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THE EFFECTS OF ALTERNATIVE VEGETATION MANAGEMENT TREATMENTS ON EPIGEAL INSECTS, COLEOPTERA, CARABIDAE AND NON-INSECTAN ARTHROPODS

by

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A Graduate Thesis Submitted
In Partial Fulfillment of the Requirements
for the Degree of Masters of Science in Forestry

Faculty of Forestry
Lakehead University
July, 1997

Major Advisor: Dr. Y. Prevost

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MAJOR ADVISOR'S COMMENTS

ABSTRACT

Ward, J.L. 1997. The Effects of Alternative Vegetation Management Treatments on Epigeal insects, Coleoptera, Carabidae and Non-insectan Arthropods. Advisor: Dr. Y.H. Prevost

Key Words: arthropods, brushsaw, Carabidae, Coleoptera, epigeal, pitfall traps, Release, Silvana Selective cleaning machine, vegetation management alternatives, Vision

The primary objective of this study was to examine the effects of alternative vegetation management on epigeal insects, Coleoptera, Carabidae, and non-insectan arthropods. This study, which is a component of the Fallingsnow Ecosystem Project, 60km southwest of Thunder Bay, Ontario, utilized roofed pitfall traps containing a saline preservative. Four blocks were treated with four vegetation management alternatives including a manual brushsaw treatment, a mechanized treatment (Silvana Selective-Ford Versatile cleaning machine), and two herbicides (Vision [a.i. glyphosate] and Release [a.i. triclopyr]). In addition, a Control (untreated) plot was located within each block. All insects and non-insectan arthropods were identified to the Order level. All Coleoptera were identified to Family, and the Carabidae (Coleoptera) were identified to species. Covariate ANOVA using 1993 data as the Covariate was used to determine treatment effects on abundant Orders, Families, and carabid species. The Shannon-Weiner index of biological diversity was used on 1994 carabid beetles to detect differences in biological diversity of carabid beetles one season post-treatment.

Results indicate that the vegetation management treatments had little effect on the majority of insects, Coleoptera, Carabidae and non-insectan arthropods tested. Homoptera was the only Order that showed significant treatment effects, while both Leoididae and Silphidae of the Coleoptera Order showed significant treatment effects. None of the carabid beetles tested showed significant treatment effects. Covariate1993 Orthoptera, Homoptera, Diplopoda showed a significant effect on the 1994 catch of these Orders, respectively. Covariate 1993 Elateridae was the only Coleoptera Family that showed significant covariate effects, while three carabid species showed significant covariate effects including

Agonum gratiosum Mann., *Pterostichus coracinus* Esch., and *Poecilus lucublandus* Say. The Shannon-Weiner diversity index indicated that the brushsaw and Silvana Selective cleaning machine treatments had the lowest diversity, the Control (untreated) plots had the highest carabid diversity while the two herbicide treatments were between the two extremes, but closer in value to the Control.

Significant covariate effects indicated that areas where populations of particular Orders, Families, or species were trapped in large numbers in 1993, they continued to be trapped in large numbers in 1994. The lack of significant treatment effects on the majority of epigeal insects, Coleoptera, Carabidae, and non-insectan arthropods indicates that the vegetation management treatments did not significantly alter their microhabitats. Lower carabid diversity indices in both the brushsaw and the Silvana Selective cleaning machine treatments may be an indication of a decrease in movement by carabids in these treatments and, thus, fewer carabids being trapped. Decreased movement in these treatments may be attributed to an increase in vegetative and woody cover. Higher diversity in the herbicide treatments may be an indication of increased movement of carabids, and, thus, increased trapping frequency due to a decrease in vegetative cover.

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ACKNOWLEDGEMENTS

I would like to thank all those who helped to bring this study to completion: Dr. Y. Prevost, my advisor, without whose guidance and constructive critisism this thesis would not have come to completion; Dr. R.A. Lautenschlager and F. Wayne Bell who provided support throughout the insect portion of the Fallingsnow study; Dr. Richard Freitag, who was extremely knowledgeable and helpful in all aspects of this study, especially with regard to the carabid beetles; Dr. Kenneth .M. Brown and Dr. W. Carmean, who provided many helpful suggestions, and my field and laboratory crew: Niki MacDonnel (formerly Hobischak) and Debi Barsi, who were both invaluable to me and this project; and, finally, Norm, who always convinced me I could get this thesis done.

The insect portion of the Fallingsnow Ecosystem Project was funded by the Ontario Ministry of Natural Resources Vegetation Management Alternatives Program and the Environmental Youth Corp. Program.

Thanks to all,

Joelle Ward

INTRODUCTION

The removal of non-crop competitive plants to release crop seedlings and saplings is a common forest management practice in Canadian forestry. This procedure is called 'conifer release' because crop trees that are typically conifers are released from competitive vegetation so that crop trees can gain a position of dominance (Lautenschlager 1986). Release usually occurs within the first ten years after harvesting to free naturally regenerated or planted conifers (Lautenschlager 1991). In the past several decades, especially in the 1970's and 1980's, conifer release relied heavily upon the use of chemical herbicides such as glyphosate, hexazinone, 2,4-D, and triclopyr (Lautenschlager 1991).

In northwestern Ontario post-harvest regeneration, whether it is planted or natural, is often dominated by one or a few shade-intolerant tree species such as black spruce (*Picea mariana* (Mill) B.S.P.) or jack pine (*Pinus banksiana* (Lamb.)), or mid- tolerant species such as white spruce (*Picea glauca* (Moench) Voss). On productive sites, angiosperm competition can be fierce under post-harvest conditions, making conifer release an absolute necessity in this region.

With an increase in concern from the general public over the environmental effects of herbicides, forest managers and natural resource managers have taken a new focus that seeks alternatives to herbicides. Presently, herbicide use is restricted in five Canadian provinces (Wagner

1993), and according to Perrin *et al.* (1993), 81% of Canadians think that chemicals used in forest management pose a health risk to humans and to the environment. However, the opinion of the general public may not be based on the scientific facts. Many believe that the debate over herbicide use in forestry stems from a lack of technical understanding by the general public (Wagner 1993).

Although much of the debate over the use of chemical herbicides in forestry may be based on political, economic, institutional or social issues, it has, nevertheless, forced scientists to reexamine changing values and the role of herbicides within these values. Perrin *et al.* (1993) states that a new paradigm in vegetation management is evolving which encompasses a greater focus on the environment, sustainability, natural regeneration and biological diversity. In short, the new paradigm permits a broader view of forest values that shifts away from a primary focus on commodities.

One of the main objectives of the new paradigm is to determine alternative vegetation management techniques that are environmentally sound, economical, and socially acceptable (Wagner 1993). To be environmentally sound, the impact of presently used techniques such as herbicides, as well as that of alternatives must be determined for crop and non-crop vegetation. In addition, the impact of these techniques must be determined for non-target animal organisms. Frequently studied non-target organisms include large mammals such as deer and moose, small mammals, and birds. Less information is known about the effects of vegetation management on the less conspicuous organisms such as terrestrial gastropods, amphibians and reptiles, and terrestrial insects. However, it is known that each vegetation management technique will have different effects for different wildlife taxa depending on their habitat requirements (Lautenschlager 1991, 1993).

Biological diversity, which describes the variety and variability of the world's organisms in terms of genetic, species, community, and biome diversity (Magurran 1988), can serve as a measure in determining the effects of vegetation management on non-target and target organisms. Changes in the composition and diversity of a particular taxon can indicate the level of impact of the vegetation management technique chosen. In order to determine the most suitable vegetation management alternative, its impact must be determined for the whole affected ecosystem. Part of the goal of the Ontario Ministry of Natural Resources' (OMNR's) Vegetation Management Alternatives Programme (VMAP) is to determine the effects of different vegetation management techniques on the whole ecosystem by examining and integrating all of the ecosystem's components.

The main objective of this study, which is a component of the OMNR's VMAP Fallingsnow Ecosystem Project in the Thunder Bay District of northwestern Ontario, was to examine the effects of four release techniques on ground associated insects and other ground associated invertebrates. Manual (brush saws), mechanical (Silvana Selective/Ford Versatile cleaning machine), and two herbicide (glyphosate and triclopyr) release treatments were utilized, as well as a control (no treatment) to determine any changes in ground dwelling insect and invertebrate abundance, composition, and richness. All insects and invertebrates were identified to the Order level. In addition, all Coleoptera were identified to family and all ground beetles (Coleoptera: Carabidae) were identified to species in order to determine any treatment effects. Ground beetles were specifically chosen because they are polyphagous predators and may be good indicators of habitat change (Jennings *et al.* 1986).

The null hypothesis of this study is that the various release treatments tried have no effect on insect, beetle, and carabid beetle composition, abundance and diversity. The alternative to the null hypothesis is that the treatments have an effect.

LITERATURE REVIEW

BIOLOGICAL DIVERSITY

Biological diversity has been defined in various ways. Reid and Miller (1989) define biological diversity as the variety and variability of living organisms and the ecological complexes in which they occur; the variety of the world's species, including their genetic diversity and the assemblages they form. Fielder and Jain (1992) define it as a full range of variety and variability within and among living organisms, their associations, and habitat – oriented ecological complexes. The term biological diversity also encompasses ecosystem, species, and landscape as well as intraspecific (genetic) levels of diversity. It is evident that these definitions of biological diversity are indeed very broad and vague. As presently understood, biodiversity encompasses multiple levels of organization (Noss 1990). In order to measure diversity, one must realize that the three primary attributes of diversity - composition, structure, and function - are nested in a hierarchy that incorporates regional landscape, community-ecosystem, population-species, and genetic components. The biological diversity of any habitat or ecosystem is forever in a constant state of flux, and forests are no exception (Reid and Miller 1989). However, much of the loss of species diversity during the last century can be attributed to human activity (Fielder and Jain 1992).

For anyone who is concerned with maintaining biological diversity, the diversity of insects must be considered, as this is where most of the diversity of animal species lies (Fielder and Jain 1992). Unfortunately, the great diversity of insects also can pose a problem. It is estimated that as little as half of the insect species in Canada have been identified, while an even greater number, go undescribed worldwide (Fielder and Jain 1992). A lack of data on the abundance of insects and other invertebrates means that declines will go unnoticed until drastic reductions have occurred. However, well studied taxa, such as Carabidae, can serve as indicators of change in invertebrate diversity (Frietag 1979, Fielder and Jain 1992).

The Measurement of Biological Diversity

The measurement of biological diversity has been the subject of much debate (Magurran 1988), and a resurgence of the importance of studying biological diversity has placed the spotlight on measures of diversity once again. A review of the literature was completed to determine the admissibility of both parametric and non-parametric measures of diversity.

Many investigations of diversity are often limited to species richness measures (Magurran 1988). Species richness refers to the number of species in a community (Begon *et al.* 1990). Normally, the majority of species are rare in a community, while a number are moderately common with the remaining few species being very abundant (Southwood 1978).

Due to a wide variety of diversity measures, scientists using diversity measurements must be aware of their appropriateness and usefulness. A diversity index should fulfil certain criteria before it can be used in a proper context. Firstly, a diversity index must be able to discriminate between sites (Magurran 1988). Secondly, its dependence on sample size must be determined. If an index is sensitive to the sample size, a mathematical transformation such as rarefaction should be used to standardize sample size. However, standardization often results in a loss of ecological information. Thirdly, the usefulness of an index depends on the component of diversity being measured (e.g. the number of species), and, lastly, the index of choice should be widely used and understood. The best indices are simple to calculate, easy to interpret, and statistically and ecologically sound (Table 1). Today powerful computers and statistical packages make calculations relatively easy.

Parametric Measures of Diversity

The Geometric Series, the Logarithmic Series, the Log Normal, and MacArthur's Broken Stick Model are the four classical species abundance models. The Geometric Series and MacArthur's Broken Stick Model are both based on biological hypotheses, whereas the Logarithmic Series and the Log Normal are of purely mathematical pedigree (May 1975). Each of these models, although used extensively in the past, has limited use in ecological studies.

Table 1. Biological diversity models and measurements in ecological studies

Model	Criterion			
	Site Discrimination	Sample Size Dependence	Measurable Component	Use
Geometric Series	poor	highly dependent	no. of individuals, percent cover, biomass	outdated, rarely found in nature
Logarithmic Series	good	not dependent	no. of individuals, percent cover, biomass	moderate use, highly recommended by Kempton & Taylor (1976)
Log Normal	poor	dependent	Continuous species abundance data	minimal use, discredited
Broken Stick	poor	highly dependent	no. of individuals	outdated, discredited
Shannon-Weiner Index	good	moderately dependent	no. of individuals in ea. species, hierarchical analysis	widespread use, does not correspond to ecological processes
Simpson's Index	poor (1/D better)	moderately dependent	no. of individuals in ea. species,	widespread use, only measures the dominance concentration

The Geometric Series originates from the niche pre-emption hypothesis where a first (dominant) species arrives and takes a proportion, k, of some limiting resource. The second most dominant species arrives and takes the same proportion, k, of the remaining resource, and so on, until the last species arrives (May 1975). The Geometric Series is generally thought to be found in species poor and often harsh environments, or in the very early stages of succession (Magurran 1988). As succession proceeds or as conditions ameliorate, species abundance patterns grade into those of the Log Series. One important determining factor of the Geometric Series is that species arrive at regular intervals.

The Logarithmic Series (Log Series) is thought to provide a good description of small, stressed, or pioneer communities (May 1975), but has been widely criticized for its lack of ecological realism (Hughes 1986). Goodman (1975) states that all theoretical models are unrealistic mathematical representations. However, some studies (Taylor 1978, Kempton and Taylor 1976) investigating the properties of the Log Series Index, a, have highly recommended its use, even when the Log Series distribution is not the best descriptor of the underlying species abundance pattern. Taylor (1978) favours the Log Series due to its good discriminant ability between sites and because it is not unduly influenced by sample size.

The Log Normal, which is based on the Central Limit Theorem (CLT), is said to indicate large, mature, and varied natural communities (Magurran 1988). This model has also been harshly criticized as being ecologically unrealistic. Hughes (1986) adds that direct application of the CLT in the context of this model is criticized because it does not include biological considerations (*e.g.* the effects of extinction). Although the Log Normal is widely criticized, it is still often used to describe large, stable communities (Magurran 1988).

The Broken Stick Model is based on MacArthur's Random Niche Boundary Hypothesis in which he likened the subdivision of niche space within a community to a stick being broken randomly and simultaneously into "s" pieces (May 1975, Magurran 1988). The division of niche space is concerned with the partitioning of only one resource, and the species occupy non-overlapping niches (Pielou 1977). This assumption has been widely discredited. The analogy of non-overlapping niches is unsound if it is postulated that what the species divide among themselves is a multidimensional niche space, since there is no way of randomly partitioning a space of more than one dimension into non-overlapping parts (Pielou 1977). In other words, when a one dimensional space is randomly broken it cannot be extrapolated to spaces of higher dimensionality. However, this objection is countered by postulating that what is divided up by the species is some single abundance-limiting factor.

Other problems of this model include a strong sensitivity to sample size and that it is only characterized by the number of species (because their abundances are so even) (Magurran 1988).

Non-parametric Measures of Diversity

Non-parametric indices of diversity make no assumptions about the shape of the underlying abundance distribution of the variable being studied. This is the one major difference between the parametric measures and the non-parametric measures of diversity. The Information Statistic Indices and the Dominance Measures are the two main categories of non-parametric indices. The Shannon -Weiner Index, H', and Simpson's Index, D, are the most popular indices which represent each of the two main categories, respectively.

The Shannon-Weiner Index is based on the rationale that the diversity, or information, in a natural system can be measured in a similar way to the information contained in a code or a message (May 1975, Magurran 1988, Begon *et al.* 1990). The Shannon-Weiner Index makes two assumptions: firstly, individuals are randomly sampled from an infinitely large population, and, secondly, all species are represented in the sample. The Shannon-Weiner Index has been the subject of much debate. Advantages to its use include being a good discriminator between sites (May 1975). In addition, if several samples are taken, their index values have been found to follow a Log Normal distribution (Taylor 1978).

Therefore, use of this index can be followed up with parametric tests such as t-tests and ANOVA. The Shannon-Weiner Index can also be used for hierarchical analysis (Magurran 1988). Hierarchical analysis considers the variety of diversity at other than the species level. The major advantage in using the Shannon-Weiner Index is its widespread popularity and use, despite some major problems.

The Shannon-Weiner Index may be one of the most popular in use, but after reviewing its drawbacks one wonders why it is used at all. The Shannon Index is insensitive to the number of rare species (Magurran 1988). Goodman (1975) states that the Shannon Index becomes progressively less sensitive to the addition of new species, or to altered abundances because these come to represent progressively smaller fractions of the total. In addition, the diversity measure becomes even less sensitive when large sample sizes are used because of its logarithmic nature.

Another major problem in using this index is that the amount of error increases as the proportion of species represented in the sample declines. The second assumption of the Information Statistic states that all species are represented in the sample. If this is not the case, due to small sample size or the actual sampling method, the error in the index value increases. Several authors (Goodman 1975, Alatalo and Alatalo 1977, Kempton and Taylor 1976) strongly discredit the Shannon-Weiner Index because it is an attempt to give a one dimensional description of species abundance. Alatalo and Alatalo (1977) state that this index fails to show interaction of dimensions and determines dimensions to be independent, while Goodman (1975) further descredits the index by arguing that there does not seem to be any ecological process that corresponds to this "imaginary" ordering of individuals. In other words, the index values do not reflect any biological mechanisms. Pielou (1972) states that the use of two or more indices may be required to do justice to the complex notions of niche and diversity.

Simpson's Index, a Dominance Measure, gives the probability of any two individuals drawn at random from an infinitely large community belonging to different species. Simpson's Index is also one of the most popular diversity indices in use (Magurran 1988). However, it also possesses some fundamental problems. The major criticism of this index is that it tends to be a measure of the "dominance" concentration, or in other words, it is a measure of the most common species and the rare species have little influence on the statistic (May 1975, Pielou 1977, Magurran 1988, Begon *et al.* 1990). Moreover, Simpson's Index is a poor discriminator between sites. Since most studies of diversity involve comparisons between sites, Simpson's Index does not seem to be the best choice. However, its reciprocal is a better discriminator, but it is still not as good as Shannon's. As well, Simpson's Index shows some sensitivity to sample size.

Ecologists have moved away from the use of the above types of diversity measurements towards complex, but more ecologically accurate, analyses including methods found in multivariate statistics. Instead of focusing on one indicator species, ecologists must measure diversity at different levels of organization and integrate the results (Noss 1990). Noss (1990) outlines four levels of organization: regional landscape, community-ecosystem, population-species, and genetic. This hierarchy concept implies that biological diversity be monitored at multiple levels of organization as well as at multiple spatial and temporal scales. Although complex, this integration of information can lead to more ecologically accurate descriptions of the organizational level of interest,

PITFALL TRAPPING

A review of the literature indicates both benefits and limitations in using pitfall traps as a sampling method for ground dwelling insects and invertebrates. Marshall *et al.* (1994) state that passive methods, such as pitfall trapping, collect large numbers of specimens, and remove bias, which is introduced in active sampling methods by differing abilities of individuals to collect specimens. In addition, passive methods are less labour intensive, and many species not usually captured by active methods can be trapped. Other advantages of pitfall trapping include low monetary expense, supplies that are readily available, extensive use in previous studies, the limitations have been studied, and live trapping, baiting, and immatures are all possible (Marshall *et al.* 1994).

In contrast to the many advantages of pitfall trapping, several limitations of the method also exist. According to Marshall *et al.* (1994), biased sampling, flooding, and the entrapment of tourists are all possibilities. Clark and Bloom (1992) agree that bias may be introduced in pitfall trapping when covers over traps are used, because the covers may help in attracting thigmotaxic invertebrates seeking covering objects.

Several factors affect variation in trap catches, such as temperature, the amount of ground vegetation, the differential susceptibility of species to trapping (due to their behaviour), population size, and locomotor activity (Greenslade 1964, Luff 1975, Adis 1979, Halsall and Wratten 1988, and Topping and Sunderland 1992). Luff (1975) concluded that trap efficiency also depended on the size, shape, and material of which it is made, as well as the characteristics of the species likely to enter the trap, such as animal size. According to Luff (1975) glass traps have the best retaining efficiency, followed by plastic then metal. In addition, larger traps are more efficient than smaller traps as they can trap both larger individuals and a greater numbers of individuals (Luff 1975). In concordance with Luff, Adis (1979) notes the importance of the diameter of the trap in relation to sampling effectiveness of pitfall traps.

With respect to ground beetles (Coleoptera;Carabidae), it was determined by Greenslade (1964) that while direct population counts in quadrats showed similar numbers of diurnal and nocturnal species, pitfall traps contained significantly higher numbers of nocturnal species than diurnal. Conversely, Halsall and Wratten (1988) found no differences in the capture rate between diurnal and nocturnal carabid species. However, Baars (1979a) found that day-active carabid species are caught less in traps with dark roofs, whereas night-active species showed no difference in numbers caught under dark or light coloured roofs.

In a study comparing pitfall trapping and soil sampling in assessing carabid beetle populations, Briggs (1960) reported that temperature was a main determining factor in the numbers of carabids caught in pitfall traps. He found that increases in numbers caught were often associated with higher temperatures and recent rain falls (Briggs 1960). Dennison and Hodkinson (1984) agree that the efficiency of pitfall trapping should rise with temperature as the motility of the beetles increases.

Much of the literature on pitfall trapping indicates difficulties in interpreting the data. Because of the large number of uncontrollable variables, such as temperature and rain fall, pitfall trap data interpretation must be used with caution. Direct estimates of population density of particular species are difficult due to the many potential sources of error (Southwood 1978, Dennison and Hodkinson 1984). However, Uetz and Unzicker (1976) found pitfall trapping gave a closer estimate of the total number of species in a community than quadrat sampling. They suggest that pitfall trapping can be used, with caution, in ecological studies. Baars (1979a) found that the use of continuous pitfall sampling could be used as a relative measure of the size of carabid populations.

Spence and Niemela (1994) compared pitfall trap catches of carabids to quantitative data about beetle density obtained by litter washing, and found that the same species that dominated the pitfall samples were also found numerously in litter washing samples, but the relative abundance of species collected by the two methods differed. For example, *Pterostichus adstrictus* Say comprised up to 57% of the catch in pitfall traps but only 14% using the litter washing technique. Spence and Niemela (1994) generally concluded that large bodied species were relatively more common in the pitfall traps while small bodied species were more common in litter washing. In addition, they state that pitfall samples are most useful for comparing carabid activity from year to year or across similar habitats. Moreover, pitfall trapping is the only alternative when conducting surveys of large geographical areas where the objective is a qualitative inventory and comparison of assemblages.

In attempt to decrease the amount of unexplained variance in the correlations and improve the accuracy of any predictions based on them, Dennison and Hodkinson (1984) utilized a transformation, which gave them a better measurement of species diversity of the total beetle population. However, Dennison and Hodkinson (1984) indicate results which are based on a single sampling techniques may be subject to large errors.

