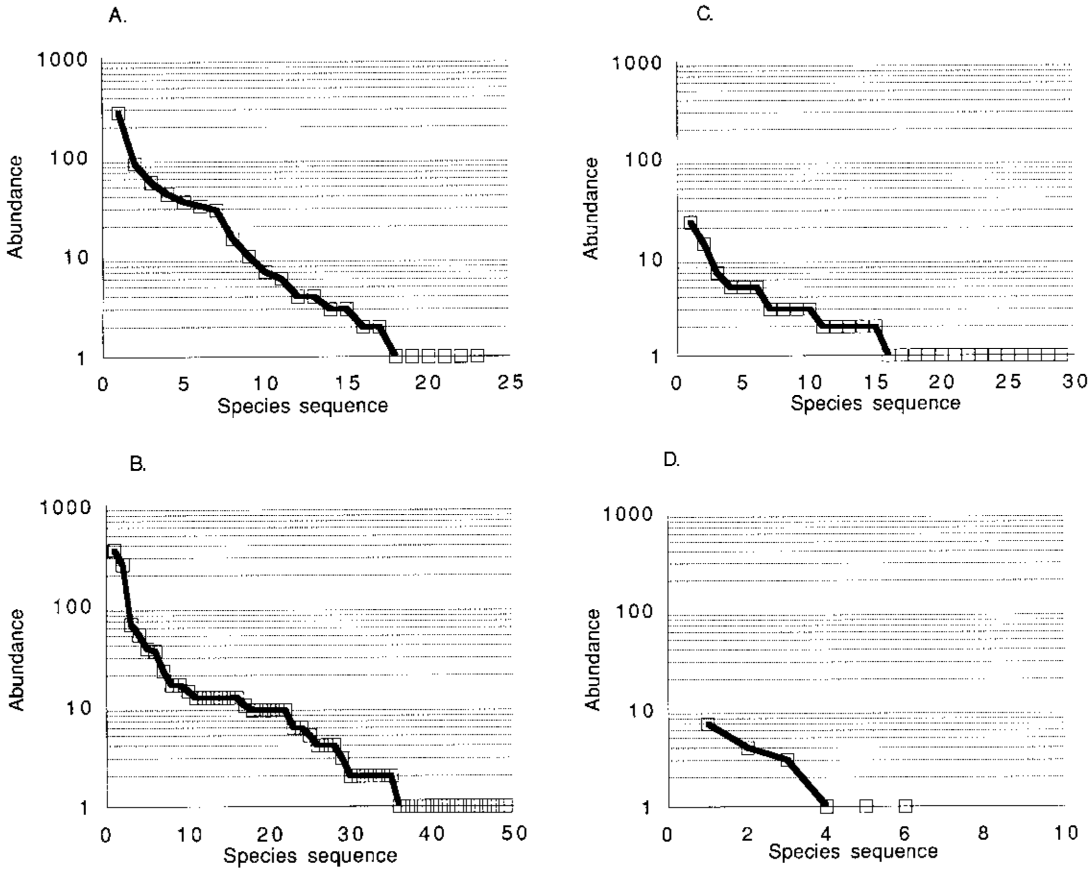

Figure 3. Rank abundance plots of Staphylinid beetles from four sites in the Upper Carmanah Valley. A = Forest floor; B = Transition zone; C = Clear-cut; D = Canopy. Abundance of each species is plotted on a logarithmic scale against the species' rank, the order from the most abundant to least abundant species.

(7). Species turnover, or Beta diversity, between these sites was explored using Jacarrd's coefficient (Table 2). Percent similarity based on species presence/absence indicated that the highest similarity was between the forest floor and transition zone. The clear-cut zone had low similarity when compared to the other sites. The canopy was most dissimilar to all other sites because of the disproportionately low number of species.

Thirty-seven species of spheciform wasp were collected in this study and percentage species similarity using Sorensen's coefficient (Figure 5) indicated that the clearcut and transition zone were the habitats that these wasps preferred. A single specimen was recorded from the forest floor, while no specimens were documented in the canopy. The percentage similarity between the clear-cut and transition zone was 50%. The known prey items of 17 spheciform wasps are listed in Table 3. The prey families of these wasps are most abundant in the clear-cut where they are associated with early successional vegetation. They are least abundant in the forest floor and old-growth canopy zone which lends support to the observed percent similarity between sites.

A subsample of oribatid mites (1000 individuals) were used to look at percent similarity between the canopy and forest floor (Table 4). Even at the family level the canopy oribatids form a distinct assemblage that is only moderately similar to the forest floor oribatids.