Several assumptions must be made in using pitfall trapping as a sampling method. Firstly, the researcher must assume that the composition of the catch corresponds to the relative abundance in the field (Topping and Sunderland 1992), and, secondly, that every species has an equal chance of being captured (Halsall and Wratten 1988). Halsall and Wratten (1988) determined this second assumption to be false for species of Carabidae as they related differences in capture rates to the differing ability of carabid species to perceive the trap edge. They also indicate that species with special physical abilities, such as the ability to climb, would be poorly represented in field catches, even if present in high densities.

GROUND-BEETLES (COLEOPTERA, CARABIDAE)

Ecological Functions of Carabidae

Feeding by Carabid Beetles

Carabids appear to be primarily opportunistic, polyphagus predators (Jennings *et al.* 1986). The majority of the knowledge gained on the subject of carabid nutrition has been formed through laboratory observations, at least for carabids with extraintestinal digestion. However, field investigations have also been conducted on carabids by way of analyses of the contents of the digestive tract. Thiele (1977) states that this method of investigation is only applicable to carabids that tear up and ingest their prey with little or no extraintestinal digestion. Skuhravy (1959) studied the crop and intestinal tracts of 2382 carabid beetles from 12 different species and found differences in composition of diet. He also found that some species consumed varying proportions of plant matter, and, in a few cases, food composition varied according to season. In general, prey items of carabids in Skuhravy's (1959) experiment consist of Arachnida, Acari, Formicoidea, Lepidoptera larvae, Aphidoidea and other Homoptera, Coleoptera and their larvae, Tenthredinidae larvae, Thysanoptera, Heteroptera, Dermaptera, Collembola and Chrysopa larvae.

Most carabid species tend to consume a wide variety of prey items, while only a few genera show a high degree of specialization (Thiele 1977). The bulk of investigations reveal that carabid species of approximately the same size show similar preferences with respect to prey in any one habitat. However, the large variety of prey items indicates that competition for food is not an important factor for carabids.

A study on prey recognition of Cicindelidae, a family previously included in the Carabid family, revealed visual stimuli to be of great importance (Faasch 1968). In their natural environment as well as in the laboratory, Cicindelidae were able to perceive prey the size of *Cantharis* at a distance of 20-30 cm and prey the size of an ant at about 10 cm. Cicindelidae will randomly pick up objects in their path and then use chemical cues to distinguish between food items and non-food items. However, the behaviour of the various carabid species will differ from that of Cicindelidae depending on several factors including whether or not the species is diurnal or nocturnal and the importance of animal protein in the diet. A nocturnal species may use chemical senses in locating prey items more than it uses visual cues.

It has been known for years that plant material constitutes a certain proportion of many carabid species' diets (Thiele 1977). Some species are able to utilize both plant and animal matter, while others are exclusively carnivorous or herbivorous. Johnson and Cameron (1969) determined the uptake of plant material by various ground beetle species. Laboratory results on 14 species including three *Amara,* three *Anisodactylus,* three *Agonum,* three *Harpalus, Agonoderus pallipes,* and *Pterostichus vulgaris* indicated that they all ate grass seeds in varying quantities, even when animal matter was available at the same time.

Some carabid species have been shown to consume insect eggs (Van Dinther and Mensink 1971). A preference of house-fly eggs (*Musca domestica* L.) was found for three species of *Bembidion,* a group of small-sized carabids. However, other species consumed eggs only on occasion, while larger species including *Pterostichus* showed little interest in the eggs. Findings such as these have helped to establish carabids as pest control agents in agriculture and forestry.

Brunsting *et al.* (1986) examined the role of larvae in the population ecology of Carabidae. Brunsting *et al.* (1986) found that cannibalism is an important mortality factor for carabids even at natural densities. Cannibalism was also influenced by the amount of food available. Loreau's (1990) findings agree with that of Brunsting *et al.* (1986).

Activity Patterns in Carabidae: Annual Activity and Life Cycles

As a general rule, all carabids have only one generation per year in the temperate zones (Thiele 1977). However, Loreau (1985) stresses the variability of the cycle in many species, and, in particular, along a latitudinal gradient. A nordic winter forces carabids to concentrate their activity towards summer and to conform to a strict life cycle pattern, while milder winters further south allows life cycles to be more flexible and more evenly distributed throughout the year.

Carabids can hibernate as adults or as larvae (Thiele 1977). Reproduction can occur at different times of the year. "Autumn-breeders" reproduce in autumn or in mid- summer onwards and normally hibernate as larvae. "Spring-breeders with autumn activity " hibernate as adults and breed from spring to early summer after which the majority die off. The new generation appears in the autumn as it becomes fully active and reproduces subsequent to hibernation. "Spring-breeders without autumn activity" follow the same pattern as those with autumn activity except the young beetles exhibit very little activity following eclosion in autumn. Dormancy is governed by photoperiod for some species and temperature for others depending on their life cycle.

Loreau (1986) examined niche differentiation and community organization in forest Carabid beetles. He found that the annual activity cycle and diet are the two main characteristics responsible for niche differences among coexisting species. In general, species with similar periods of activity have different diets, and species with similar diets have different periods of activity. Moreover, it is the expectation that closely related species tend to have similar niches and that niche differentiation may then occur in a more precise manner.

Carabid Mobility

Thiele (1977) examined the speed of locomotion of various carabid species from widely differing habitats. He revealed speeds of approximately 10 cm/s over 30 cm distances on a smooth surface. These speeds correspond to several metres per minute. In a field investigation Refseth (1980) found that habitats with an open field layer permitted greater speed of movement which resulted in greater trapping frequencies than those obtained in habitats with a more dense vegetation cover. Refseth (1980) emphasizes that his remarks apply particularly to larger species, which tend to move faster than smaller ones, and are more easily trapped.

It seems carabids have adapted their locomotor habits to their life styles. Evans (1986) found that carabids extend over much of the speed/force spectrum clearly indicating carabid beetles' capabilities as speed/force specialists (force being the equivalence of strength). Evans (1986) investigation revealed that burrowing species tend to possess more massive legs and have larger muscles for stronger wedge and horizontal pushing. However, larger, stronger legs reduce maximum sprint speed as the beetle's stride is slower. Moreover, Evans (1986) links rapid running as the ancestral norm while pushing/burrowing represents newly evolved behaviour.

Knowledge of the potential speed of carabids does not reveal the actual patterns of their movement. Baars (1979b) revealed two patterns of movement: "Random Walk" and "Directed Movement". "Random Walk" is characterized by the coverage of small distances and a continual change of direction, while "Directed Movement" is characterized by the coverage of long distances in a more or less constant direction. In his experiment Baars (1979) noted directed movement up to 87 m /day, and supposed that directed movement was a valuable strategy for escaping unfavourable habitats. Furthermore, Baars (1979) inferred that the random walk was the result of frequent encounters with food.

An investigation on carabid mobility by Grum (1971) found that satiated individuals showed low mobility while hungry ones were very mobile. These results seem to concur with the findings of Baars (1979b) in that random walk covers short distances and frequent encounters with food. Grum (1971) determined that for two species, *Pterostichus oblongopunctatus* Fabricius and *P. vulgaris* auct. nec Linnaeus, mean mobility decreased along with improved site conditions and was highest on the periphery of the population area.

Many carabid beetles possess the ability to fly, however, den Boer (1971) considers this ability to be primal. Flight of carabids is closely related to the presence and degree of development of the hind wings. Many species have lost their hind wings over evolutionary time or they have become polymorphic or dimorphic (Thiele 1977). Within a species or within a single population, individuals with well developed hind wings (macropterous) may occur alongside individuals with reduced hind wings (brachypterous). According to Thiele (1977), even individuals with well developed wings are not necessarily capable of flight. A species such as *Pterostichus oblongopunctatus*, which possesses well developed hind wings is not known to fly. Paarmann (1966) suggests that the ratio of body length to wing length (1:0.68) is not sufficient for this species to fly. In other words, the wings are too small in relation the body size. Crowson (1981) suggests that the macropterous condition is most often found in unstable populations where dispersal is common, whereas, the brachypterous condition is found in more stable populations. Similarly, Mader (1986) indicates that the majority of pioneer species tend to be fully winged, while non-pioneer species (eg. transitional species and second colonization species) tend to have slightly less of a tendency to be fully winged. In addition, Mader (1986) states that variations in the carabid fauna are due to changes in the environment, especially the vegetation.

Spatial Distribution of Carabids

It has been determined by Niemela (1990) and Niemela *et al.* (1992) that ground-beetles show non-random spatial distributions both within and between habitats. Niemela (1990) found that ground-beetles tend to occur in aggregations and were associated with particular microhabitat types. Niemela (1990) also determined that ants can affect the small scale distribution of carabids where an increase in the ant catch corresponded to a decrease in the carabid catch. Results of Niemela *et al.* (1992) indicated that the forest is a patchy environment for carabids and that variation in soil moisture is an important factor in carabid distribution.

Historical literature concerning the distribution of ground-beetles and ants indicated that ants did not have a large role as enemies of carabids (Thiele 1977). However, Kolbe (1968) determined that ants can exert a considerable influence on carabid populations. The results of a field study indicate a sharp decrease in numbers of individuals and of species of carabids and all other soil-dwelling Coleoptera in the vicinity of ants's nests. Kolbe (1969) states that carabids are attacked and can be injured by ants, and that ants can exert a definite influence in the chances of a carabid occupying a particular habitat.

Humidity and Carabids

Most humidity experiments are conducted in laboratories using choice chambers. Anderson (1985) examined the humidity responses and water balance of riparian species of the tribe Bembidiini (Coleoptera: Carabidae). He utilized choice chambers with varying levels of humidity and temperature. Several species initially showed a hygronegative reaction followed by a change to a hygropositive one. Andersen (1985) found that the duration of the hygronegative reaction varied with species age, temperature, and relative humidity. Two species, *Bembidion litorale* (Olivier) and *B. semipunctatum* (Donovan) changed response when they had lost 8-9% of their initial body weight in water. In addition, transpiration rate appeared to be inversely proportional to the relative humidity.

In humidity responses of species of Bembidiini a correlation between between behaviour/habitat affinity and humidity response exists (Andersen 1985). For example, diurnal species living in sandy, silty, or half exposed habitats had an initial hygronegative response, whereas those species which hide among gravel/ stones, leaves or vegetation were indifferent or hygropositive. Other studies do not show such a definite trend. However, Thiele (1977) points out that carabids possess a very well developed ability to distinguish between small differences in air humidity.

Preferred Light Intensity and Habitat Affinity

According to Thiele (1977), a definite correlation between preferred light intensity and habitat affinity exists. Generally, carabids which show a preference for light in a light intensity gradient tend to be day active. Similarly, carabid species showing a preference for darkness were almost always night active. Species exhibiting no preference were often both day and night active. Furthermore, night active carabids preferring darkness were most often forest species and day active carabids showing various degrees of light preference were most often field species.

CARABID BEETLES AS BIOLOGICAL INDICATORS

The use of carabid beetles as biological indicators has been well documented. According to Refseth (1980), carabids are well known taxonomically, therefore, their identification is easy. As well, most species are restricted to a particular habitat but are able to move in response to environmental changes. Jenkins (1971) indicates pertinent criteria for the selection of biological monitoring organisms. These criteria include: 1. Cosmopolitan, 2. Abundant, 3. Sensitive to pollution - fragile, 4. Show well defined response, a. change or mutate, b. die or decrease, c. replacement, 5. Nontarget species - not objects of control, 6. Changes visible by remote sensing. Based on the above criteria and on previous studies of carabid beetles and pollution, carabids meet at least five of the six criteria, indicating that the role of Carabidae as bioindicators is limitless (Freitag 1979). Present and future studies may be able to utilize remote sensing to show changes over large geographical areas. Other sensitive criteria may comprise of a sufficient sensitivity to provide an early warning of change, a capability of providing a continuous assessment over a wide range of stress, a relative independence of sample size, easy and cost effective to measure, collect, assay, and/or calculate, an ability to differentiate between natural cycles or trends and those induced by anthropogenic trends, and a relevance to ecologically significant phenomena (Cook 1976, Sheehan 1984, Munn 1988).

Specific sensitive criteria of early warnings of change are given by Freitag (1979) who showed that carabid beetles are sensitive to a variety of pollutants, such as oil pollution, atmospheric pollutants, traffic pollution, insecticides and herbicides. Duchesne and McAlpine (1994) also recognize carabid beetles as indicators of soil diversity after disturbances caused by a variety of factors including forest fire, clear-cutting, scarification, pollution, land reclamation, management of primeval or old growth, and climate change. Moreover, carabids are good indicators of biological communities because they are important predators in forest soils.

The effects of insecticides on carabid beetles has been studied extensively (Freitag *et al.* 1969, Freitag and Poulter 1970, Freitag *et al.*

1973, Tomlin 1975). Each of these studies found decreases in carabid populations during and after the spraying of insecticides. In the study conducted by Freitag and Poulter (1970), it appeared that one year after the forest was sprayed, there was a suppression of the arthropod population at sprayed stations.

CARABID DIVERSITY

Modern herbicide formulations are generally much less toxic than the herbicides of the past. Brust (1990) investigated the direct and indirect effects of four herbicides including atrazine, simazine, paraquat, and glyphosate on the activity of carabid beetles. This field study, which was conducted at the Central Crops Research Station in Clayton, North Carolina, tested for acute and chronic toxicity, and repellent effects on five common carabid beetles (*Amara* sp., *Agonum* sp., *Pterostichus* sp., *Anisodactylus* sp., and *Harpalus* sp.). None of the herbicides produced any significant acute or chronic effects on carabid longevity and food consumption during one year after exposure to initial field rate applications. However, carabids seemingly responded to the destruction of plant material which, after treatments, became less favourable to larger carabids (> 10 mm in length). In addition, both glyphosate and paraquat had the greatest effect on carabids within two weeks of treatments as fewer large carabids were found in these treatments compared to the control. On the other hand, the treatments tended not to have an effect on smaller (<10 mm) carabid beetles. Brust (1990) argued that with the loss of canopy cover, soil surface temperatures tend to increase and soil moisture levels decrease. This habitat change may create an unfavourable habitat for many of the larger carabids and possibly for their prey (earthworms, collembola, crickets, lepidopteran larvae), while smaller carabids are able to cope by burrowing into the soil. Butterfield and Coulson (1983) also contend that a change in physical factors of a particular habitat including soil water content, vegetation height, and temperature will affect the carabid beetles found in that habitat. The previous findings of Newton (1975) reinforce this idea adding that while spray treatments have no physical impact, wildlife habitat is modified mainly with regard to changes in ratio of favoured food species.

House (1988) conducted a comparable agricultural study, which also occurred at the Central Crops Research Station in North Carolina. One of the objectives of the study was to quantify the impact of tillage practices and herbicide usage on soil arthropod population dynamics and trophic composition. Ground beetles were specifically examined because of their role as a beneficial predator of agriculture pests. Eight treatments were designed forming a gradient from the highest disturbance (conventional tillage, summer crop cultivation, and herbicides applied) to the lowest disturbance (continuous no-tillage, no herbicides). Results showed that predatory soil arthropods, which were predominantly ground beetles, were most abundant in the no-tillage with herbicide treatment. Similar numbers were found in all of the remaining treatments. Other predatory arthropod taxa caught included staphylinidae (Coleoptera), ants (Hymenoptera; Formicidae), spiders (Acarina; Araneae), and centipedes (Chilopoda).

Carcamo *et al.* (1995) conducted a similar study which examined the effects of agronomic practice on ground beetle populations and community structure. The experminent was performed on cultivated land at the Ellerslie Research Farm near Edmonton, Alberta. A nearby uncultivated meadow was also studied for comparison to determine the general impact of cultivation on carabid abundance, diversity and dominance. Treatments included combinations of chemical, organic, conventional tillage and non-tillage farming regimes. Carcamo *et al.* (1995) found that ground beetle abundance and species richness were higher in plots operated under an organic farming regime than in those under a chemical regime. However, carabid abundance was highest in the uncultivated meadow.

Several authors have studied carabid diversity and, specifically, patterns in diversity in a changing environment. In southern Belgium Baquette and Gerard (1993) determined the effects of spruce plantations on carabid beetles. They found that colonizing species, which were mainly either generalist species (well fitted to colonization) or forest species, generally associated with young spruce plantations (< 10 years). Also, the greatest number of carabid species was found in the 5 year old spruce plot as opposed to older spruce plots. In addition, their study showed that the age of the plantation affects both species composition and richness of carabid communities, and these variations are correlated with changes in both structural and vegetational characteristics of the plantations.

The impact of forest cutting on the diversity of carabid beetles has also been examined. Lenski (1982a and b) utilizing live pitfall trapping and hierarchical analysis of diversity, found a significant increase in the within-genus component of species diversity after forest cutting. However, the trend in intrageneric diversity was obscured by a nonsignificant reduction in diversity at the generic level. Specifically, Lenski (1982b) found the abundances of *Carabus limbatus* and *C. sylvosus* were much more evenly distributed in the clearcut than in the forest.

Jennings *et al.* (1986) investigated carabid beetles associated with strip clear cuts and a dense spruce-fir forest in Maine. Three levels of cutting were examined including clearcut strips, uncut residual strips, and dense spruce-fir stands. For both of the study years (1977-78), significantly more individuals were collected in the uncut residual strips than in clearcut strips or dense stands. These results indicate that strip clearcutting may contribute to species diversity of carabid beetles in northeastern United States spruce -fir forests as both species richness and evenness were increased in strip-clearcut stands than in dense stands.

Moreover, their results support the hypothesis that disturbances tend to increase species diversity. Jennings *et al.* (1986) also add that uncut residual strips provide islands of habitat where species and populations are maintained.

Niemela *et al.* (1993a) studied the effects of clearcut harvesting on boreal ground beetle assemblages in Western Canada. They used pitfall data to compare relative abundances within species between habitats, and to assess habitat effects on carabid diversity. Results indicated that logging did not have a negative effect on species richness, which actually increased after cutting. However, some mature forest specialists did disappear after logging. Niemela *et al.* (1993b) outlined general responses of ground beetles to logging; 1) initially, species typical of open, grassy habitats increase, 2) forest generalists decrease but seem to recover with forest regeneration, and; 3) some mature forest specialists fail to colonize regenerating forests and are at risk of extinction in logged patches. These conclusions concur with the previous results of den Boer (1985) where he stated that rapid and large scale changes in the environment will favour opportunistic species, whereas most specialist species may die out.

In a comparison of the effects of logging and ground beetle assemblages in western Canada and Finland, Niemela *et al.* (1992) found that catches on both continents were equally high or higher on sites cut less than 10 years ago than for sites in the mature forest. Similar changes in carabid assemblages on the two continents were summarized as follows; 1) high overall abundance in the recently cut sites, 2) high species richness in the regeneration sites compared to the mature sites, and; 3) disappearance of some mature forest specialists. These conclusions strongly agree with the previous conclusions of Day and Carthy (1988) whose research supports the hypothesis that the clearance of natural or semi-natural forest often results in new fauna with a loss of forest specialists.

Duchesne and McAlpine (1994) studied the effects of scarification with fire, and clearcutting without fire against a control on carabid species composition, number of catches, and species diversity. They found that burned over sites had the highest species diversity. Duchesne and McAlpine (1994) also contend that the different results among the treatments may be a consequence of physical and chemical site factors such as temperature, vegetation cover, soil water content, or by the influence of site conditions on carabid prey. In a similar study Parry and Rodger (1986) analysed the effect of soil scarification on the ground beetle fauna of a Caledonian pine forest in Scotland. The three habitat types in their study were a natural forest (no forestry operations), scarified Caledonian pine areas, and riverine areas with scattered tree cover. Parry and Rodger (1986) found that scarified forests had the highest species diversity of the three habitat types. These results agree with that of

Duchesne and McAlpine (1994) in that natural forests with no forestry practices tend to have lower species diversity than scarified forests.

While logging operations may virtually eliminate many plant species from an area, release treatments tend only to change the relative abundance of plant species(Lautenschlager 1991, 1993). Individual species are seldom eliminated because treatments are designed to reduce competitive vegetation, not eliminate it. In addition, treatment areas often contain skips (ie. areas that are missed by treatments), and low growing vegetation is often excluded by sprays as it is sheltered by taller vegetation.

RELEASE TREATMENTS

Mechanical Release Techniques

Before widespread use of herbicides, manual release with brush saws was a primary mode of competition removal. However, due to high labour costs and worker injury, chemical alternatives seemed preferable to many forestry companies and forest managers. In the wake of a renewed environmental awareness in the late 1980's non-chemical vegetation management techniques were again being sought. Manual vegetation management with brush saws is now looked upon as a more "environmentally friendly" alternative to chemical herbicides. However, virtually no studies have considered the effects of manual techniques such as brush saws on non-target organisms including insects. I reasoned that this lack of information is due to the fact that when manual techniques were widely utilized, environmental assessments were not common practice. Also, no literature exists which compares chemical and non-chemical methods of release on non-target biota. However, the differences between chemical and non-chemical methods can be measured by the differences in the behaviour of ecosystems, while these ecosystems are headed towards the same long-term objectives (Newton 1975).

In addition to chemical and manual methods, the combination of technology and ingenuity has brought forth new mechanical techniques in vegetation management. The Silvana Selective/Ford Versatile Cleaning Machine was created through the addition of Swedish technology (a boom) mounted onto a conventional Canadian Ford Versatile bidirectional tractor (St. Amour and Ryans 1992). The boom itself has a reach of 5.5 metres with four cutting heads sandwiched between two discs. St. Amour and Ryans (1992) made an operational assessment of the Silvana Selective/Ford Versatile cleaning machine and found that in Quebec, the Silvana Selective/ Ford Versatile operation can be economical for plantation cleaning.

The Ontario Ministry of Natural Resource's Vegetation Management Alternatives Programme (OMNR's VMAP) is assessing the Silvana Selective/Ford Versatile cleaning machine for its environmental impact at the Fallingsnow Ecosystem Project located southwest of Thunder Bay, Ontario. In this study the machine was used for only the second time in Canada. Sweden experienced a similar pull away from chemical herbicides in the late 1970's, resulting in a research program to develop mechanized cleaning machines. After various systems were developed and tried, the Silvana Selective cleaning machine was created. This latest system is the most advanced in that the tractor has a ground clearance of fifty-eight centimetres (cm) when equipped with one-hundred and forty-seven cm diametre tires, and the boom is able to maintain the same height in the horizontal plane while being retracted or extended. The Silvana Selective/Ford Versatile cleaning machine has not been the subject of a non-target impact study before now, therefore, the only information found is operational in nature.

Herbicides

Herbicides are used predominantly for weed and brush control, both for the establishment of seedlings as well as for the release of seedlings from competing species (Norris 1984). All herbicides used in Canada must undergo stringent testing and be registered for use, and their use is limited to label instructions. According to Norris (1984), traditional risk assessments are generally assessments of single organisms, not of ecosystems. Additionally, he states the importance of studying the indirect effects of herbicides, which have been largely ignored, and which "may be of equal or greater importance in maintaining the structure and function of an ecosystem and the well being of its inhabitants". Since herbicides directly affect plant cover, the animal habitat is modified which, consequently, influences the carrying capacity for specific wildlife species. Indirect effects of forest release using herbicides can be long lasting as they can transform the short term composition as well as the long term course of succession of the plant community (Newton and Norris 1976). Furthermore, the development of a dominant tree cover affects all subordinate vegetation, thus, indirectly affecting all non-target biota.

In a study by Mayack *et al.* (1982), abundance of terrestrial invertebrates in herbicide treated forested watersheds was compared to abundance in control watersheds. Mayack *et al.* found no consistent variation in the abundance of Acarina and other forest invertebrates in hexazinone treated watersheds and the controls. However, devegetation of a forested ecosystem can disrupt the regulation of several processes such as the hydrologic cycle, energy flow, decomposition, mineralization, erosion, and nutrient cycling, thus the disruption of these processes would probably alter the abundance of terrestrial invertebrate communities within the ecosystem. Mayack *et al.* (1982) conclude that the removal of the vegetation, not herbicide toxicity, is probably responsible for the decrease in abundance in the macroinvertebrates, while the increase in light and heat at the forest litter layer probably forced smaller invertebrates deeper into the soil.

Herbicide use versus mechanical site preparation was studied by Nelson *et al.* (1984). Nelson *et al.* (1984) found that a long term comparison of growth and yield would be required for a proper comparison, but added that weed competition can be severe on good sites following mechanical site preparation.

Glyphosate

Glyphosate, the active ingredient in the herbicide Vision, has been the subject of many studies since its registration for site preparation and conifer release in Canada. Glyphosate is a non-selective herbicide, effective on grasses, herbs, deep-rooted perennial weeds, brush and trees (Canadian Pulp and Paper Ass. 1985). In spray applications, glyphosate is absorbed through the leaves and is translocated throughout the plant. The function of glyphosate is to inhibit the formation of an essential amino acid in plants, causing metabolic failure and death. In conifer release, spraying must be carried out after the conifers have developed well-set buds and before abscission begins.

Glyphosate is practically non-toxic to pollinator invertebrates (Canadian Pulp and Paper Ass. 1985). In addition, there is a lack of retention, and a rapid elimination of glyphosate shown in studies which indicates that bioaccumulation in the food chain will not occur. Most aerially applied glyphosate is non-mobile in soils. Vision contains IPA glyphosate, which readily biodegrades in soil into carbon dioxide, water, nitrogen, and phosphorus (Canadian Pulp and Paper Ass. 1985).

Several studies on the adsorption, persistence, movement, and degradation of glyphosate in different soil types have been undertaken with varying results. Eberbach and Douglas (1983) found that while glyphosate may be rapidly inactivated in some soils, this is not the case for all soils. They have indicated that inactivation is slow in soils of high sand content. In Saskatchewan soils, Smith and Aubin (1993) reported faster degradation of glyphosate in clay soil than in a loamy sand. Similarly, Glass (1987) revealed that the adsorption of glyphosate decreased in the following order: clay loam > silt loam > sandy loam, and he indicated that adsorption appears to be related to the clay content of the various soils. These results are in concordance with Sprankle *et al.* (1975) who reported that more C^{14} glyphosate was absorbed by a clay loam than a sandy loam. In addition, Glass (1987) reported that soil pH had no effect on glyphosate adsorption.

An important finding on the dynamics of glyphosate in Canadian boreal forest soils was discovered by Roy *et al.* (1989). In this study Roy *et al.* (1989) determined that glyphosate was essentially non leachable and non mobile down an 8 degree slope in either the run off water or through subsurface flow in one selected clay site. Similarly, Feng and Thompson (1990) found that glyphosate was not susceptible to leaching.

Glyphosate has been reported as being a non-toxic substance to non-target organisms. One recent study by Wardle and Parkinson (1990) demonstrated how glyphosate may even be utilized by living organisms. Their study indicated a stimulatory effect of the herbicide on soil bacterial numbers and fungi. A likely explanation for the effect is that many fungal species utilize glyphosate as a resource, and, although glyphosate may influence fungi directly, the chemical may also have indirect effects on organisms which utilize and interact with the fungus.

Kreutzweiser *et al.* (1989) determined the effects of glyphosate on the drift response of stream invertebrates. They found that the application of glyphosate on or adjacent to small stream tributaries of Carnation Creek did not result in undue disturbance of stream invertebrates. However, Kreutzweiser *et al.* (1989) did find that aerially applied glyphosate did produce, at most, slight and ephemeral drift increases of one mayfly species.

A Forest Research Report of the Nova Scotia Department of Lands and Forests (1989), found that lower than recommended rates of Vision^{tm} were effective in controlling the major species of competing vegetation in that region, including raspberry and red maple. As these are early results (two years after application), substantial decreases in the competition indicy of all competing species together resulted, even when using the lowest rates of Vision^{tm}. Additionally, when a decrease in the cover of target species occurred, a considerable increase in the cover of non-target species occurred.

Triclopyr

Similar studies have been made on the effects of triclopyr, the active ingredient in the herbicide, Release, on various environmental components. Triclopyr is used in right of way, forest, and range vegetation management programs (Bentson and Norris 1991). In a study which determined foliar penetration and dissipation of triclopyr butoxyethyl ester herbicide on leaves and glass slides in the light and dark, Bentson and Norris (1991) demonstrated the importance of temperature in the decomposition of triclopyr BEE from deposits. They found that a rise in temperature caused an exponential increase in the decomposition of triclopyr BEE, and an increase in foliar penetration depending on species. In addition, Bentson and Norris (1991) reported that triclopyr penetrates the foliage of some plant species more readily than others, and where there is greater foliar penetration, triclopyr loss is reduced. The importance of photodegradation of triclopyr was also evident when other processes such as wash-off, metabolism, and volatization were not in operation.

Unlike glyphosate, triclopyr dissipates rapidly in both clay and sandy soils (Stephenson *et al.* 1990). However, similar to glyphosate, 90% or more of the triclopyr was recovered from the upper organic layer of both clay and sandy soils. As well, Stephenson *et al.* (1990) reported little, if any, difference in leaching of triclopyr in the two soil types; both soil types demonstrated little mobility of the chemical, therefore, problems with persistence and mobility in soils typical of northern Ontario forestry soils are not likely to occur. These results agree with the earlier findings of Lee *et al.* (1986), who reported no movement of triclopyr and its ethylene glycol butyl ether ester in a forest soil. The soils' sorptive capacity was high enough for all residues to be held at, or near, the point of application. Triclopyr has also been found to be non persistent in a northern Ontario aquatic environment (Solomon *et al.* 1988). Only 5% of the chemical was present after 15 days, while detectable residues were not observed after 42 days.

Fewer studies have been conducted on the toxicity of triclopyr and its biproducts on non-target organisms. Gerzich *et al.* (1984) examined the acute and chronic toxicity of triclopyr to *Daphnia magna* Straus, and found that chronic toxicity was not a factor unless the environmental concentration in water was three times greater than the maximum rate of application.

METHODS

STUDY AREA: LOCATION AND DESCRIPTION

The study area was located within the Great Lakes - St. Lawrence Forest Region in the Quetico Forest Section. This is an area west of Lake Superior along the Canada - United States border, extending north just beyond the 49th parallel (Rowe 1972). According to Wickware and Rubec (1989), this area is described as the Thunder Bay Plains Ecoregion, and this ecoregion comprises the Moist Low Boreal (LBx) ecoclimatic region (Ecoregions Working Group 1989). The Thunder Bay Plains Ecoregion is characterized as having warm, relatively dry summers and cold, snowy winters. Daily temperatures occur above 0 ° C from early April to late October, but frosts are common except during June, July and August. Precipitation varies from 40 mm in most months to a maximum of 88 mm in August (Wickware and Rubec 1989).

SITE DESCRIPTION

Four study blocks 30 to 85 ha in size were located in Fraleigh Township, approximately 60 km southwest of the Thunder Bay, Ontario airport. The longitude and latitude of the four blocks are: (a) block 1: 89 ° 49'west/48 ° 14'north; (b) block 2: 89 ° 49'west/48 ° 12'north; (c) block 3: 89 ° 50'west/48 ° 9'north; and (d) block 4: 89 ° 50' west/48 ° north (Ontario Ministry of Natural Resources Provincial Map Series - Thunder

Bay NTS 52a/SW 1:100 000).

Block 1 was harvested between 1986 and 1988, and was mechanically site prepared with a power disc trencher in 1990. Block 1 was planted in1991 with with approximately two thirds black spruce, one third white spruce and a small proportion (< 2%) paperpot jack pine.

Block 2 was harvested in 1987, and site preparation with Young's teeth occurred in the summer of 1989. Block 2 was planted in 1990 with bareroot white spruce.

Block 3 was harvested in 1985, and site preparation occurred in the fall of the following year, 1986. Bareroot white spruce was planted except for the southern tip of the brushsaw treatment area, which was planted with bareroot black spruce.

Block 4 was harvested in 1987. Young's teeth were used to site prepare the block in the summer of 1988. Block 4 was planted with bareroot white spruce in the spring of 1989.

Aerial infra-red photos (1:5,000 scale reduced to 73% of original to fit page) of the four study blocks illustrate the topography and ground moisture patterns across each of the blocks. Photos were taken in the spring of 1994 following the application of all treatments in the fall of 1993. Water and varying degrees of moisture show up as black and shades of black (eg. a lake or a stream appear black on the photo).

Block 1 shows variable degrees of wet (moist) areas (Figure 1). In

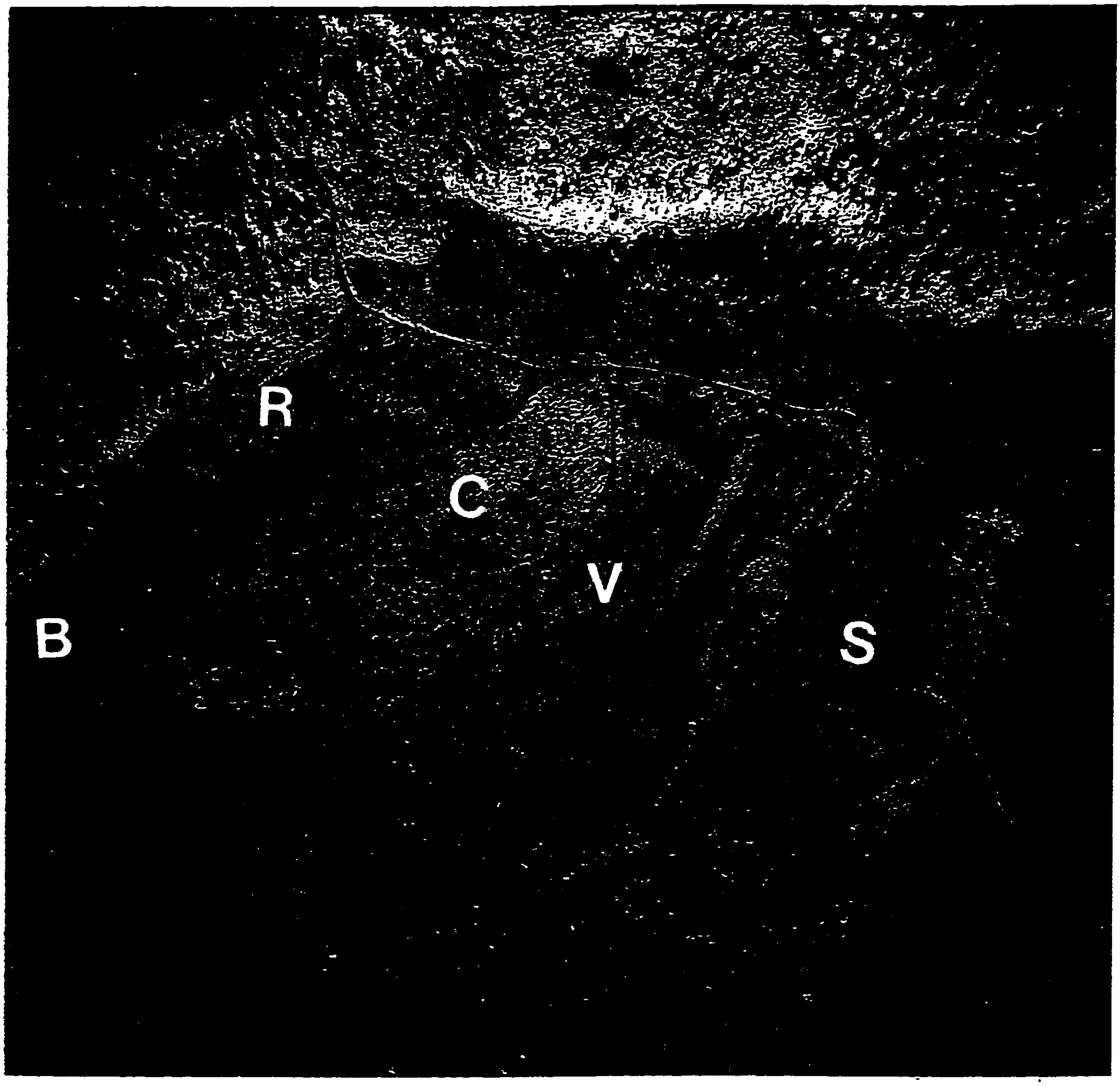

Figure 1. Aerial infra-red photo (73% of 1:5,000 scale) of block 1, Fallingsnow Ecosystem Project southwest of Thunder Bay, Ontario (R=Release, C=Control, V=Vision, S=Silvana Selective cleaning machine, B=Brushsaw)

the southwest portion of the block relatively moist conditions exist in comparison to much of the rest of the block. This moist region generally corresponds to the Brushsaw treatment (indicated as "B" on all photos). On the east side of the north-south running road in the centre of the block, the entire Vision treatment, "V", as well as a portion of the Control treatment, "C", are also relatively moist. A small area with standing water is located in the northeast of the Vision treatment just south of the main road. In addition, extremely wet conditions occurred in the south end of the Vision treatment. A clump of residual trees in a water pool and surrounded water pools is located in this region. Moisture increases from north to south on block 1 corresponding with the slope of the land and the south facing aspect.

Block 2 is a well drained site located on a plateau atop a small mountain (Figure 2). However, in the north of the block and to the east of the ridge (in the Silvana "S" treatment), patches of moisture exist near the tree line and throughout the Silvana and the Brushsaw treatments. The areas where Vision and Release "R" treatments were applied indicate moist ground conditions relative to much of the rest of the block. Downslope areas of the block tend to have the greatest levels of moisture probably because of moisture seepage from upslope areas.

Block 3 had the greatest levels of moisture in the Control and Silvana treatments, with moist conditions in the Release treatment also (Figure 3).

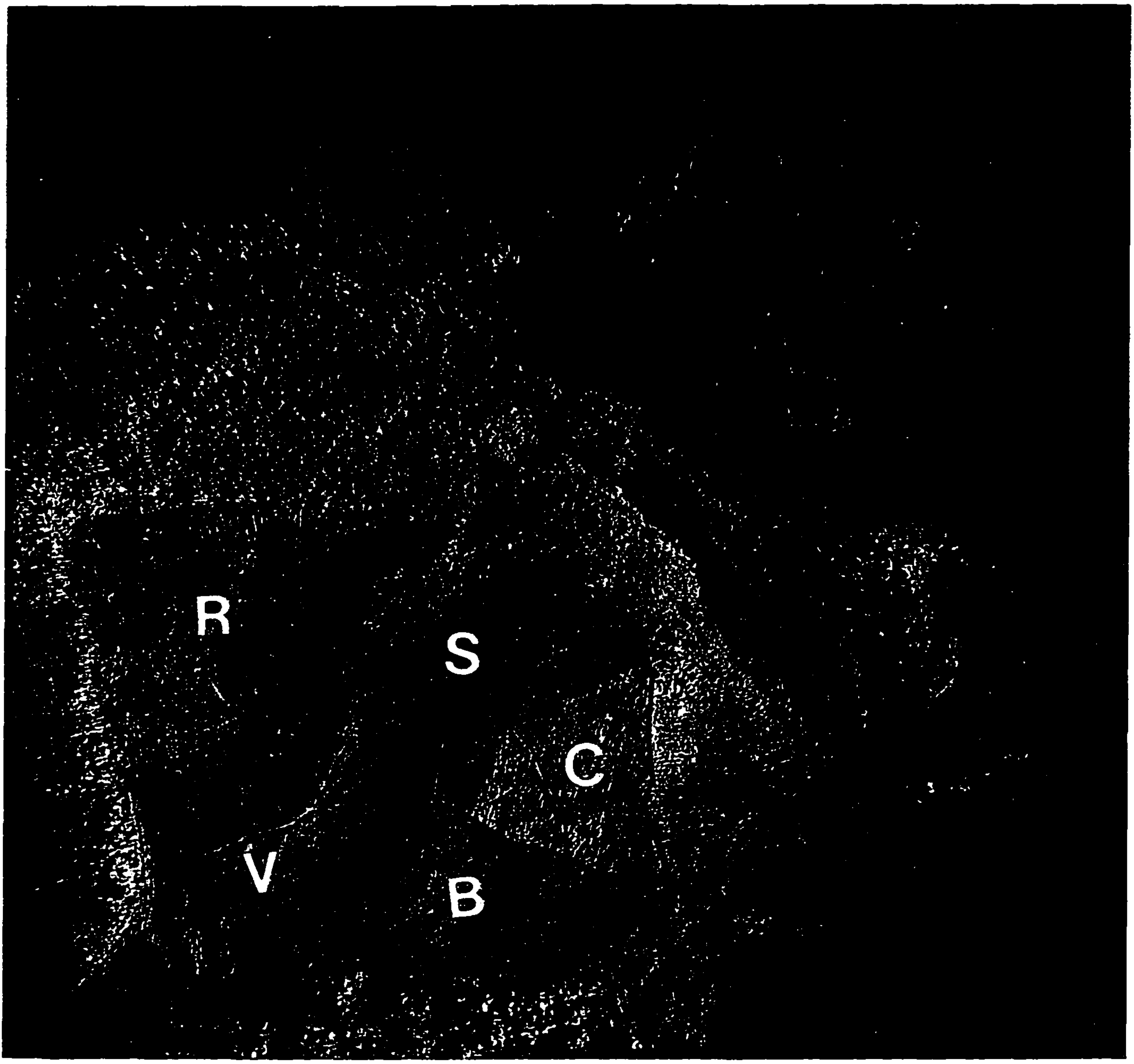

Figure 2. Aerial infra-red photo (73% of 1:5,000 scale) of block 2, Fallingsnow Ecosystem Project southwest of Thunder Bay, Ontario (R=Release, C=Control, V=Vision, S=Silvana Selective cleaning machine, B=Brushsaw)

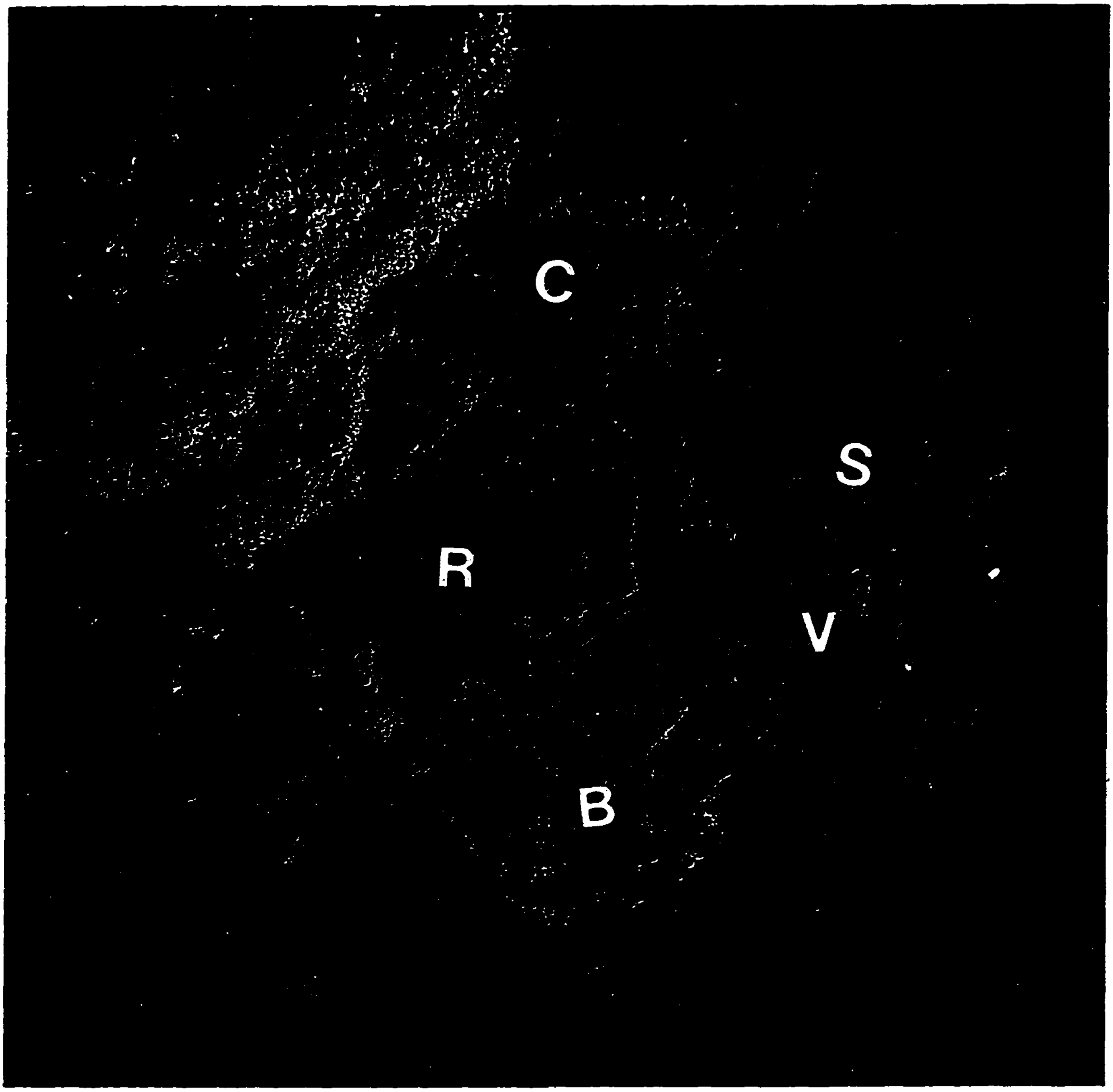

Figure 3. Aerial infra-red photo (73% of 1:5,000 scale) of block 3, Fallingsnow Ecosystem Project southwest of Thunder Bay, Ontario (R=Release, C=Control, V=Vision, S=Silvana Selective cleaning machine, B=Brushsaw)

All three treatments are located in the north end of the block, which has less of a slope than the southern half. The Release treatment contained many areas of standing water. Much of the standing water was located in deep ruts presumably caused by logging or site preparation. In addition to moist areas or areas of standing water, a stream runs north to south from the Silvana treatment into the Vision treatment along the side of the north-south, in-block road. The lower end of the stream often floods the Vision treatment.

Block 4 is generally a drier site (Figure 4). The Brushsaw treatment and the Release treatment contain the most water/moisture of the entire block. The Release treatment contains some small water pools along the northwestern boundary. A gully located in the Release treatment was used as the boundary between the Release treatment and the Silvana Selective treatment; this gully also contains standing water (shown as black on the photo). In addition, a small stream runs through the north end of the Brushsaw treatment. Like block 3, which is located a short distance from block 4, block 4 has a south to southeastern facing aspect. The northern portion of the Block is located on a plateau with the elevation increasing from the start of the inblock road to the end of the inblock road.