Discussion

The general form of the arboreal community is related to characteristics of the tree, and the

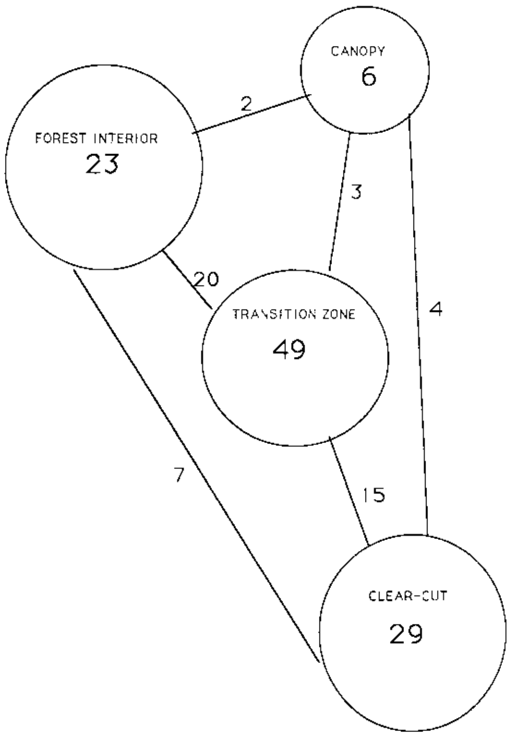

Figure 4. Numerical relationship between staphylinid species in study sites of the Upper Carmanah Valley. Data are pooled from the Malaise and Pan/window trap collections. Numbers along the lines represent those species in common between the sites and numbers within the circles represent those species common to that site.

TABLE 2. Beta diversity (Jaccard's coefficient of similarity) of Staphylinidae caught in Malaise traps from four sites in the Carmanah Valley. British Columbia (temporal sequencing omitted).

	Forest Floor	Trans Zone	Clear cut	Canopy
Forest Floor	1			
Trans. Zone	.65	1		
Clear cut	.12	.20	1	
Canopy	.06	.05	.19	1
# of species	27	39	20	5
# of individuals	486	324	89	24

magnitude of the populations of particular species will be influenced by a variety of factors. The resident canopy arthropod fauna in this study was dominated by the phytophagous and predator/parasitoid guilds, supporting previous stud-

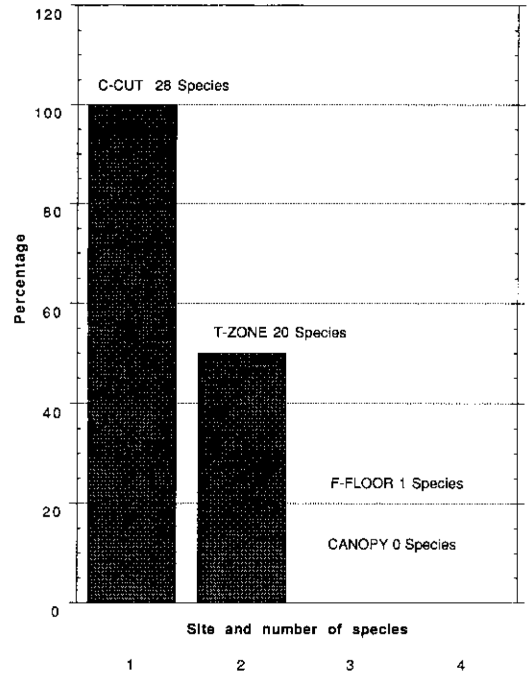

Figure 5. A bar graph comparing the percentage species similarity (Sorensen's Coefficient) of spheciform wasps of the canopy, forezst floor (F-Floor), transition zone (T-Zone) and clear-cut (C-Cut) compared with that of the clear-cut site.

ies by Schowalter and Crossley (1987) and Schowalter (1989). Most of the phytophagous guild is composed of species that are feeding on the developing vegetative buds and female cones. These species appear to have a small effect on the host with a negligible loss in developing plant material. We infer from this guild structure that herbivory in this mature, structurally-complex forest is relatively insignificant and, through a series of checks and balances, that large scale herbivore damage (insect outbreaks) is negligible. This information supports previous findings by Reichle et al. (1973), Nielson (1978), Ohmart et al. (1983), and Schowalter (1989) where it was noted that herbivory was less than ten percent of the standing crop in mature forests. The maintenance of a high predator loading in a structurally and functionally diverse ecosystem such as the Carmanah Valley supports previous findings by Kareiva (1983), Risch (1981) and Schowalter (1986,1989).

Perhaps the most interesting habitat contained in the Sitka spruce canopy is that provided by the

TABLE 3. List of phytophagous insect prey of spheciform wasps, grouped according to their feeding behaviour.