EXPERIMENTAL DESIGN

The study was conducted as a Randomized Complete Block Design with four blocks and five treatments. Treatments include: (a) aerial

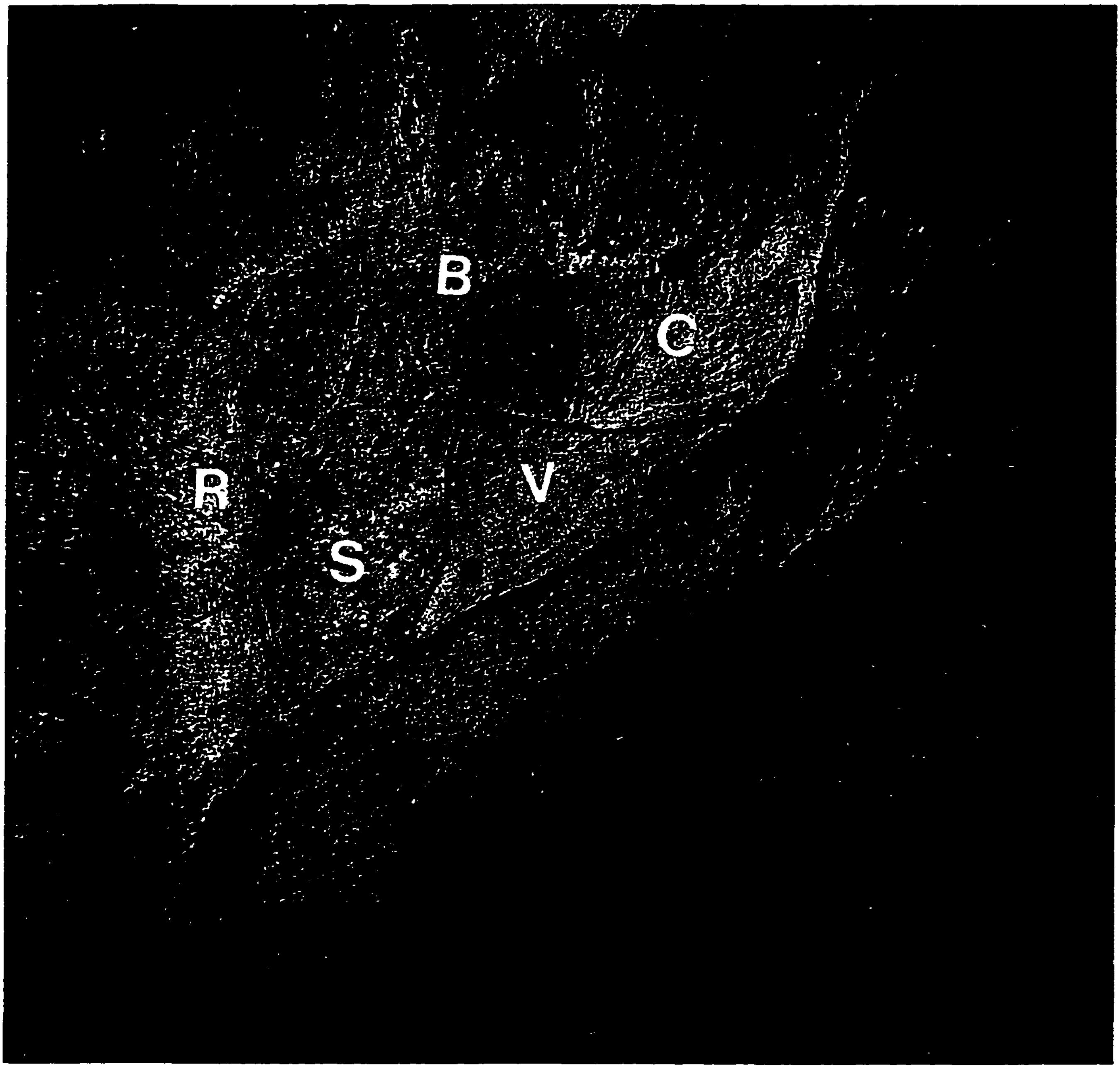

Figure 4. Aerial infra-red photo (73% of 1:5,000 scale) of block 4, Fallingsnow Ecosystem Project southwest of Thunder Bay, Ontario (R=Release, C=Control, V=Vision, S=Silvana Selective cleaning machine, B=Brushsaw)

application of Vision (glyphosate), (b) aerial application of Release (triclopyr), (c) mechanical release with the Silvana Selective/Ford Versatile, (d) manual release with brush saws, and; (e) a control (no treatment). Treatment of the plots occurred in the fall of 1993 (between August and November). Each treatment plot was between 5 and 10 ha with buffer zones surrounding each.

Five sample stations for each of the five treatments were randomly selected giving a total of twenty-five sample sites per block. If a randomly chosen sampling station occurred on a road, in a buffer zone, or some other restricted location, another sample site for that treatment was randomly chosen. Each block had a grid structure, with the letters of the alphabet running from east to west 60 m apart and numbers from 1 to 'n' running from north to south 60 m apart, thus, randomly chosen sample sites were actually grid coordinates (eg. sampling station coordinate A8) (Appendix I). Traps were always placed within 3-4 m in any direction of the grid post.

INSECT SAMPLING

Terrestrial insects and invertebrates were sampled from the soil surface using pitfall traps. Pitfall traps were set up at sampling stations in each treatment at each of the four blocks. The trap was a plastic, cylindrical deli container with diameters of 11.5 cm across the top, 9 cm across the bottom and 14 cm deep. Each trap was set into the ground so that the lip of the container was level with the soil surface. Each trap contained a saline solution for preserving insects, and a small amount (about 2 drops) of Photoflow^{Tm} to reduce the surface tension of the solution ensuring that trapped insects sank. To prevent rainfall overflow and to slow evaporation, a 20 x 20 cm roof was constructed using treated chipboard. The roof was raised using two different nail lengths which formed post-like structures in each of the four corners of the roof. While allowing rain to roll off of the roof, this design allowed insects to walk into the trap from any direction (Figure. 5).

One hundred traps were placed at randomly chosen grid locations in the four Blocks during the weeks of May 31, 1993 and June 7, 1993 (Appendix I), and all traps were activated with the saline solution during the week of June 14, 1993 (Table 2). Sampling began on block 4 on June 21, 1993 and ended, after two repetitions, at block 1 on July 13, 1993 for a total of 23 days of sampling.

The sampling period for 1994 was the same as 1993 with set-up and activation from June 1 to June 15, and sampling beginning on June 22 and ending on July 14 for a total of 23 sampling days (Table 2). The number of days between visits to each site was the same for both years of sampling. Traps were placed at the same sample sites in both years. Small mammals caught unintentionally in the 1994 season were placed in zip lock bags and frozen until they could be transferred and identified by

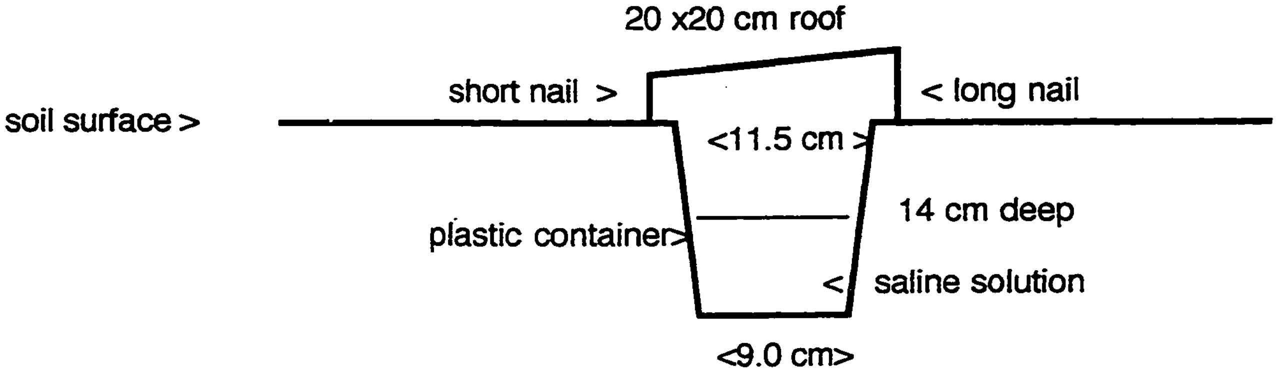

Figure 5. Pitfall trap design, Fallingsnow Ecosystem Project

Table 2. Pitfall trap set-up, activation, and sampling days for 1993 and 1994 sample periods, Fallingsnow Ecosystem Project

	1993	1994
Pitfall trap set-up	May 31 - June 14,	June 1 - June 15
Activation	June 15 - June 20	June 16 - June 21
Sampling Period:		
Collection #1:		
Block 4	June 21 & June 22	June 22
Block 3	June 22 & June 23	June 23
Block 2	June 25	June 26
Block 1	June 29 & June 30	June 30
Collection #2:		
Block 4	July 5 & July 6	July 6
Block 3	July 6	July 7
Block 2	July 10 & July 13	July 11
Block 1	July 13 & July 14	July 15

another research group at the study site.

The trap contents were poured through a 150 mm sieve into an aluminum bucket. Insects and invertebrates then were removed from the sieve and placed into labelled plastic vials containing 70% ethanol; forceps were used for larger, less delicate specimens, and a small paint brush was used for smaller specimens. Lastly, the sieve was washed with 70% ethanol into the collecting vial so that any remaining organisms would be recovered.

Organisms such as small mammals and amphibians (salamanders) that were occasionally found in the traps were noted. Amphibians were kept along with the rest of the sample, while the small mammals were noted but discarded. The amphibians caught in traps were separated from the rest of the catch and were forwarded to a research group headed by Dr. James Bogart of the College of Biological Science, Guelph, Ontario, who was studying area amphibians and reptiles.

Once sampling was complete, the saline solution was poured back into the pitfall trap from the bucket. This method of reusing the saline solution allowed field crews to carry minimal amounts of extra saline solution in the field. Small amounts of saline solution were used on occasion where traps had been broken, or fouled from the presence of dead, small mammals.

LABORATORY METHODS

The contents of the collecting vials were transferred into 250 ml glass mason jars in the laboratory. The contents of both repetitions (*i.e.* collections) were combined in 1993 and labelled by sampling station and block in 1993. The same laboratory procedures were used for the 1994 season, except repetitions were kept separate.

Insects and other invertebrates including: centipedes (Class; Chilopoda), millipedes (Class; Diplopoda), spiders (Araneae; Arachnida), harvestmen (Opiliones; Arachnida) and isopods (Isopoda; Malacostraca; Crustacea) were counted and identified to Order. Coleoptera collected in traps in 1993 and 1994 were counted and identified to Family, and the ground-beetles (Coleoptera: Carabidae) were counted and identified to species. All species of Carabidae were identified under the supervision of Dr. Richard Freitag of the Department of Biology, Lakehead University. Identification and verification of *Bembidion wingatei* Bland and *Harpalus laticeps* Leconte was provided by Dr. George Ball of the Department of Biological Sciences, University of Alberta, Edmonton, Alberta. In addition, several species were sent to the Biosystematics Research Centre in Ottawa, Ontario where Dr. Yves Bousquet verified these species.

Once identified to Order, Family, or species the specimens from each sample were placed into glass vials according to sampling station, and Order, Family or species. All specimens were identified using appropriate keys for Order and Family identification (Arnett *et al.* 1980, Borror *et al.* 1989). The Carabid beetles were identified to species using keys from Lindroth (1961-1969).

STATISTICAL ANALYSIS OF PITFALL CAPTURES

All statistics were calculated using Datadesk^R software package. Summary statistics including total numbers, mean and standard deviation were calculated for each Order, Family and species. Total numbers by block were compiled for each Order, Family, and carabid species which comprised at least 2% of the total number of individuals within its taxa. Data were transformed with Log or square root where appropriate (transformations are indicated in the Results).

Covariate ANOVA (α=0.05) using the absolute numbers of 1994 taxa, with the corresponding 1993 data used as the covariate, was conducted on selected Orders including Araneae, Coleoptera, Collembola, Diplopoda, Diptera, Homoptera, and Orthoptera. Tested taxa were chosen based on their relative abundance in comparison with less abundant taxa.

Covariate ANOVA (α=0.05) was also conducted on abundant Coleoptera Families including Carabidae, Curculionidae, Elateridae, Endomychidae, Leoididae, Silphidae, Staphylinidae, and Tenebrionidae. Covariate ANOVA (α=0.05) was performed on abundant species of Carabidae including *A. gratiosum* Mannerheim, *Poecilus lucublandus* Say, *Pterostichus coracinus* Newman, *P. pensylvanicus* Leconte, and *Synuchus* *impunctatus* Say.

The Covariate ANOVA with 1993 data as the covariate was chosen as the method of analysis in order to directly determine if the 1993 data collected had an influence on the 1994 data collected. The Covariate ANOVA is a more precise test than the standard ANOVA in determining whether the vegetation management treatments had an effect on epigeal insects and arthropods. The Least Significant Difference test (a multiple range test) was performed on taxa showing significant treatment effects at $\alpha=0.05$ to show which treatments differed significantly.

Scatterplots with Lowess Smoothing of transformed data of 1994 taxa plotted against the corresponding1993 data were completed for taxa showing significant covariate effects to determine the relationship between 1993 and 1994 trap catches. Lowess (an acronym for Locally Weighted regression Scatterplot Smoothing) combines weighted regression with robust measures of location. Smooth traces pass through the "center" of the data (Velleman 1988). At every point along a smooth trace drawn over a scatterplot of a data sequence, there should be roughly the same number of data points above the smooth trace as below it. Lowess smoothing provides a general idea of the center of the data values at each part of the data sequence.

The Shannon-Wiener index was used to provide an indication of the biological diversity of1994 Carabidae species in each of the vegetation management treatments including the Control. The Pearson Product-Moment Correlation and Spearman Rank Correlation were performed to determine the relationship between Carabidae and Formicidae (e.g. to determine if sharing of territories occur).

CHAPTER 1

RESULTS

Orders Collected:

In the summers of 1993 and 1994 a total of 60,921 arthropods were sorted and identified to the Order level. Thirteen insect Orders were present as well as nine non-insect Orders (Table 3). In 1993 a total of 24,776 arthropods were trapped, whereas, 36,145 were caught at the same sample sites in 1994. The most abundant Orders in both years were the Acari (ticks and mites), Araneae (spiders), Coleoptera (beetles), Diptera (*i.e.* flies), and the Hymenoptera (*e.g.* ants, wasps).

Increases in numbers trapped in pitfall traps during the 1994 sampling period were evident for Acari, Araneae, Chilopoda, Coleoptera, Collembola, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, Opiliones, Psocoptera, Siphonaptera, and Thysanoptera (Table 3). Decreases in numbers trapped in 1994 were evident for Chelonithida, Diplopoda, Diptera, Gastropoda, and Orthoptera. Rare Orders trapped including Neuroptera and Tricoptera decreased by one individual each. Large standard deviations were noted for many of the most abundant Orders over both sampling years including Acari, Araneae, Coleoptera, Diptera, and Hymenoptera (Table 3).

Differences in abundance between blocks was also evident (Appendix II). An obvious trend in numbers trapped in blocks over both sampling

Table 3. **Total numbers with mean/trap and standard deviation of arthropod Orders collected from pitfall traps, Fallingsnow Ecosystem Project (1993 and 1994)**

Arthropod Order	1993 Mean/ Trap	S.D.	1994 Mean/ Trap	S.D.	Total Numbers 1993	Total Numbers 1994
Acari	40.6	124.8	76.0	141.3	3982	7499
Diptera*	69.1	75.4	53.3	54.3	6847	5224
Araneae	42.2	20.9	65.1	41.7	4314	6413
Coleoptera*	37.6	48.4	50.3	47.4	3658	4932
Hymenoptera*	31.5	28.7	73.0	56.4	3047	7272
Orthoptera*	7.5	7.1	7.3	7.0	651	633
Gastropoda	6.4	5.0	5.8	5.3	538	478
Diplopoda	6.3	9.3	2.8	2.6	528	186
Homoptera*	4.9	4.1	8.5	7.5	391	748
Collembola*	4.7	9.0	17.5	16.9	370	1653
Opiliones	3.0	3.4	4.7	5.0	196	367
Chelonithida*	1.5	5.2	1.0	0.1	52	3
Lepidoptera*	1.5	0.9	2.9	6.1	50	191
Hemiptera*	1.5	1.1	5.1	7.5	49	406
Siphonaptera*	1.2	1.0	1.9	1.7	24	88
Chilopoda	1.1	0.2	1.2	0.4	5	16
Thysanoptera*	1.0	0.2	1.2	0.6	4	20
Tricoptera*	1.0	0.1	1.0	0.1	2	1
Neuroptera*	1.0	0.1	1.0	0.0	1	0
Psocoptera*	1.0	0.0	1.0	0.3	0	8
Total Number					24,776	36,145

* - indicates insect orders

years was not determined, however, blocks 1 and 4 appear to be more impoverished for some Orders including Acari, Coleoptera, Collembola (1993 only), Diptera, Gastropoda (block 4 only). For a few Orders including Hemiptera, Homoptera, Hymenoptera, and Orthoptera, block 4 proved to be highly abundant in comparison to the other blocks.

The 1993 (pre-treatment) Coleoptera showed differences in abundance between the treatments (Figure 6), in addition to variation in abundance between the blocks. In 1993 the Control (untreated plots), Vision, and Silvana Selective treatments were of higher abundance and more similar to one another than the brushsaw and Release treatments.

Post-treatment: 1994

Covariate ANOVA for both Coleoptera and Araneae did not show significant treatment effects at $\alpha=0.05$ (Appendix III). In addition, the 1993 Coleoptera data (*i.e.* the covariate) did not show significant effects in relation to the 1994 catch. Likewise the 1993 Araneae catch was found to be an insignificant factor on the numbers of Araneae trapped in 1994. Covariate ANOVA for Collembola (springtails) and Diptera also did not find significant treatment effects or covariate effects (Appendix III).

Similar to the Araneae, Coleoptera, Collembola, and Diptera, Covariate ANOVA for Orthoptera also did not show significant treatment effects (Appendix III). However, the covariate (*i.e.* the 1993 Orthoptera data) did show significant effects, and a scatterplot graph of 1994 data plotted

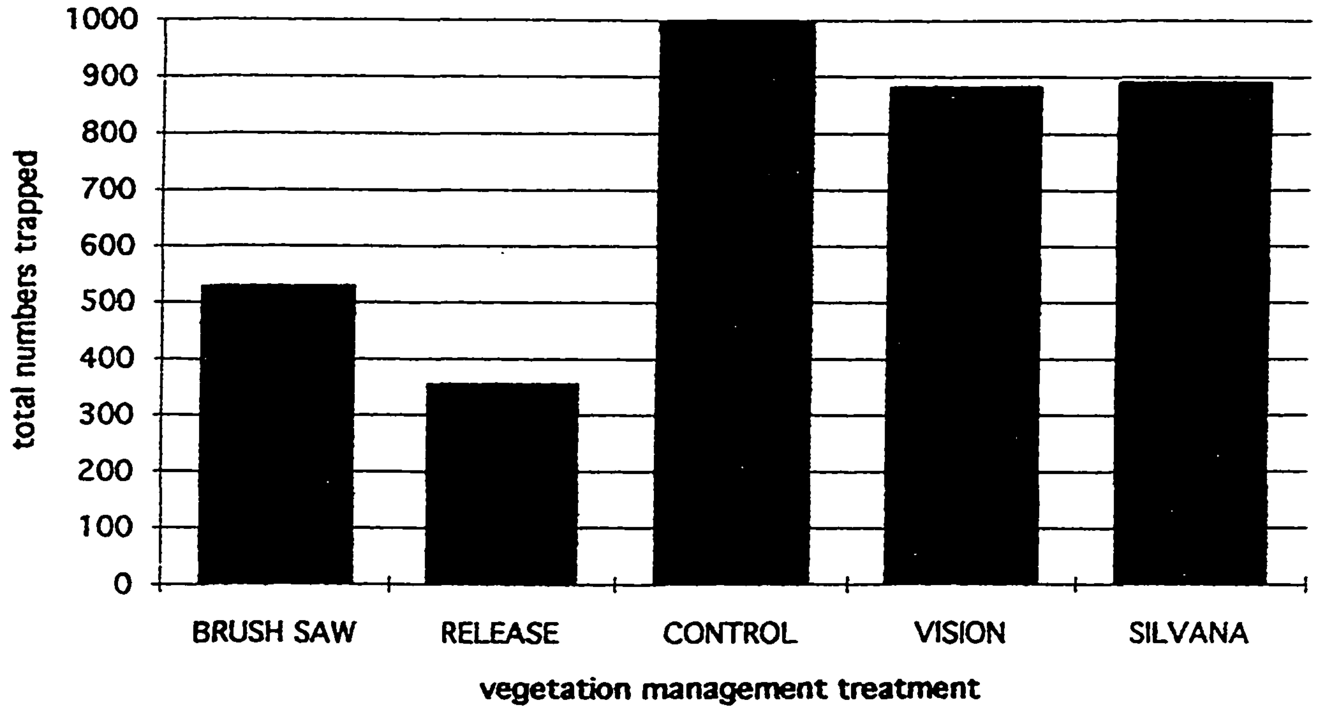

Figure 6. Numbers of Coleoptera collected in 1993 for the five vegetation management treatments, Fallingsnow Ecosystem Project

against the 1993 data shows a positive relationship between the two data sets (*i.e.* traps containing large numbers of Orthoptera in 1993 also contained large numbers of Orthoptera in 1994) (Figure 7).

Covariate ANOVA of the Diplopoda also exhibited significant covariate effects, but did not reveal significant treatment effects. A scatter plot of 1994 data plotted against 1993 data shows a positive relationship, similar to that for Orthoptera, between 1994 and 1993 data (Figure 8).

Covariate ANOVA for Homoptera indicate both significant treatment effects as well as significant block by treatment interaction effects (Appendix III). Examination of the expected cell means for each of the treatments shows that the Vision treatment had the lowest expected cell mean of the five vegetation management treatments, while the other four treatments were closer to each other numerically. A Least Significant Difference test found that the Vision treatment differed significantly from the other four treatments including the Control (untreated) plots (Appendix III).

The covariate for the Homoptera test (*i.e.* the 1993 Homopteran data) was also found to be significant. A scatterplot of 1994 Homoptera plotted against 1993 Homoptera data shows a positive relationship between these two data sets. Traps that contained high numbers of Homoptera in 1993 also contained high numbers of this Order in 1994 (Figure 9).