Prey role	Prey taxon	Predator taxon
Sap feeder	Cercopidae	Pemphredonidae
		Mimesa gregaria
		M. pauper
		M. lutaria
		Mimumesa mixta
		M. nigra
		M. propinqua
	Aphididae	*Pemphredon concolor*
		P. inornata
		Diodontus argentinae
		D. boharti
		Passaloecus armeniacae
		P. monilicornis
		P. patagiatus
		Stigmus inordinatus
		Spilomena sp.
Foliage feeder	Noctuidae	SPHECIDAE
		Podalonia mickeli
	>>Lepidoptera	*Ammophila strenua*

TABLE 4. Comparison of the oribatid ("beetle mite") fauna (subsample of 1000 individuals) from the Sitka spruce canopy and forest floor, Upper Carmanah Valley, British Columbia.

	Canopy	Forest Floor
# of Families	19	21
% similarity = 35%		
# of species	32	36
% similarity = 19%		
# new species	8	15
% similarity = 13%		

4-28 cm deep moss mats which support a well developed soil layer. These mats are primarily composed of four moss species, *Isothecium myosuroides, Antitrichia curtipendula, Dicranum fuscescens* and *Scapania bolanderi* , which are also abundant on the forest floor. Soil micro-arthopods dominate this canopy soil/litter habitat, a fact which has not been well documented in previous canopy studies. From the small collection of oribatid mites that have been processed to date there is strong evidence that we are dealing with a distinct arboreal assemblage of species. One might expect the taxonomic similarity to be highest between the forest floor and the canopy. However, even at the family level this similarity is low and subsequently is further reduced at finer taxonomic resolution. The discovery of several new species is not surprising given the scope of this study but several of these undescribed species also appear confined to the canopy. We suggest that there maybe enough differences in canopy microhabitat conditions to promote the development of taxonomically discrete species assemblages which in turn would enable these differences to be observed throughout the taxa that comprise the moss mat community.

Habitat changes that occur through logging of old-growth forests have been well documented, but the effect that this type of habitat alteration has on arthropods has only been addressed to a limited extent (McLeod 1980; Chandler 1987,1991; Niemela et al. 1988, 1993; Schowalter 1989; Chandler and Peck 1992). This study indicates that of the 78 species of staphylinid beetles recorded many have not made the transition to the clear-cut site. The majority of the species recorded in the clear-cut are represented by a single individual and it seems unlikely that this indicates long-term habitat use. The canopy habitat does not appear to provide the conditions necessary for this group of beetles, although the one species recorded in any abundance is a new species of Omaliinae which occurs throughout the sampling season. Many of the species recorded in this study are restricted to old-growth forests where two important conditions for survival are met: first, a supply of over-mature, fallen logs which are allowed to decay under natural conditions in the shade of the forest canopy and, secondly, the maintenance of deep layers of undisturbed forest floor litter which have not been eradicated by the extreme conditions of clear-cuts and the subsequent exposure to desiccation and erosion (Campbell and Winchester 1994). Two species, *Pseudohaida rothi* and *Trigonodemus fasciatus* are endemic to British Columbia (Scudder 1994) and specimens of several new species of Omaliinae appear to rely on old-growth forests as a source area to maintain reproductively viable subpopulations.

The depression of species in altered areas such as clear-cuts does not hold true for all arthropod groups. The spheciform wasps from this study are not a group that inhabits old-growth or canopy areas. These wasps are active fliers and have the ability to seek out prey sources and suitable nest sites for their developing young. The prey base sought by several species in this study are the sap and foliage feeders from homopteran families such as the Cercopidae, Aphididae, as well as caterpillars of the Noctuidae. Members of these families are more speciose and abundant in the clear-cut area where they quickly build up their numbers as they feed on developing seedlings, forbs and shrubs. This accumulation in the phytophagous guild has been well documented by Schowalter (1986, 1989) and Schowalter et al. (1981), a 23-fold increase in aphids followed logging practices has been reported.

Although the analysis of our data is in a preliminary state there are strong trends that indicate that we are dealing with a unique set of organisms that are old-growth dependent. It is not unusual in an entomological study of this scope to find new species. However, several of these species exhibit habitat specificity that restricts their distribution to structural attributes of the old-growth forest both on the forest floor and in the canopy. Forest conversion affects arthropod diversity by altering key patterns of natural processes that are inseparably linked to habitat diversity. The summarizing of these key patterns and documentation of changes due to disturbances should identify ecological roles of arthropods that are at the heart of the biodiversity challenge. The 1.2 million arthropod specimens collected in our study will provide an understanding of the diversity and food web dynamics within these systems, as well as documentation necessary for the elucidation of the biogeographical significance of these species assemblages.

Acknowledgements

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