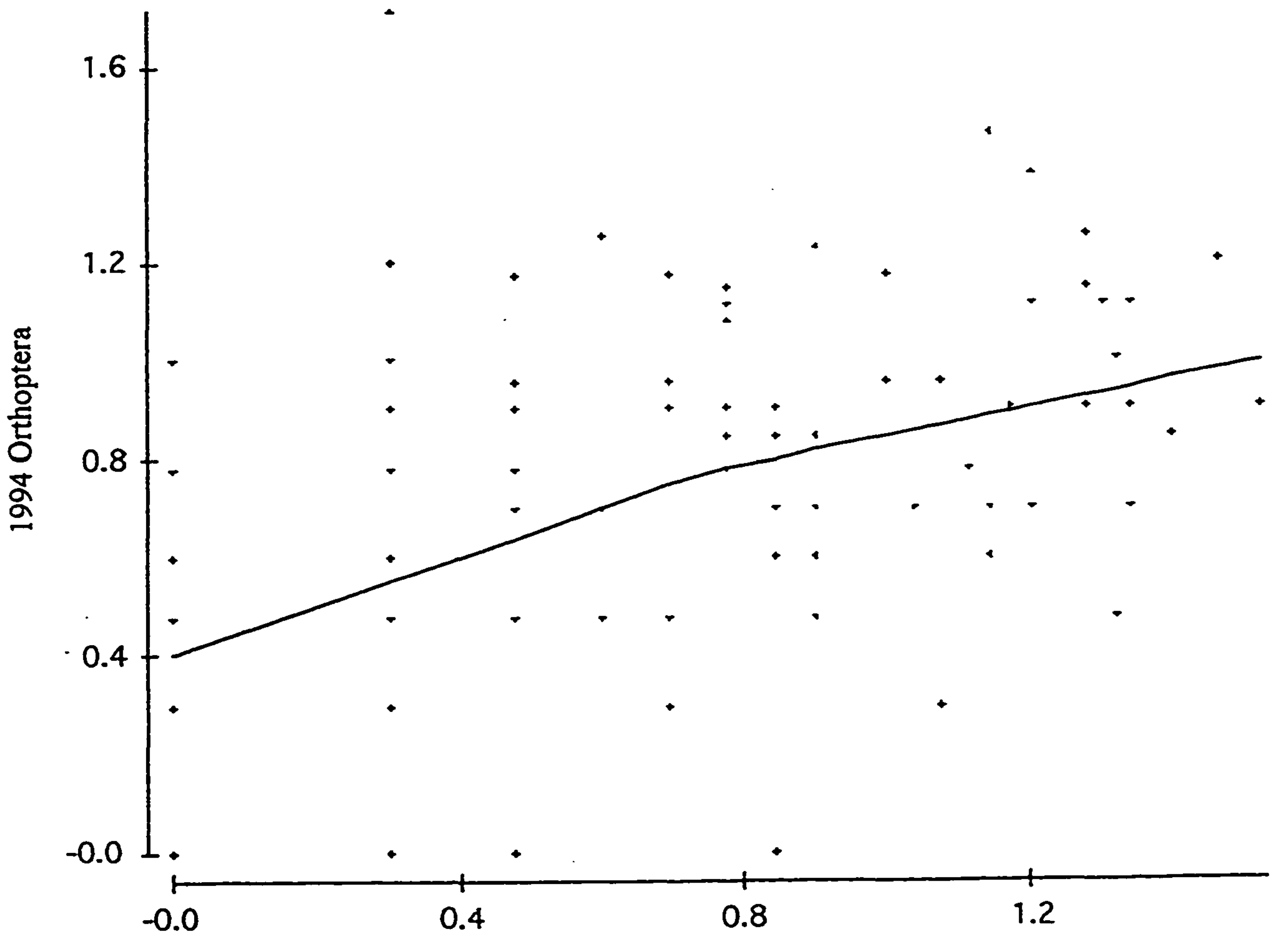

Figure 7. Scatterplot graph with Lowess smoothing showing 1994 Orthoptera (log units) plotted against 1994 Orthoptera (log units), Fallingsnow Ecosystem Project

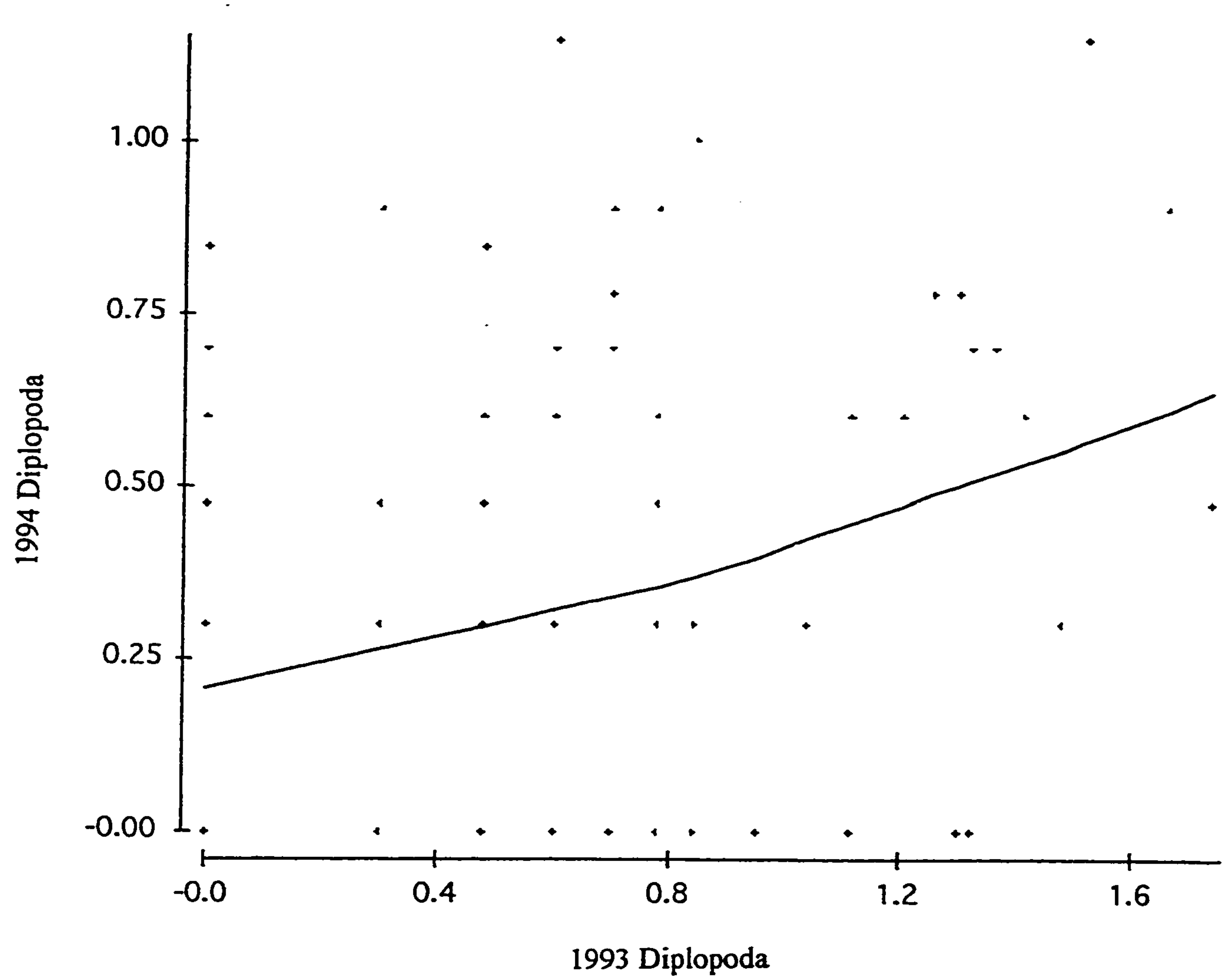

Figure 8. Scatterplot graph with Lowess smoothing showing 1994 Diplopoda (log units) plotted against 1993 Diplopoda (log units), Fallingsnow Ecosystem Project

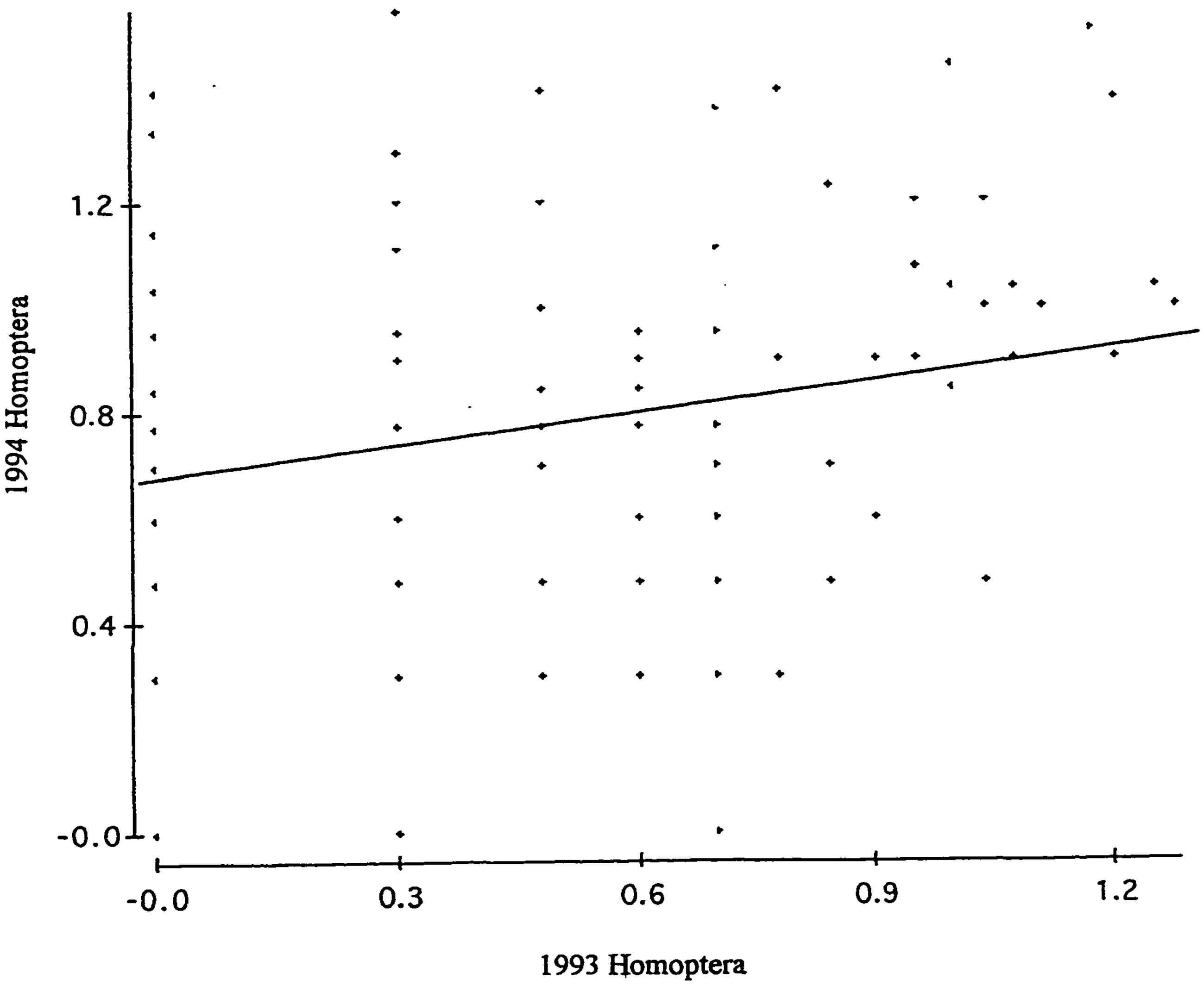

Figure 9. Scatterplot graph with Lowess smoothing showing 1994 Homoptera (log units) plotted against 1993 Homoptera (log units), Fallingsnow Ecosystem Project

DISCUSSION

Orders Collected:

The natural variation between and within the four study blocks accounts for the between and within block differences for insect and arthropod abundance. Each of the four blocks has different soil types, drainage patterns, pre-harvest stand history, slope, aspect, and, to a lesser extent, present vegetation composition and structure. Soil characteristics, especially its depth, texture, permeability, moisture regime and drainage pattern, will greatly influence the vegetation growing on the block. In turn, soil and topography differences, and differences in drainage pattern, and vegetation composition will influence microclimate, microhabitats, and, consequently, the abundance of specific insects or arthropods (Thiele 1977).

Block 1 does not appear to contain the same kind of micro-habitat features for ground-dwelling insects and arthropods as the other blocks. Generally speaking, Block 1 was one of the wetter blocks with more areas of standing water relative to the other blocks. The soils of block 1 are shallow sandy loam soils with highly variable drainage (Lautenschlager and Bell 1994). Lower numbers of insects such as the Orthoptera (grasshoppers, crickets, katydids) in block 1 may have been due to too much standing water due to poor drainage and above average rainfall in July of 1993 (Appendix IV). The general wetness of block 1 may have adversely affected food supplies and reproduction of the Orthoptera as they require well drained soil for oviposition (Borror *et al.* 1989).

However, block 1 seems to hold an appeal for many Orders that require moist or damp conditions for part or all of their lives. The Gastropoda (snails and slugs) and Diplopoda (millipedes) were both collected in notably higher numbers in block 1 when compared with blocks 3 and 4. Both of these Orders require a high degree of soil moisture to carry out life processes (Dindal 1990). The Gastropods generally prefer habitats offering shelter, adequate moisture, and an abundant food supply (Dindal 1990). Block 1 certainly provided adequate moisture, as well as an abundance of early seral vegetation upon which to feed.

Millipedes are usually found in damp places such as under leaves, in moss, under stones or boards, in rotting wood or in surface soils (Borror *et al.* 1989, Dindal 1990). Furthermore, the abundance and diversity of millipedes seems to be correlated with the presence of calcareous substrates (Dindal 1990). Some millipedes will construct a nest-like cavity in the soil in which they deposit their eggs (Borror *et al.* 1989). A combination of factors such as soil type, drainage, presence of calcareous substrates, and vegetation composition may have contributed to the relative abundance of millipedes in block 1. However, factors such as calcareous substrates within the soil were not recorded in this study, therefore, a direct correlation with calcareous properties cannot be made.

Opiliones (harvestmen), which were trapped in significantly higher numbers in block 1, also prefer damp conditions for survival, and will inhabit the forest floor, the litter, as well as the surface soil and caves (Dindal 1990). The naturally damp conditions of block 1 combined with unusually high rainfall during the sampling period in 1993 may have contributed to higher numbers of trapped Opiliones. Opiliones have also been known to feed on dead animals (Borror *et al.* 1989), however, the results of a sub-study by Hobischak (1994 unpublished) indicate that no significant correlation exists between small mammal carrion in the pitfall traps and the number of trapped Opiliones.

Block 2 seems to be the most productive of all four blocks as it consistently contained the highest numbers of most insect and arthropod Orders. This result seems to indicate that excellent conditions exist on this block for many insect and arthropod populations to thrive. Block 2 is characterized by a clay loam soil that is well drained due to its hillside location (Lautenschlager and Bell 1994). The fine clay loam soil of block 2 the soil is capable of holding much available soil moisture, and the good soil structure of this well-drained soil provides good conditions for vegetative growth and, consequently, growth of animals.

The Acari (ticks and mites) occur in practically all habitats (Borror *et al.* 1989), and were trapped in the greatest numbers on block 2. Terrestrial Acari are quite abundant in the soil and organic debris, while many other species are parasitic on both vertebrates and invertebrates. It was not clear whether Acari found in traps without hosts were parasitic or free-living, therefore, all were counted. It is possible that the numbers of Acari trapped can be related to the productivity of the block. Firstly, some of the Acari trapped were likely free-living soil dwelling species, which would indicate productive soils (Dindal 1990). Secondly, some of the Acari trapped were parasitic on vertebrates (small mammals) and invertebrates. A large number of parasitic Acari is also indicative of a productive site because they were found on a large number of hosts relative to the other blocks. However, it should be noted that pitfall traps are not an efficient method for Acari counts (Dindal 1990). Studies specific to Acari numbers in forest soils normally concentrate efforts in evaluating Acari taken from soil samples. Indeed, temperate coniferous and deciduous forests can contain anywhere from approximately 20,000 mites/m2 to 120,000 mites/m2 (Dindal 1990). Acari counts taken from soil samples for the four blocks in this study would verify or add strength to the supposition that block 2 differs in productivity from the other blocks.

Block 3, which is similar to block 1 in that it is a wetter block containing areas of standing water and riparian vegetation, does not exhibit the same trends as block 1. Lower numbers of some moisture dependent arthropods such as Opiliones and Diplopoda in block 3 cannot be easily explained. However, lower numbers in block 3 may be the result of the natural variation between the blocks as outlined previously on page 68. Calcareous substrates, which may limit the abundance and diversity of millipedes, may not be present in block 3 to the same degree as block 1. However, many species of Gastropoda also require calcareous substrates for existence (Dindal 1990), and gastropods do not show the same trend in block 3 as the millipedes. Factors that influence the abundance and distribution of the millipedes, gastropods, Opiliones and other insect and arthropod Orders may be imperceptible to researchers examining data at this level of organization.

Very low numbers of Hemiptera were trapped in all study blocks and this probably indicates the ineffectiveness of pitfall traps relative to other sampling methods for capturing members of this Order. Thus, Hemiptera caught in pitfall traps may not reflect actual population numbers of this Order. Many species of Hemiptera feed on plant juices (Borror *et al.* 1989), and, therefore, may not frequently occupy ground level microhabitats. On the other hand, species of Homoptera were trapped more frequently than the Hemiptera on all blocks in 1993 indicating that the Homoptera may be more susceptible to pitfall traps and/or they spend more time feeding on vegetation at or near ground level.

Both the Hemiptera and the Homoptera were caught in their greatest numbers in block 4, which seems to imply a possible difference in vegetative cover, microclimate, and/or microhabitat for these Orders in this block. However, since pitfall traps are not the most effective means of trapping the Hemiptera and Homoptera, inferences on these data sets should be taken with caution.

The Hymenoptera were also trapped in their highest numbers on block 4 due in large part to ample numbers of Formicidae (ants) trapped. A possible explanation for the block by block difference in Formicidae trapped is that one or more pitfall traps in block 4 was placed near an ant nest. Unfortunately, this information was not recorded at sample sites. However, the chance of placing a pitfall trap near an ant nest should be the same for all four blocks since all sample sites were randomly chosen. Therefore, block 4 may possess a healthy population of Formicidae possibly due to a wide variety of factors including soil type, moisture content, vegetation type and cover, and lack of competition.

Lower numbers trapped in block 4 of other Orders including the Acari, Coleoptera, Collembola, Diptera, Gastropoda and Opiliones suggest that block 4 does not contain sufficient habitat for many of these Orders. It is not clear why this is the case. The deep clay soils with moderate to poor drainage (Lautenschlager and Bell 1994), combined with above normal rainfall during the sampling period of 1993 may have created wet areas that were not suitable for some insects and arthropods, however, some orders such as the Gastropoda and Opiliones require a damp environment in which to live. It is also possible that the fine clay particles did not provide adequate pore space for many insects and arthropods that burrow (Thiele 1977). However, according to Thiele (1977) many Carabidae (Coleoptera) species are more frequently found on clay soils than other soil tyes. Examination of the data reveals that approximately half of the Coleoptera trapped on block 4 are carabids, a much higher ratio than on the other blocks. In any event, the fine intricacies of Family or species preferences within Orders does not allow one to extrapolate Thiele's (1977) observation to all insects and arthropods.

Increases in the numbers of insects and arthropod Orders trapped in 1994 can be primarily attributed to the weather conditions experienced in the spring and summer of 1994. Normal rainfall for June and July, 1994 and above normal temperatures in June, 1994 probably helped increase trapping efficiency over 1993 (Appendix IV). In a few cases during the 1993 sampling period, traps were pushed up and out of the ground due to high ground water in all four blocks. Although this also occurred in some wet areas in 1994, it did not occur as frequently. Moreover, warmer than average temperatures in July, 1994 may have contributed to increased activity of many insects and arthropods. Increased activity would, therefore, increase the chance of an insect or arthropod being trapped.

Briggs (1960) and Dennison and Hodkinson (1984) both agree that the efficiency of pitfall trapping should rise with temperature as the motility of carabid beetles increases. This result can probably be extrapolated to many other insects and arthropods. However, increased activity and trapping efficiency in 1994 may also be a sign that many ground-dwelling insects were migrating from an unfavourable environment (e.g. treatment plots) to a favourable one in search of food (Thiele 1977). In addition, an increase in 1994 in the numbers of trapped insects and arthropods may also be a result of natural population fluctuations alone, or in combination with the effects of the better weather conditions of 1994.

One very interesting observation was the notable decrease in the number of Diplopoda trapped in 1994. Since the decrease was fairly uniform across all four blocks, and the vegetation management treatments did not have an effect, the decrease was probably a result of the warmer, drier weather of 1994, that may have reduced the amount of damp niches that millipedes are so dependent upon.

Post-treatment:1994

Only the Homoptera showed significant treatment effects, indicating that, overall, the treatments had very little impact on ground-dwelling insects and arthropods one year after treatment. The Homoptera, which are usually associated with vegetation and not the soil milieu were trapped in far greater quantities in 1994 than in 1993. Treatment effects for

Homoptera, whose sole source of food is vegetation, were not a surprise. Significantly low numbers of Homoptera in the Vision treatment indicate that this treatment did not contain the abundance and diversity of plant species necessary to sustain this Order to the same extent as the other treatments and the Control. The highest numbers of Homoptera were trapped in the brushsaw treatment and the Control, therefore, the Vision treatment was the least similar to the Control and brushsaw treatment in the type and amount of food and microhabitats they provided. The Silvana Selective and Release treatments showed closer expected cell means to the Control and brushsaw treatments. The insignificant difference between these treatments indicates that the Silvana Selective and the Release treatments contained similar amounts and types of vegetative food and microhabitats relative to the Control and brushsaw treatments.

Differences in numbers of Homoptera trapped in the Control and Vision treatment is not an unexpected result. Although structurally the Vision treatment resembles the Control treatment (*i.e.* all structural vegetation layers are still present), the taller vegetation (*e.g.* aspen, and tall shrubs) was impacted to the greatest extent by the herbicide. Lower vegetation layers were impacted to varying degrees depending on the percent cover of the upper vegetation layer. The Vision treatment removed a greatest percent cover of vegetation of any of the treatments (Bell *et al.* 1996 unpublished). With the effective removal of the upper vegetation layers in the herbicide treatments, and the temporary decrease in cover of the lower vegetation layers especially in the Vision treatment, many Homopterans may have moved to areas of increased cover and structure for food, shelter, and suitable microhabitats for reproduction. The Release treatment did not impact Homoptera to the same extent as the Vision treatment, and this may be due to the fact that Release (active ingredient; triclopyr) does not impact grasses or sedges, while Vision (active ingredient; glyphosate) does. The numbers of Homoptera trapped in the Control, brushsaw and Silvana Selective were similar implying that these vegetation management treatments do not negatively impact Homoptera. Both the Silvana Selective and brushsaw treatments were quite lush by the beginning of July, 1994 as the lower vegetation layers, including low shrubs, were not disturbed to the same degree as in the herbicide treatments.

It is not clear why the brushsaw treatment and Control plots showed a similar response for Homoptera. Vegetation was cut at 18cm above the ground in the brushsaw treatments while the Controls were left untreated. A high expected cell mean for the Control was anticipated as these plots provide the Homopterans with the most vegetation cover and structure. The high expected cell mean in the brushsaw treatment may be more an indication of the Homopterans' activity at a lower structural level in the vegetation within this treatment, rather than an inference on the population size within this treatment. Any Homopterans within the brushsaw treatment would be spending the majority of their time within 18cm of the ground, and, thus, may have inadvertently increased their chances of being trapped.

Block by treatment interaction effects for Homoptera indicate that treatments within certain blocks produced a significantly different response from the Homopterans. In addition, the significant effect of the 1993 Homopteran catch on the 1994 catch indicates that the 1993 catch had a positive influence on the numbers caught in traps in 1994. This result indicates that sampling of Homoptera in pitfall traps over two years at the same sampling sites did not have a negative impact on the population. Instead, it appears that a healthy population of Homoptera in 1993 continued to be a healthy population in 1994. It should be noted that pitfall trapping is not the primary method for trapping flying insects, therefore, inferences on the results of flying insects should be taken with caution.

1993 Orthoptera significantly influenced the 1994 Orthoptera catch indicating that high numbers trapped in 1993 positively influenced the numbers trapped in 1994. Similar numbers of Orthoptera in both years and the lack of significant treatment effects indicates that the vegetation management treatments did not have a noticeable effect on this Order.

The lack of notable treatment effects on the Araneae and Coleoptera

Orders is likely a reflection of the diversity of Families and species within these Orders. The primary Order of interest, the Coleoptera were trapped most often in the Release treatment, which is in contrast to the 1993 results. A large number of Coleoptera trapped in the Release treatment indicates a preference of many Families for open-country habitats.

The 1994 Diplopoda were significantly influenced by the 1993 Diplopoda catch. The relationship between the two years of sampling indicates that healthy millipede populations were not negatively impacted by sampling in the same location over two consecutive years. In addition, the lack of treatment effects implies that changes in vegetation cover and abundance, and soil moisture and temperature also did not have a negative impact on the millipedes. It is possible that the increase in organic debris within the treatments caused by the treatments may have provided the millipedes with adequate amounts of moist microsites and food.

Both the 1994 Collembola and Diptera failed to show treatment effects, indicating that the vegetation management treatments did not produce a notable impact on these Orders. This result concurs with the results of other epigeal insect and arthropod Orders examined, indicating that changes in the vegetation and soil did not negatively impact them.

CONCLUSIONS: ORDERS COLLECTED

1. Between block and within block variation can be attributed to the natural, uncontrollable variation (e.g. soils, slope, aspect, vegetation cover, microclimate, microhabitat) between and within the blocks.
2. Block 2 is the most productive site as revealed by the data, which shows significantly higher numbers of insects and arthropods trapped in this block.
3. In most cases, only generalities can be made when discussing results at the Order level. Variation among Families and species allows one only to speculate as to why significant differences occur in numbers trapped.
4. Significant changes between the 1993 and 1994 numbers of insect and arthropod Orders trapped can be primarily attributed to the warmer, drier spring and summer of 1994. The improved weather conditions of 1994 likely contributed to increased activity of insects and arthropods, and, therefore, a higher trapping efficiency. Moreover, trapping efficiency was increased in 1994 because fewer traps were pushed out of the ground due to a high water table from excessive rainfall as was the case in 1993. Natural population fluctuations alone or in combination with the above mentioned factors also may have contributed to the increased catch in 1994.
5. It is possible that increased activity of insects and arthropods may

also be due, in part, to migration from unsuitable conditions within the treatment plots to more suitable conditions outside the treatments.

6. Generally, the vegetation management treatments had very little effect on ground-dwelling insects and arthropod Orders. Significant treatment effects were only evident for the Homoptera. Differences in vertical structure, vegetation composition and abundance among the treatments probably are responsible for the treatment effects for Homoptera.
7. Block by treatment interaction effects for Homoptera indicate that the treatments within certain blocks influenced the numbers trapped.
8. 1993 catches of Diplopoda, Homoptera, and Orthoptera positively influenced the numbers of these Orders trapped in 1994.
9. Pitfall trapping is not the primary method for sampling flying insects, therefore, the results of flying insects should be taken with caution.

CHAPTER 2

RESULTS

Coleoptera Collected:

Fourty-seven Coleoptera Families were identified over the two years of sampling. The ground-beetles (Coleoptera: Carabidae) were the most abundant Family in both 1993 and 1994 (Table 4, Appendix V). The numbers of rove-beetles (Coleoptera: Staphylinidae) increased sharply in 1994 and were a close second to the carabid beetles. Carabidae were much more abundant on the drier blocks 2 and 4 in 1994 than on blocks 1 and 3. Other abundant beetle families include Curculionidae (Weevils), Elateridae (Click beetles), Endomychidae (Handsome fungus beetles), Leiodidae (Round fungus beetles and Small carrion beetles), Silphidae (Carrion beetles), and Tenebrionidae (Darkling beetles).

A notable difference in numbers trapped of Carabidae was not found between pre- and post-treatment sampling years, although changes in abundance within the treatments did occur between the sampling years. In 1994 the brushsaw treatment, Release treatment and the Control all increased in the numbers of Carabidae trapped over 1993, while the numbers trapped in the Vision treatment decreased (Figure 10). The numbers of Carabidae trapped in the Silvana Selective treatment also decreased slightly in 1994.

Differences in numbers of Coleoptera Families trapped in 1993

Table 4. **Total numbers with mean/trap and standard deviation of Coleoptera Families collected from pitfall traps, Fallingsnow Ecosystem Project (1993 and 1994)**

Family	1993		1994		Total Numbers	
	Mean/ Trap	S.D.	Mean/ Trap	S.D.	1993	1994
Carabidae	11.4	7.3	12.7	9.8	1040	1183
Leoididae	8.8	29.4	7.8	11.6	771	676
Silphidae	4.7	12.6	6.0	11.9	373	497
Staphylinidae	3.4	5.1	12.4	20.2	240	1146
Scolytidae	2.2	5.2	1.1	0.5	120	13
Pselaphidae	2.2	2.9	1.2	0.5	116	16
Lampyridae	2.1	1.8	1.9	1.2	110	93
Endomychidae	2.0	1.5	2.5	2.4	99	153
Nitidulidae	1.9	4.5	2.2	2.0	92	119
Tenebrionidae	1.9	2.2	2.2	1.8	91	79
Ptiliidae	1.6	4.7	1.9	4.8	59	85
Elateridae	1.6	1.4	2.7	3.8	58	172
Curculionidae	1.4	1.0	1.8	2.5	43	83
Phalacridae	1.4	1.5	1.2	0.6	40	16
Cicindelidae	1.3	1.4	1.1	0.5	31	8
Scarabaeidae	1.3	0.6	1.7	1.6	28	57
Mycetophagidae	1.2	1.0	1.3	1.1	24	26
Erotylidae	1.2	1.0	1.1	0.5	23	5
Chrysomelidae	1.2	0.6	1.6	1.9	21	64
Biphyllidae	1.2	0.1	1.0	0	17	0
Histeridae	1.2	0.7	1.5	1.8	16	53
Meloidae	1.1	0.4	1.0	0.1	13	1
Rhysodidae	1.1	0.5	1.0	0	13	0
Brentidae	1.1	0.5	1.0	0.2	11	4
Trogossitidae	1.1	0.7	1.0	0	11	0
Cryptophagidae	1.3	1.0	1.4	2.2	10	36
Hydrophylidae	1.1	0.8	1.0	0.2	10	8
Cucujidae	1.1	0.3	1.2	1.0	6	19
Byrrhidae	1.1	0.4	1.1	0.4	6	10
Melandyridae	1.1	0.3	1.0	0	5	0
Mordellidae	1.0	0.2	1.1	0.3	4	13
Haliplidae	1.0	0.2	1.0	0	4	0
Cleridae	1.0	0.1	1.0	0.2	3	0.2
Cerambicidae	1.0	0.2	1.1	0.5	3	14
Cantheridae	1.0	0.2	1.1	0.3	3	8

Family	Mean/ Trap	S.D.	Mean/ Trap	S.D.	Total Numbers 1993	1994
Bostrichidae	1.0	0.1	1.0	0	2	0
Corylophidae	1.0	0.2	1.0	0.1	2	2
Anthribidae	1.0	0.1	1.0	0	1	0
Bruchidae	1.0	0.1	1.0	0	1	0
Ciidae	1.0	0	1.0	0.1	1	1
Coccinellidae	1.0	0.1	1.0	0.1	1	2
Dermestidae	1.0	0.1	1.0	0	1	0
Derodontidae	1.0	0.1	1.0	0	1	0
Dytiscidae	1.0	0	1.0	0.1	0	1
Languriidae	1.0	0	1.0	0.1	0	2
Lathridiidae	1.0	0	3.7	4.3	0	267
Pyrochroidae	1.0	0	1.0	0.1	0	1
Throscidae	1.0	0	1.0	0.4	0	6
Unidentifiable					28	74
Total					3,518	5,016

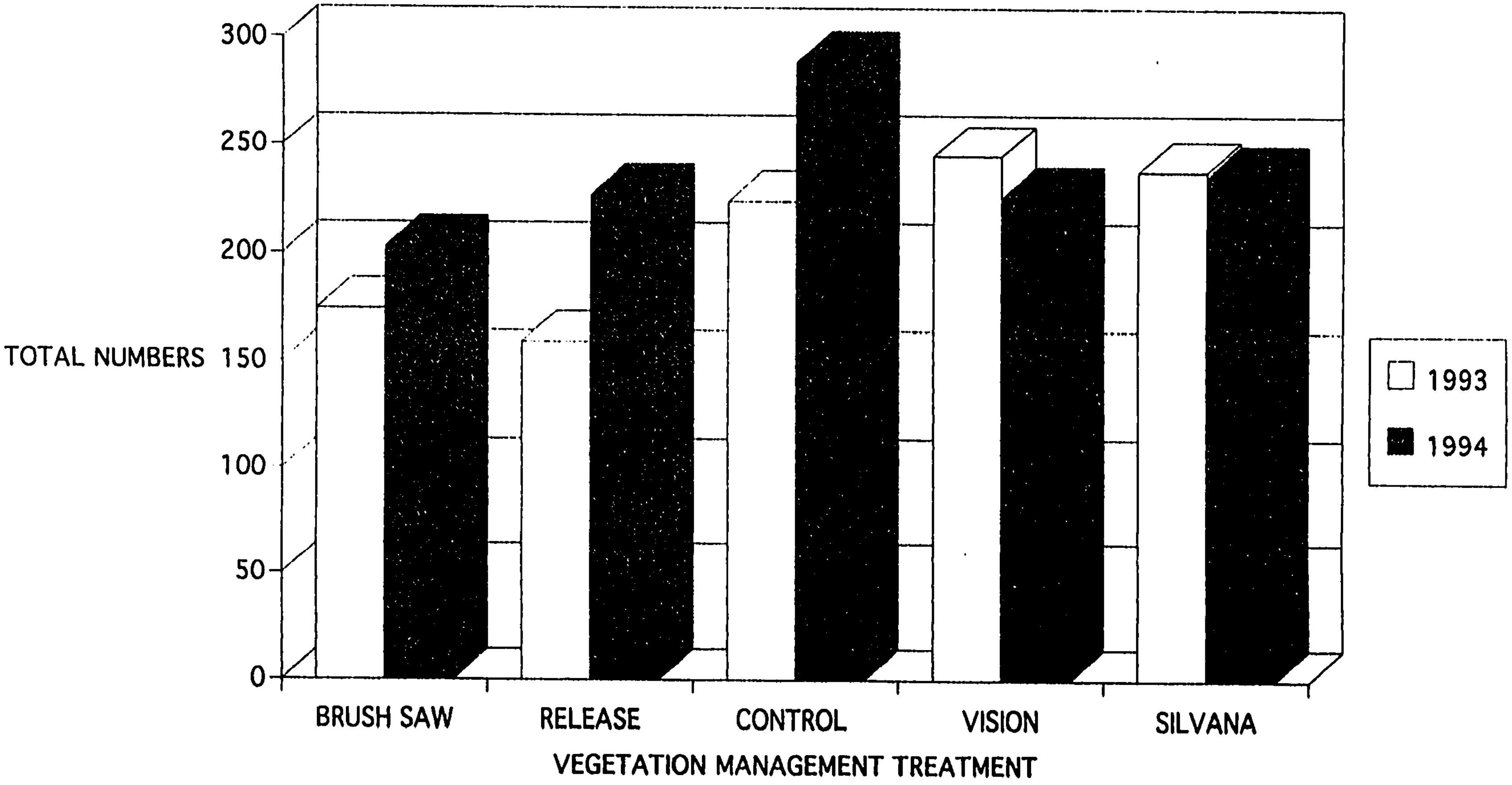

Figure 10. The distribution of the Coleopteran Family Carabidae (1993 and 1994) across the vegetation management treatments, Fallingsnow Ecosystem Project

within the four blocks can be primarily attributed to the natural variation between and within the blocks as described previously on page 68. Block differences were notable for many Families including Carabidae, Cicindelidae, Mycetophagidae, Nitidulidae, Pselaphidae, Scolytidae, Silphidae, and Staphylinidae (Appendix V). Mycetophagidae, Pselaphidae, and Scolytidae were all more abundant on block 1 than on the other blocks. However, Cicindelidae was most abundant on block 4, while Silphidae was most abundant on block 2, and Staphylinidae was most abundant on blocks 2 and 3.

Post-treatment: 1994

Block differences were found for several Coleoptera Families including Carabidae, Chrysomelidae, Curculionidae, Elateridae, Endomychidae, Leiodidae, Phalacridae, Silphidae, and Staphylinidae (Appendix V). Both sampling years show higher numbers of Staphylinidae in blocks 2 and 3, although the total numbers in 1994 are much higher overall (Table 4). The distribution of Silphidae among the blocks does not show an obvious trend between the two sampling years. In general, block 2 contained the largest numbers of Coleoptera trapped in 1994, and many Families including Chrysomelidae, Lathridiidae, Leoididae, Nitidulidae, Scarabaeididae, and Staphylinidae were trapped most frequently in this block.

Block differences for the ground-beetles (Carabidae), the Coleoptera

Family of primary interest show that block 4 continued to trap the largest numbers of individuals over both years of sampling (Appendix V). Although block differences were not as notable in the 1993 carabid catch, total numbers caught in 1994 were slightly higher and the contrast in total numbers between the blocks was much greater. In particular, blocks 2 and 4 had much higher total numbers of ground-beetles in 1994 than did blocks 1 and 3. Block 3 contained especially low numbers trapped in comparison with the other blocks. Total numbers by block of 1993 Carabidae also indicate the lowest numbers in block 3 (Appendix V). Significant treatment effects were not evident for Carabidae in 1994. Moreover, covariate effects were also found to be insignificant.

The Covariate ANOVA conducted for Endomychidae, Curculionidae, Staphylinidae, and Tenebrionidae did not show significant treatment effects, block by treatment interaction effects, or covariate effects (Appendix VI). However, significant treatment effects were found for both Leoididae and Silphidae (Appendix VI).

Expected cell means of the treatments for Leoididae show the highest expected cell mean in the Control (untreated) plots, and the lowest expected cell means in the brushsaw and Silvana Selective treatments. A Least Significant Difference test for Leoididae shows significant differences between the brushsaw and Release treatments, brushsaw and Control, and the Silvana Selective and the Control (Appendix VI).

Expected cell means of the treatments for1994 Silphidae show extremely low cell means in both the brushsaw treatment and the Silvana Selective treatment, while the highest cell mean was found in the Release treatment (Appendix VI). A Least Significant Difference test for 1994 Silphidae shows signficant differences between the Release and the brushsaw treatments, and the Release and Silvana Selective treatments (Appendix VI).

Covariate ANOVA for Elateridae found significant covariate effects, but it did not show significant treatment effects. A scatterplot of 1994 Elateridae data plotted against 1993 Elateridae data shows a positive relationship exists between the two data sets (Figure 11). Pitfall traps that contained large numbers of Elateridae in 1993 continued to trap large numbers of this Family in 1994.

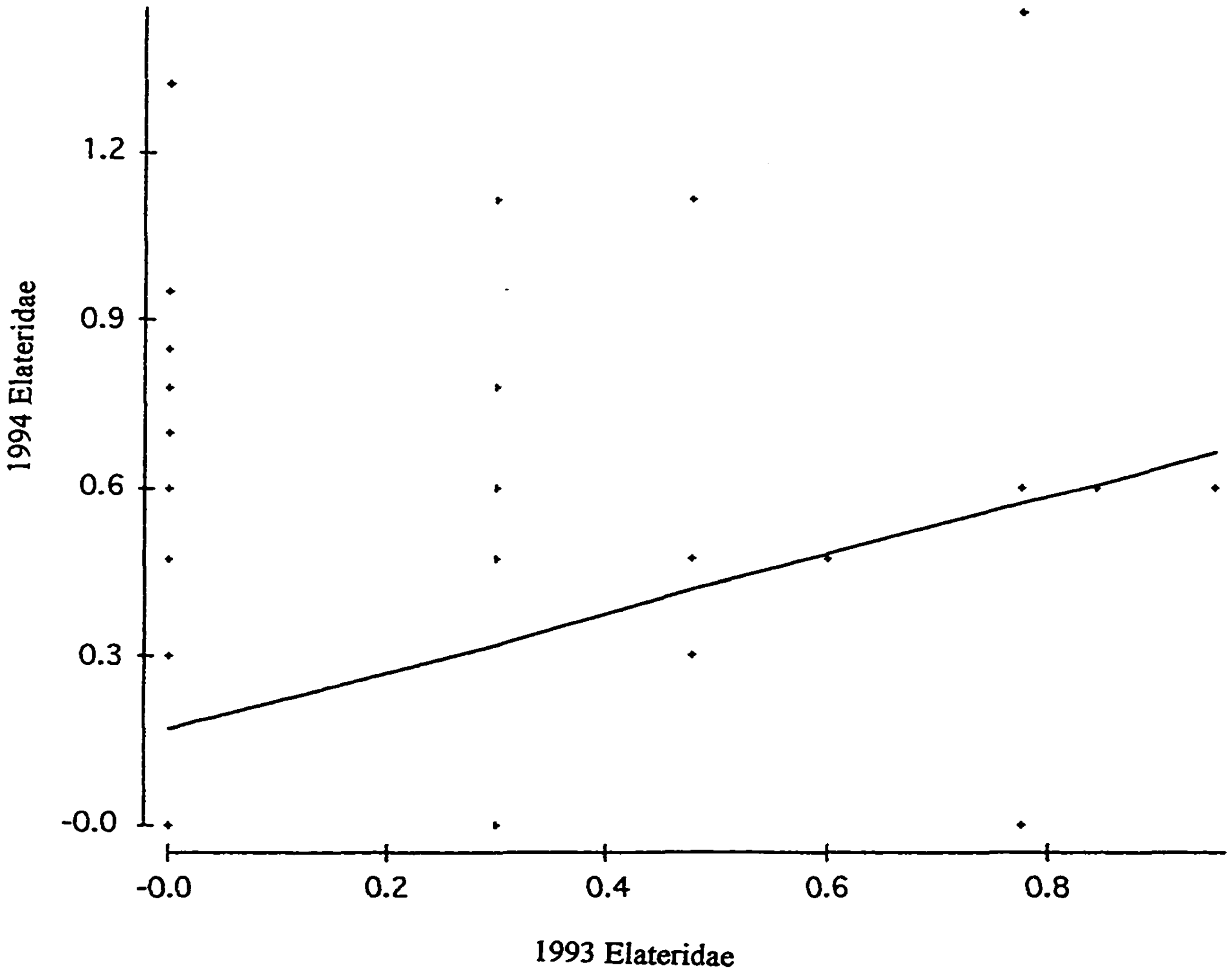

Figure 11. Scatterplot graph with Lowess smoothing showing 1994 Elateridae (log units) plotted against 1993 Elateridae (log units), Fallingsnow Ecosystem Project

DISCUSSION

Coleoptera Collected:

Between block and within block variations probably account for differences in the numbers of trapped Carabidae, the third largest Coleoptera Family in North America. The deep clay soils of block 4 may provide many species of Carabidae with optimum microhabitats and food supply. Thiele (1977) also noted the higher frequency of carabids on clay soils and reasoned that this is probably a result of a more favourable microclimate but also is due in part to the generally higher productivity of organic substances, which in turn, ensures a better food supply. In contrast, the deep silty soils of block 3 may provide a less than optimum habitat for carabids.

Cicindelidae, the tiger beetles, were once considered a member of the Carabidae Family. The Cicindelidae (*Cicindela limbalis* Say) also showed notably higher numbers trapped in block 4. Most of the Cicincelidae were trapped in open areas of the block where vegetation was sparse. This result concurs with Borror *et al.* (1989) and Bland and Jacques (1978) who state that Cicindelidae frequent open, sunny places often on sandy soils while other species are more often found on clay soils. *C. limbalis* Say, the only species trapped in this study, is known to frequent clay soils such as the ones found in block 4 (Freitag personal communication 1997). Blocks 1 to 3 may not have provided enough of these open habitats or soil types, and, therefore, the number of individuals of this tiger beetle species trapped in these blocks was much lower.

The carrion beetle, Silphidae, also revealed between and within block differences. As a Family that is naturally associated with carrion, a concern arose that traps containing small mammal carrion would also contain significantly larger numbers of carrion-eaters, including Silphidae. Hobischak (1994 unpublished) conducted statistical analyses to determine whether the number of carrion-eaters (dung eaters excluded) and non-carrion eaters found within the traps were independent of the presence of small mammal carrion.

Statistical results for differences in Silphidae numbers trapped in carrion and non-carrion traps were non-significant (Hobischak 1994 unpublished), indicating that the presence of carrion did not significantly affect the numbers of Silphidae trapped. The great variation within the sample resulted in no significant difference when compared to between sample variation. Hobischak (1994 unpublished) concluded that the small mammal carrion did not effect the number of non-carrion individuals found within the traps, but it did cause an insignificant increase in the number of invertebrate carrion eaters.

Pselaphidae, the short-winged mold beetles, and Mycetophagidae, the hairy fungus beetles, both feed on fungi and were trapped in higher numbers in block 1. In addition to the above average rainfall during the sampling period in 1993, block 1 contained a large number of low-lying, wet areas. The overall wet condition of block 1 makes it a prime site for fungi proliferation. In turn, large numbers of fungi feeders were trapped on block 1 in comparison with the other blocks.

Nitidulidae, the sap beetles, are also known to live in damp places and feed on fungi (Borror *et al.* 1989), and were trapped in notably higher numbers on block 3 . Again, block 3 contains many wet areas where fungi proliferation is probable. Some species are also associated with the carcasses of dead animals, and it is likely that many of the Nitidulids trapped were caught in traps having small mammal carrion.

Differences in the number of Coleoptera trapped between 1993 and 1994 can primarily be attributed to the warmer, drier weather conditions in June and July, 1994. Again, the warmer weather caused an increase in the activity of many Coleoptera species. Increased activity due to warmer temperatures and the reduction of traps being pushed out of the ground from high ground water conditions increased the trapping efficiency and, therefore, increased the numbers of Coleoptera trapped in 1994. Briggs (1960) and Dennison and Hodkinson (1984) both agree that a rise in temperatures should increase the motility of carabid beetles. This statement should also apply to many other beetle Families as well as other insect Orders. However, the increase in average temperature in June, 1994 did not act to notably increase the carabid beetle catch as the numbers caught in 1994 were only slightly more than those trapped in 1993.

The large increase in 1994 in the number of Lathridiidae, minute-brown scavenger beetles, trapped was due to a few traps containing higher numbers of Lathridiidae relative to the large majority of traps. It is also possible that some Lathridiidae may have been mis-identified in 1993 and, therefore, the 1993 numbers of this Family may not be an accurate reflection of actual numbers trapped. Lathridiidae are often mistaken for silken fungus beetles (Cryptophagidae), hairy fungus beetles (Mycetophagidae), tooth-necked fungus beetles (Derodontidae), cerylonid beetles (Cerylonidae), and rhizophagid beetles (Rhizophagidae) (White 1983), so it is not unusual for mis-identification especially since all of these beetles are extremely small (< 5mm) and possess similar features.

The leaf beetles, Chrysomelidae, most notably feed on herbaceous plants, leaves and flowers as adults (White 1983). The larvae feed on the roots, mine leaves, bore stems, and feed on foliage of the same vegetation types as adults (White 1983). A large increase in the number of Chrysomelidae trapped in 1994 can be likely attributed to the increased cover of herbaceous vegetation in all of the treatments including the Control in 1994, one year after treatment (Bell *et al.* 1996 unpublished).

Notable decreases in 1994 in some beetles such as the short-winged mold beetle, Pselaphidae, are likely due in part to the warmer, drier weather conditions during the sampling period in 1994 which may have decreased the food supply (*i.e.* molds) of this Family. However, this decrease is likely temporary as the increase in debris and litter on the ground surface one year after treatment should supply this Family with ample food supplies and suitable micro-habitats in which to live. It is also possible that the numbers of Pselaphidae trapped in 1994 did not reflect true numbers of individuals. The increase in woody debris and litter on the ground in 1994 after the treatments were applied may have produced excellent conditions for the Pselaphidae for food, shelter, and reproduction and, thus, reduced their mobility in 1994. Lower mobility would decrease the number of Pselaphidae trapped in pitfalls.

Due to the considerable variation in habits of the scarab beetle, it is difficult to determine reasons for the large increase in the number of Scarabaeidae trapped in 1994. Many scarab beetles are dung feeders or feed on decomposing plant materials, as well as carrion (Borror *et al.* 1989). Some Scarabaeidae live in ant nests or in the nests or burrows of vertebrates. In addition, some feed on fungi and others feed on plant material including grasses, foliage, fruits, and flowers. The majority of scarab beetles identified in this study were earth-boring dung beetles (subfamily Geotrupinae), which are normally found beneath cow dung, horse manure, or carrion. It is quite possible that these scavenging Scarabs were attracted to the pitfall traps due to the presence of small mammal carrion or invertebrate carrion. The warmer weather of June, 1994 may have helped to both increase Scarab mobility and increase the rate of decay of carrion in the traps. Even with the saline preservative in the traps, some decomposition of small mammal carrion was evident in some pitfalls.

The Staphylinidae (Rove beetles) was an interesting Family to examine due to their similarities in niche to the carabid beetles. The Staphylinidae are represented by nearly 400 genera and 3,000 species in North America (Dindal 1990), and they are the only Coleoptera whose niche partially overlaps that of the carabids (Thiele 1977). However, nutritionally the Staphylinidae are not considered a serious competitor. Most soil staphylinids can be found in uncompacted, moist forest litter which is rich in decomposing organic material (Dindal 1990). Many staphylinids occur in soil-related microhabitats such as dung and carrion, higher fungi, vertebrate and invertebrate nests, and wet sites along streams and other bodies of water.

The largest and most notable increase in numbers trapped of any Coleoptera Family was that of the rove beetles, Staphylinidae. Each block experienced dramatic increases in the number of rove beetles trapped, however, the most marked increases occurred in blocks 2 and 3. Many of the Staphylinidae identified in 1994 were extremely small in size (< 5mm in length), whereas, far fewer extremely small rove beetles were trapped in 1993. According to Thiele (1977) the forest litter layer favours staphylinids over carabid beetles, as their long slender form offers less resistence for movement in this niche. Within the forest litter and soil, smaller staphylinid species are favoured over larger ones as their small size permits a greater ability for movement within the soil and crevaces of the litter layer. Although Staphylinidae are primarily predaceous, many of the soil and litter dwelling species feed on decaying organic matter or fungi (Dindal 1990). It is possible that the dramatic increase in Staphylinidae in 1994 is due, in part, to an increase in decomposing litter caused by the vegetation management treatments.

Most adult rove beetles are very good fliers and many of these rove beetles may have dispersed to the blocks by flying. Moreover, according to Dindal (1990), many Staphylinidae species can have several generations per year. Therefore, if factors such as an abundance of favourable microhabitats and good weather conditions prevail, it is possible that more than one generation reproduced during the summer of 1994, thereby, dramatically increasing the Staphylinidae population and numbers trapped.

Conversely, it is also possible that the dramatic increase in Staphylinidae trapped in 1994 could be attributed to increased mobility due to migration to a more suitable habitat. However, increased mobility due to migration via walking is unlikely since staphylinids are good flyers. Therefore, many staphylinids would choose flight over walking to a more suitable habitat, and flying staphylinids would not be trapped frequently in pitfall traps that target ground- and soil-dwelling insects and arthropods. Furthermore, the extremely small staphylinids (< 5mm) often burrow into the litter layer and soil when experiencing unsuitable conditions above the ground (Thiele 1977). Therefore, if the treatments produced adverse conditions, the number of staphylinids trapped in 1994 should have decreased rather than increased.

Tenebrionidae, the darkling beetles, also experienced a large increase in numbers trapped in 1994. Most species of Tenebrionidae feed on plant materials while others feed on fungi (Borror *et al.* 1989). According to White (1983), nearly all of these species are scavengers on decaying vegetation, dung, seeds and cereals. The vegetation management treatments increased the amount of decaying plant material on all four blocks, and, therefore, likely contributed to the increase in the numbers of Tenebrionidae trapped.

Post-treatment: 1994

Natural variation (as described previously on page 68) between and within the four blocks accounts for block differences in the numbers trapped of many Coleoptera Families. Generally, the vegetation management treatments had little effect on the tested Families of the Coleoptera. Silphidae and Leoididae were the only two beetle Families exhibiting significant treatment effects.

Leoididae (subfamily Leoidinae), the round fungus beetles, are small, 1-6.5 mm beetles that spend both larval stages and the adult stage on fungi, on slime molds, in decaying vegetation, or under bark (White 1983). The small carrion beetles (formerly Leptodiriidae) were once considered a separate Family from Leoididae, but are now included in the Leoididae Family (subfamily Catopinae). These small carrion beetles live primarily in moist forests and are generally found in decomposing material such as carrion, humus, dung, and fungi, while some are found in forest litter, in soil, beneath bark, or in nests or burrows of small mammals, owls, tortoises and ants (White 1983). The majority of Leoididae trapped in both sampling years belonged to the Catopinae subfamily with approximately twice as many as the Leoidinae subfamily. Hobischak's (1994 unpublished) results showed that 137 Catopinae were associated with twelve pitfall traps containing small mammal carrion in 1993, while only 9 were found in the same number of non-carrion traps. Therefore, it is likely that a large number of the Leoididae (subfamily Catopinae) were attracted to traps containing small mammal carrion.

The significant difference in the number of Leoididae trapped between the Control and Silvana Selective treatment and the Control and the brushsaw treatment indicate that the removal of vertical vegetation structure has had a negative impact on this Family. However, in removing the vertical vegetation cover an increase in large and small organic debris on the ground occurred, and this increase in ground level debris may have created suitable microhabitats for this species. In addition, the increase in the amount of obstacles on the ground may have slowed the mobility of Leoididae, thus, reducing their numbers in the pitfall traps. The significant difference in numbers of Leoididae trapped in the brushsaw treatment and the Release herbicide treatment likely indicate increased mobility by this Family in the herbicide treatment due to a reduction in vegetative obstacles, and possibly the search for a more suitable microhabitats and food.

Significant differences between the brushsaw and Release herbicide treatments, and between the Silvana Selective and the Release herbicide treatments for Silphidae also imply that the brushsaw and Silvana Silvana treatments had a negative impact. However, the same reasoning as applied for Leoididae can be applied to Silphidae as well. Lower mobility due to an increase in large and small organic debris in the brushsaw and Silvana Selective treatments likely caused a decrease in the number of Silphidae trapped. Higher mobility and, thus, higher trapping frequency in the Release herbicide treatment may indicate Silphidae moving to more suitable microhabitats in which to live. Although Silphidae are primarily associated with carrion as a food source, a trend in the number of traps containing small mammals in the treatments was not found.

The Carabidae, which exhibited block differences in 1993, revealed the same trend in 1994 with even stronger block effects. Like 1993, block 4 appears to contain the best habitat for carabid beetles, which may be due, in large part, to the deep clay soils. Block 2 also revealed high numbers of Carabidae trapped. This result may also be attributed to the presence of a well drained clay loam soil type, and an abundant food supply as a consequence of its productive soils. Both blocks 2 and 4 possess clay based soils, which according to Thiele (1977) is where most carabids are found. Niemela (1990) and Niemela *et al.* (1992) stresses the importance of adequate soil moisture in the distribution of carabid beetles, therefore, the soil characteristics of blocks 2 and 4 probably provided carabids with optimal soil moisture for survival and reproduction.

The lack of a notable response by the Carabidae to the vegetation management treatments is not an unexpected result because of the large amount of diversity in habits and lifestyles of the many carabid species within the blocks. Most carabids are able to move in response to environmental change (Refseth 1980), therefore, if the vegetation management treatments caused enough of a change in the microhabitats of the Carabid species, dispersal to more hospitable habitats would have occurred. Since Carabid catches and overall species composition did not change from 1993 to 1994, the treatments apparently did not have a significant effect on this Family. This result indicates that the vegetation management treatments did not produce a severe enough change to the

Carabids microhabitat to alter their abundance one year post-treatment. This result also indicates the responses of individual species within the Carabid Family may have masked any treatment effects at the Family level of organization. Further discussion on the effects of the treatments on Carabidae follows in the next discussion section dealing specifically with Carabid species.

The large increase in the number of Elateridae (Click beetles) trapped in 1994 may be due, in part, to an increase in the amount of decaying vegetation on the blocks as some Elateridae can live in decaying vegetation (White 1983, Borror *et al.* 1989). However, the treatments did not produce a notable effect.

The highly significant covariant effect for Elateridae (*i.e.* the effect of the 1993 catch on the 1994 catch) implies that traps containing high numbers of this Family in 1993 tended to contain high numbers of Elateridae in 1994 as well. This stands to reason as productive microhabitats for this Family may have been even more productive in 1994 along with the better weather conditions. This result is also an indication that suitable microhabitats for Elateridae are patchy, and areas with high numbers of Elateridae trapped in both years likely reflects areas of suitable microhabitats and adequate food supply.

The lack of significant treatment effects on other beetle Families tested including Curculionidae, Endomychidae, Staphylinidae, and

Tenebrionidae indicates that the vegetation management treatments did not change the distribution of these Families. It also indicates that the vegetation management treatments did not adversely effect the microhabitats and food supply of these Families significantly.

CONCLUSIONS: COLEOPTERA COLLECTED

1. Block differences among the 1993 and 1994 Coleoptera can be attributed to the natural variation between the four blocks.
2. Beetle Families preferring open terrain, such as Cicindelidae, are found more abundantly on block 4 because this block contains more open habitats in relation to the other blocks.
3. The presence of small mammal carrion in pitfall traps influenced the number of Coleoptera carrion feeders in the traps, however, this result was not statistically significant (Hobischak 1994).
4. The general increase in the number of Coleoptera trapped in 1994 over 1993 can be primarily attributed to natural population fluctuations, and better weather likely causing an increase in Coleopteran mobility.
5. Little change occurred in the number of Carabidae trapped between 1993 and 1994, and the treatments did not have a significant effect. This result indicates that, in general, Carabid beetle populations appear to be stable in abundance and distribution despite the application of the vegetation management treatments in the fall of 1993.
6. Non-significant treatment effects for Carabidae may also be a reflection of the diversity of carabid species identified, each of which exploits a different niche, thereby, masking any treatment effects at

this level of organization.

7. Some Coleoptera Families such as the Elateridae, Staphylinidae, and Tenebrionidae may have benefited from the vegetation management treatments due to an increase in decaying vegetation in the treatment plots. All three Families contain many species dependent on decaying vegetation.
8. Significant covariate effects for Elateridae indicate that healthy Elateridae populations in 1993 continued to thrive in 1994 despite the application of the vegetation management treatments.
9. The Leaf beetles, Chrysomelidae, increased in trapped numbers in 1994 due to an increase in herbaceous vegetation on which this Family feeds.
11. Significant treatment effects for Leoididae and Silphidae can be attributed to changes in vegetation structure and cover likely resulting in an decrease in mobility in the brushsaw and Silvana Selective treatments, and, thus a decrease in the numbers of these Families trapped.

CHAPTER 3

RESULTS

Carabidae Collected:

A total of twenty-three species of Carabidae were identified from the 1993 catch (Table 5), and four additional species were found in 1994. Two species, *Poecilus lucublandus* Say. and *Pterostichus coracinus* Newman, were the most abundant in both years of sampling (Figure 12). Ten species were of intermediate abundance (*Agonum cupripenne* Say, *A. decentis* Say, *A. gratiosum* Mannerheim, *A. thoreyi* Dejean, *Harpalus laticeps* Leconte, *Chlaenius emarginatus* Say, *Pterostichus adstrictus* Esch., *P. pensylvanicus* Leconte, *Sphaeroderus lecontei* Dejean, *Synuchus impunctatus* Say). One of these species, *C. emarginatus* Say, has not been previously identified in the Thunder Bay area. The remaining species were rare in occurrence: *Amara impuncticollis* Say, *Agonum placidum* Say, *Apristus subsulcatus* Dejean, *Badister obtusus* Leconte, *Bembidion muscicola* Hayward, *B. mutatum* Gemm & Harold, *B. wingatei* Leconte, *Bradycellus lugubris* Leconte, *Carabus maeander* Fischer, *C. limbatus* Say, *Cymindis cribricollis* Dejean, *Elaphrus clairvillei* Kirby, *Notiophilus semistriatus* Say, *Scaphinotus bilobus* Say, and *Trechus apicalis* Motschulsky.

Several carabid species including *A. cupripenne* Say, *P. lucublandus* Say, and *S. impunctatus* Say showed a large increase in numbers trapped

Table 5. Total numbers with mean/trap and standard deviation of Carabidae collected from pitfall traps, Fallingsnow Ecosystem Project (1993 and 1994)

Species	1993		1994		Total Numbers	
	Mean/ Trap	S.D.	Mean/ Trap	S.D.	1993	1994
Pterostichus coracinus Newman	3.5	2.7	3.3	2.7	212	237
Poecilus lucublandus Say	3.2	3.4	4.2	5.3	167	322
Synuchus impunctatus Say	2.0	1.8	2.4	3.1	76	135
Pterostichus pensylvanicus Leconte	1.9	2.2	2.1	2.0	67	114
Agonum gratiosum Mannerheim	1.5	1.3	1.7	2.1	37	74
Harpalus laticep Leconte	1.4	1.1	1.2	0.6	29	16
Pterostichus adstrictus Esch.	1.2	0.7	1.3	1.5	25	20
Spheroderus lecontei Dejean	1.3	0.6	1.1	0.4	23	16
Agonum thoreyi Dejean	1.2	0.7	1.5	1.1	16	54
A. decentis Say	1.2	0.6	1.2	0.6	14	23
Chlaenius emarginatus Say	1.1	0.4	1.2	0.7	12	20
Amara impuncticollis Say	1.1	0.3	1.0	0.3	6	7
Agonum placidum Say	1.0	0.2	1.2	0.4	4	15
Scaphinotus bilobus Say	1.0	0.2	1.0	0.1	3	1
Carabus maeander Fischer	1.0	0.1	1.0	0	2	0
Badister obtusus Leconte	1.0	0.1	1.0	0.2	1	3
Bembidion wingatei Leconte	1.0	0.1	1.0	0.1	1	2
Bradycellus lugubris Leconte	1.0	0.1	1.0	0.1	1	2
Agonum cupripenne Say	1.2	0.6	1.4	1.1	1	40
Apristus subsulcatus Dejean	1.1	0.4	1.3	0.9	0	34
Bembidion muscicola Hayward	1.0	0	1.0	0.1	0	1
B. mutatum Gemm. and Harold	1.0	0	1.0	0.1	0	2
Carabus limbatus Say	1.0	0	1.0	0.1	0	1
Cymindis cribricollis Dejean	1.0	0	1.0	0.1	0	1
Elaphrus clairvillei Kirby	1.0	0	1.0	0.2	0	3
Notiophilus semistriatus Say	1.0	0	1.0	0.1	0	1
Trechus apicalis Motschulsky	1.0	0	1.0	0.2	0	9
Unidentified						21
Total					712	1184

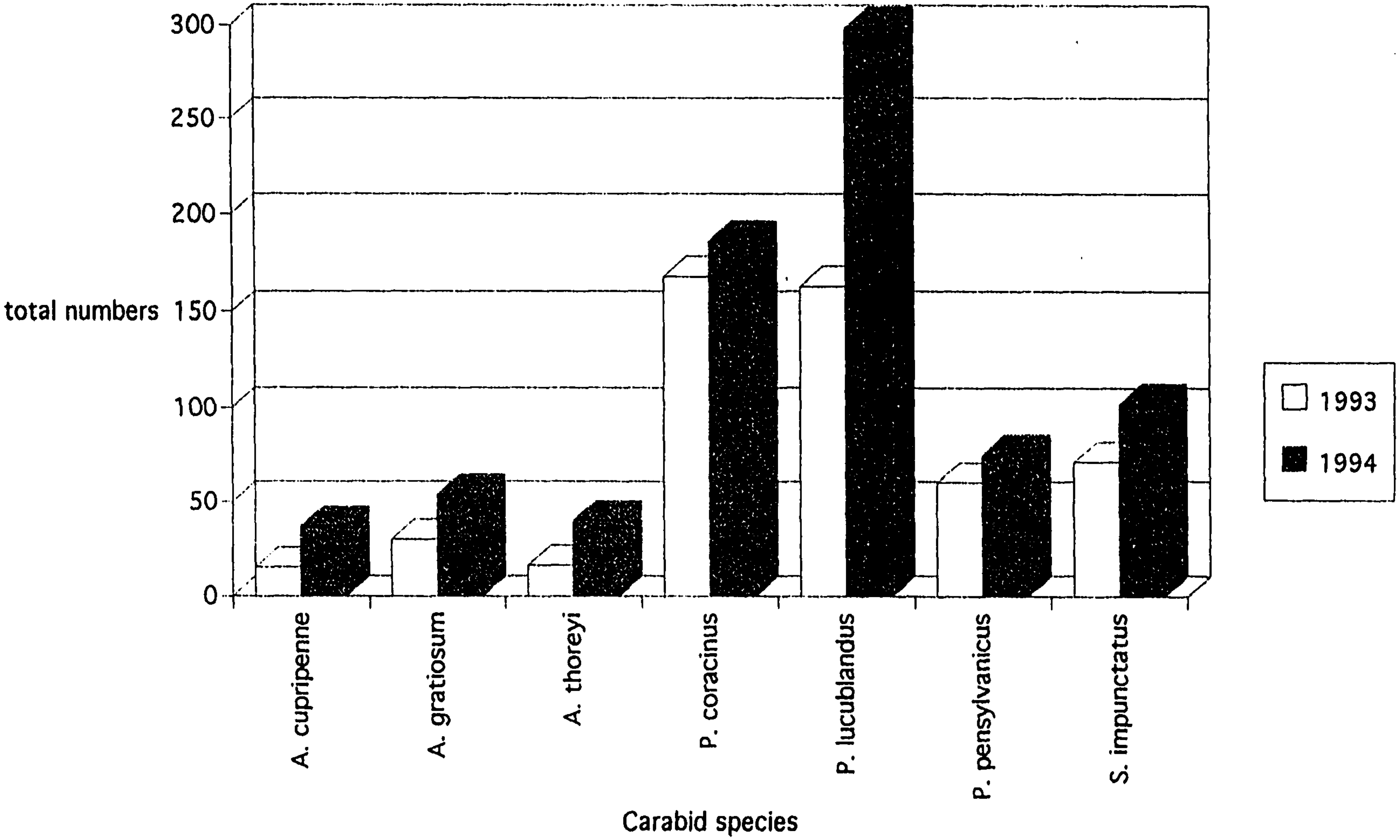

Figure 12 Abundant carabid species (1993 and 1994) total numbers trapped, Fallingsnow Ecosystem Project

in 1994, while both *H. laticeps* LeConte and *P. adstrictus* Esch experienced a large decrease in numbers trapped in 1994. *P. lucublandus* Say, which experienced the largest increase in numbers trapped in 1994, increased in all treatments except the Vision herbicide treatment (Figure 13).

Block differences were notable for *A. cupripenne* Say, *A. decentis* Say, *C. emarginatus* Say, *H. laticeps* LeConte, and *P. lucublandus* Say (Appendix VII). Each of these species exhibits higher numbers in block 4 (*H. laticeps* and *P. lucublandus*), blocks 2 and 4 (*A. cupripenne*), block 2 (*C. emarginatus*) and block 1 (*A. decentis*) (Appendix VII). The distribution of carabid species among the four blocks is variable, although blocks 2 and/or 4 often hold higher numbers of the various species and block 1 often has the fewest numbers of insects.

Post-treatment: 1994

Block differences were notable for a few carabid species including *A. cupripenne* Say, *P. lucublandus* Say, *P. pensylvanicus* Leconte, and *S. impunctatus* Say (Appendix VII). Both *A. cupripenne* Say and *P. lucucblandus* Say exhibited prominent block differences as well in 1993. *A. cupripenne* Say was found almost exclusively in blocks 2 and 4 in both sampling years. *P. lucublandus* Say was consistently most abundant in block 4.

Covariate ANOVA's for *A. gratiosum* Mann., *P. coracinus* Say, and *P.*

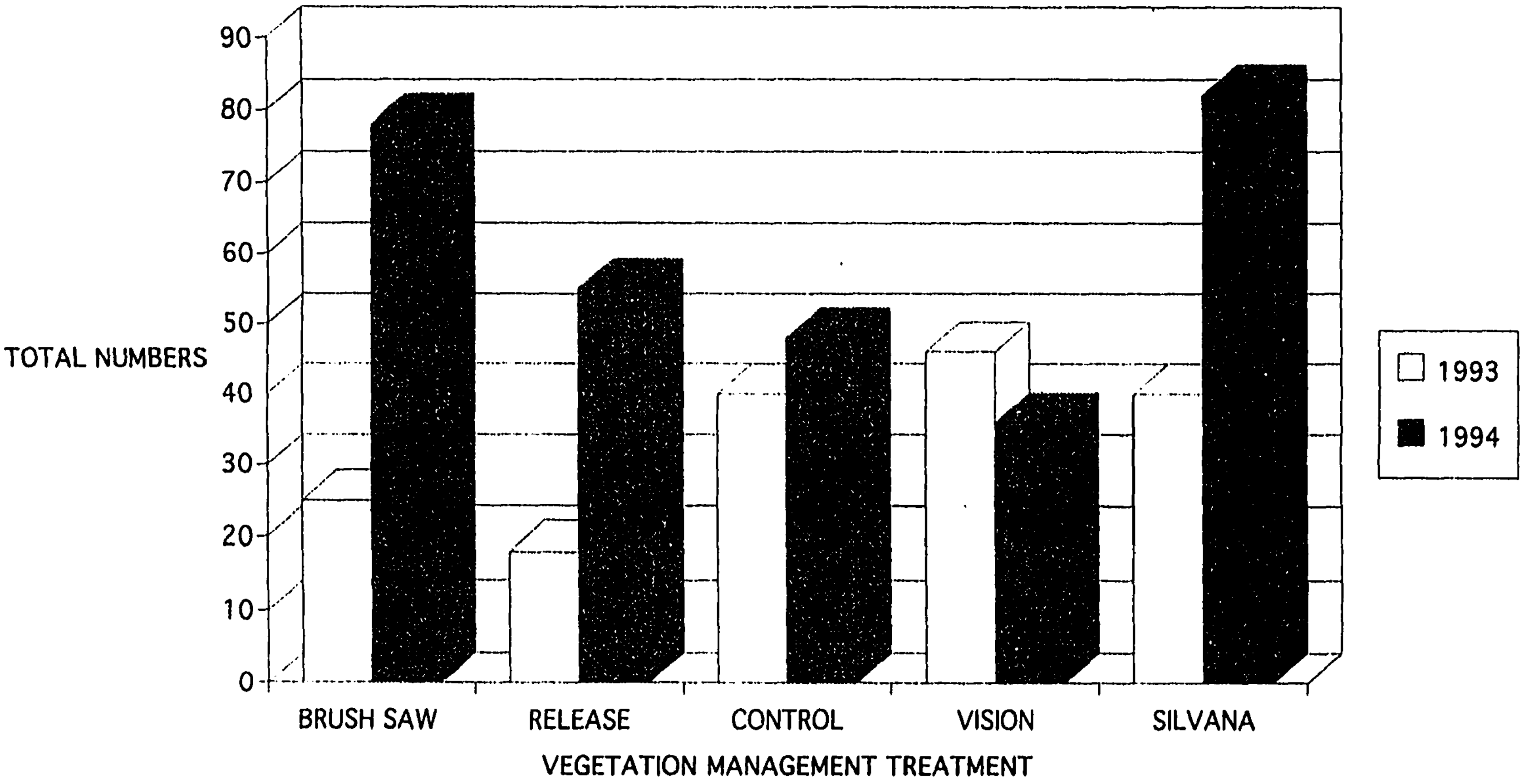

Figure 13. 1993 and 1994 *P. lucublandus* Say across the vegetation management treatments, Fallingsnow Ecosystem Project

lucublandus Say found significant covariate effects (Figure's 14, 15 and 16). However, none of the Covariate ANOVA's of 1994 Carabid species tested found significant treatment effects (Appendix VIII). Nevertheless, the genera *Agonum* and *Pterostichus* and *Poecilus lucublandus* showed some interesting distribution patterns among the treatments.

A. gratiosum Mann. exhibited its highest numbers trapped in the Control plots and lowest numbers in the Brushsaw and Silvana Selective treatments, while *A. thoreyi* Dejean showed its highest numbers trapped in 1994 in the Vision treatment (Figure 17). Similarly, *P. coracinus* Esch. experienced its highest numbers trapped in the Vision treatment in 1994, while *P. lucublandus* Say was trapped the least often in the Vision treatment (Figure 18).

Carabidae Biodiversity

The Shannon-Weiner biodiversity index found that the Control (untreated) plots had the highest diversity of carabid species in 1994, followed closely by both herbicide treatments (Figure 19). Both the Brushsaw and Silvana Selective cleaning machine treatments had similar, but lower indices. Generally, in all treatments the genus *Pterostichus* and the species *Poecilus lucublandus* Say were found in higher proportions than most other species or genera (Appendix IX).

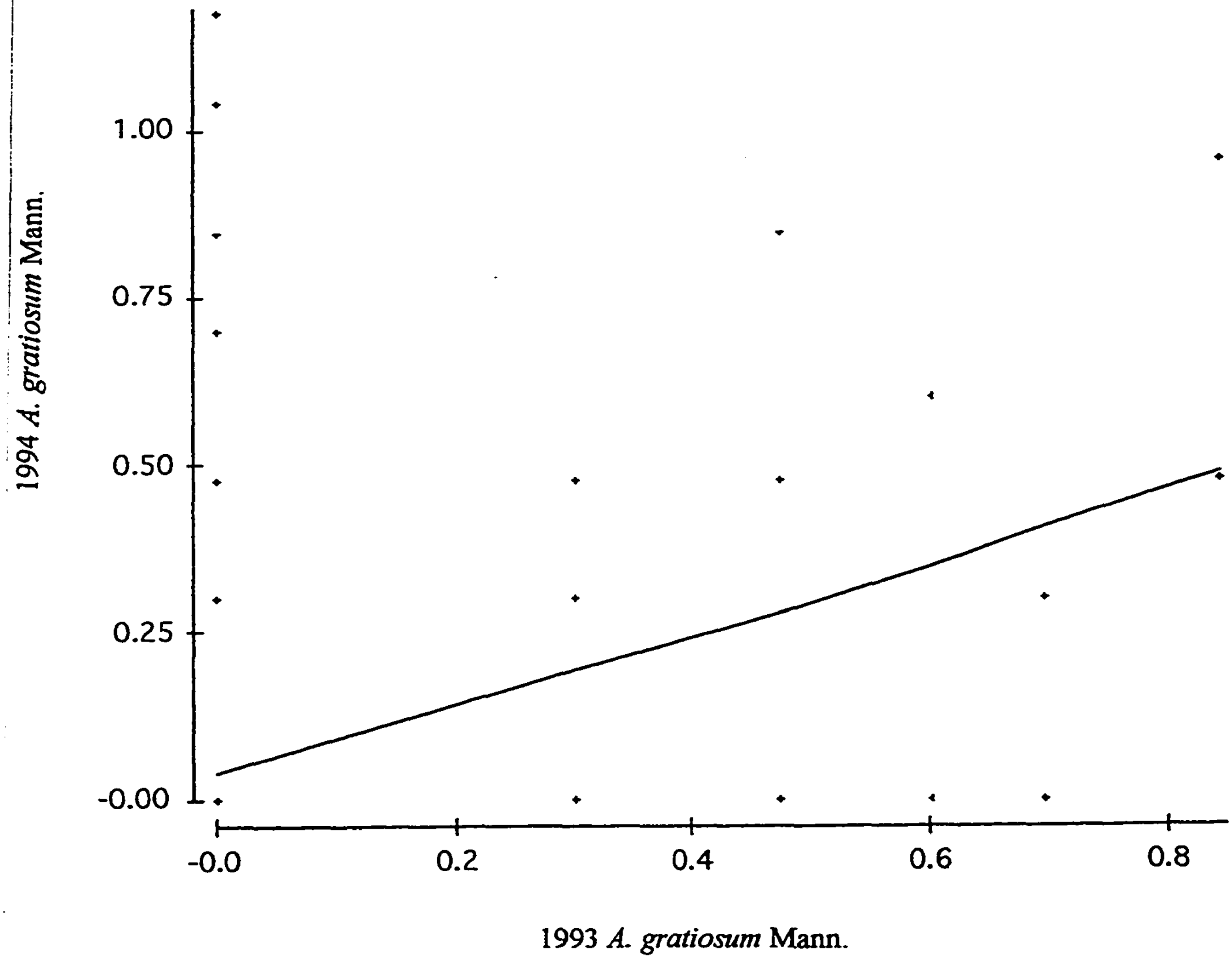

Figure 14. Scatterplot graph with Lowess smoothing showing 1994 *A. gratiosum* Mann. (log units) plotted against 1993 *A gratiosum* Mann. (log units), Fallingsnow Ecosystem Project

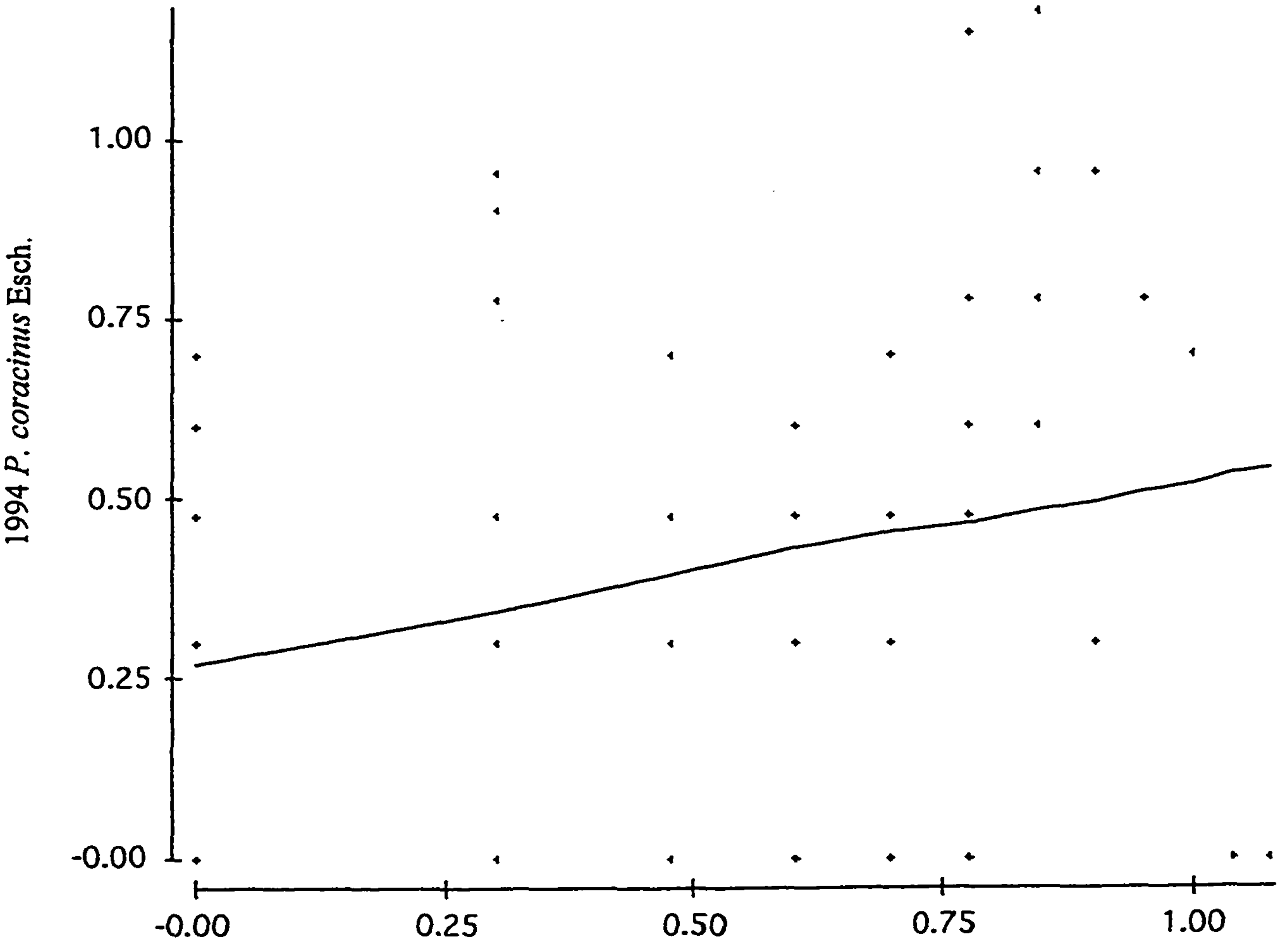

Figure 15. Scatterplot graph with Lowess smoothing showing 1994 *P. coracinus* Esch. (log units) plotted against 1993 *P. coracinus* Esch. (log units), Fallingsnow Ecosystem Project

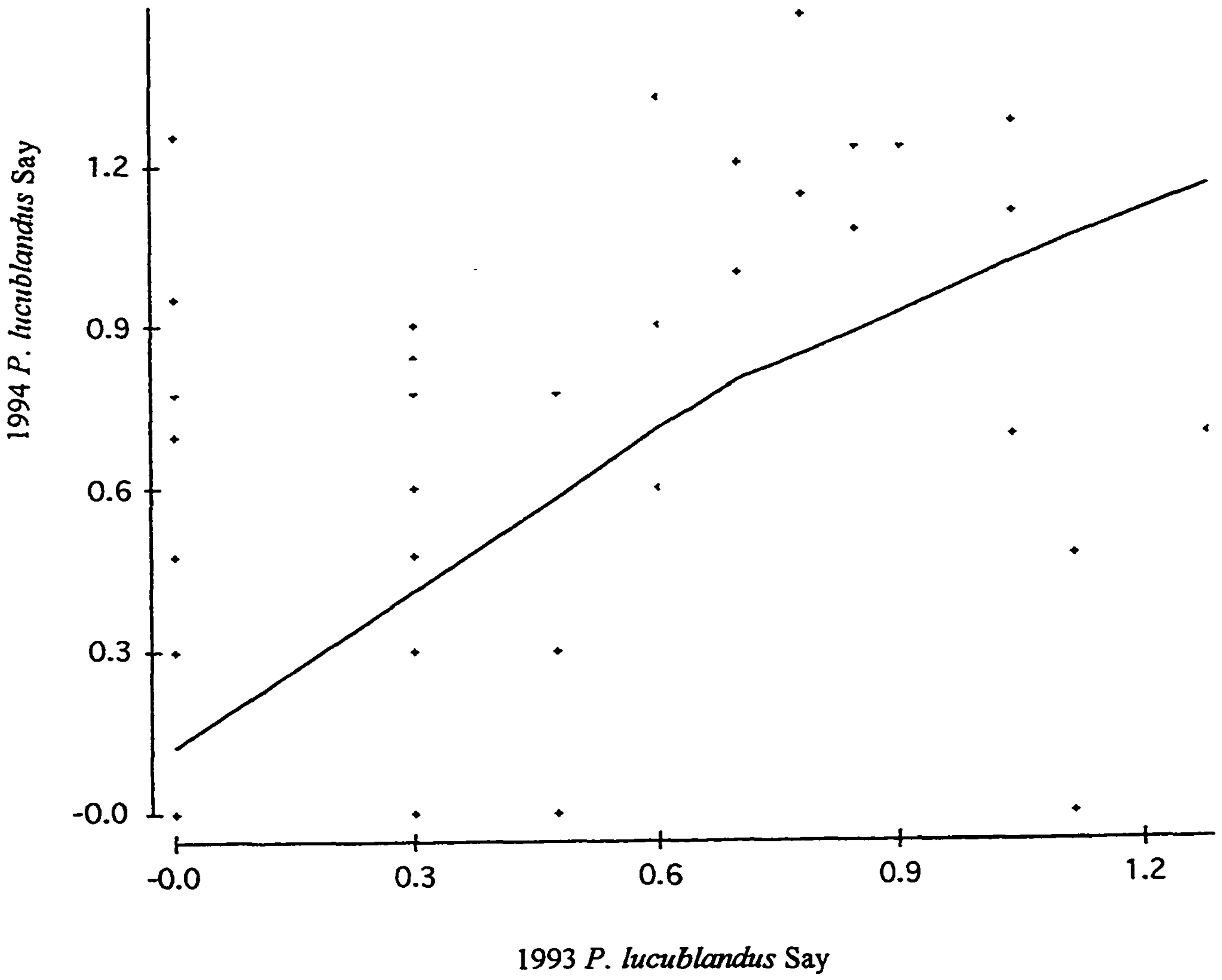

Figure 16. Scatterplot graph with Lowess smoothing showing 1994 *P. lucublandus* Say (log units) plotted against 1993 *P. lucublandus* Say (log units), Fallingsnow Ecosystem Project

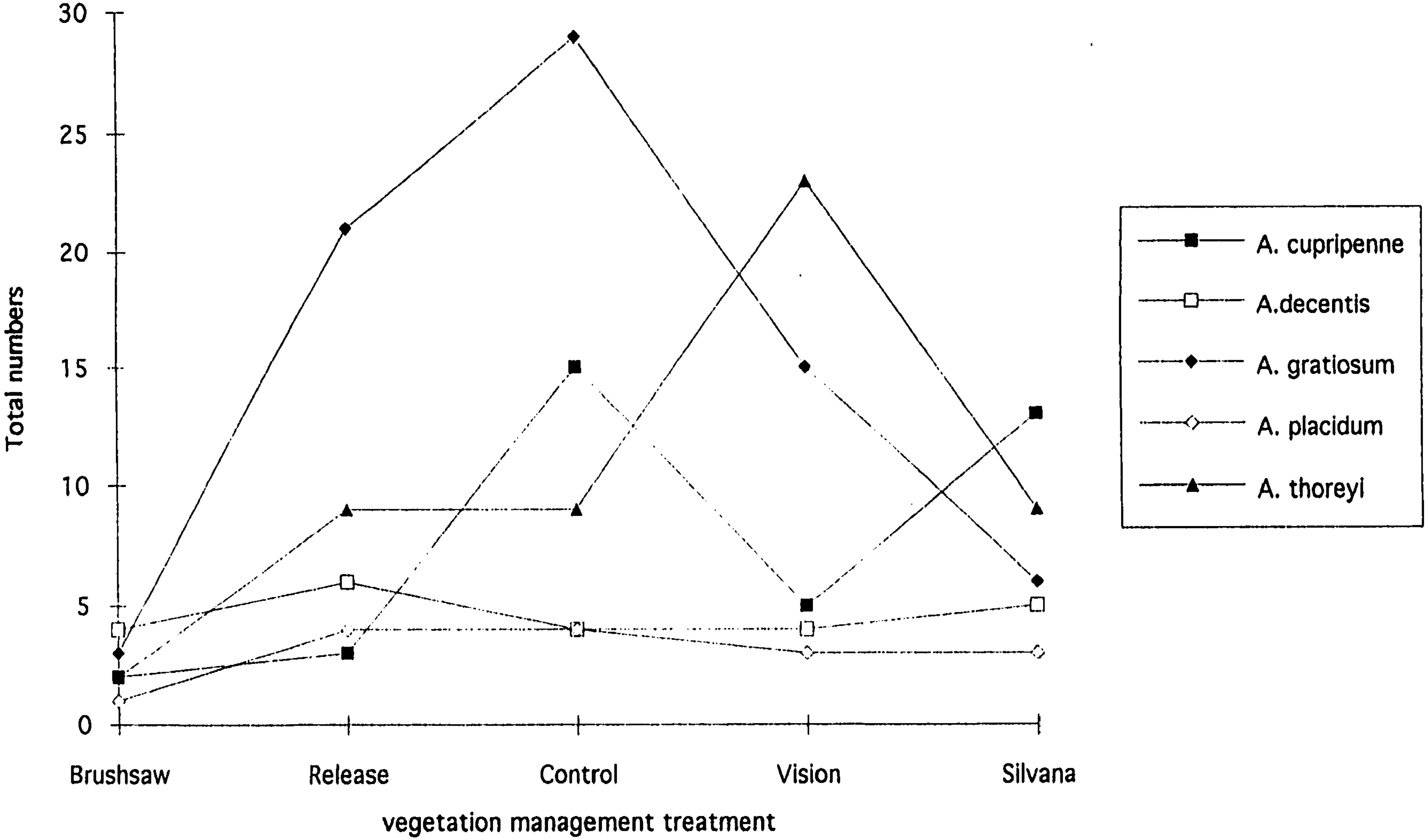

Figure 17. The distribution of *Agonum* spp. across the vegetation management treatments (1994), Fallingsnow Ecosystem Project

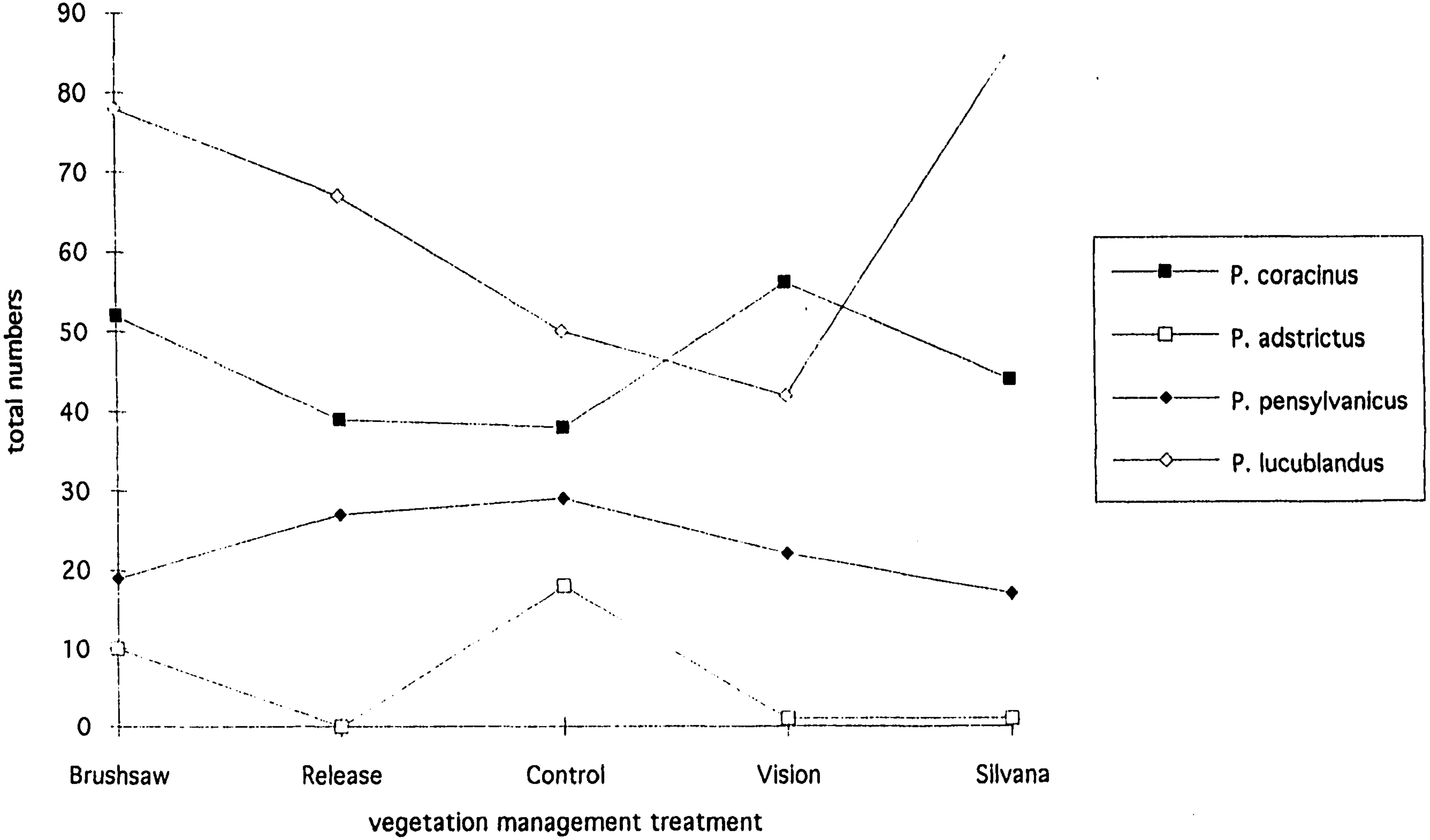

Figure 18 The distribution of *Pterostichus* spp. and *Poecilus lucublandus* Say (1994) across the vegetation management treatments, Fallingsnow Ecosystem Project

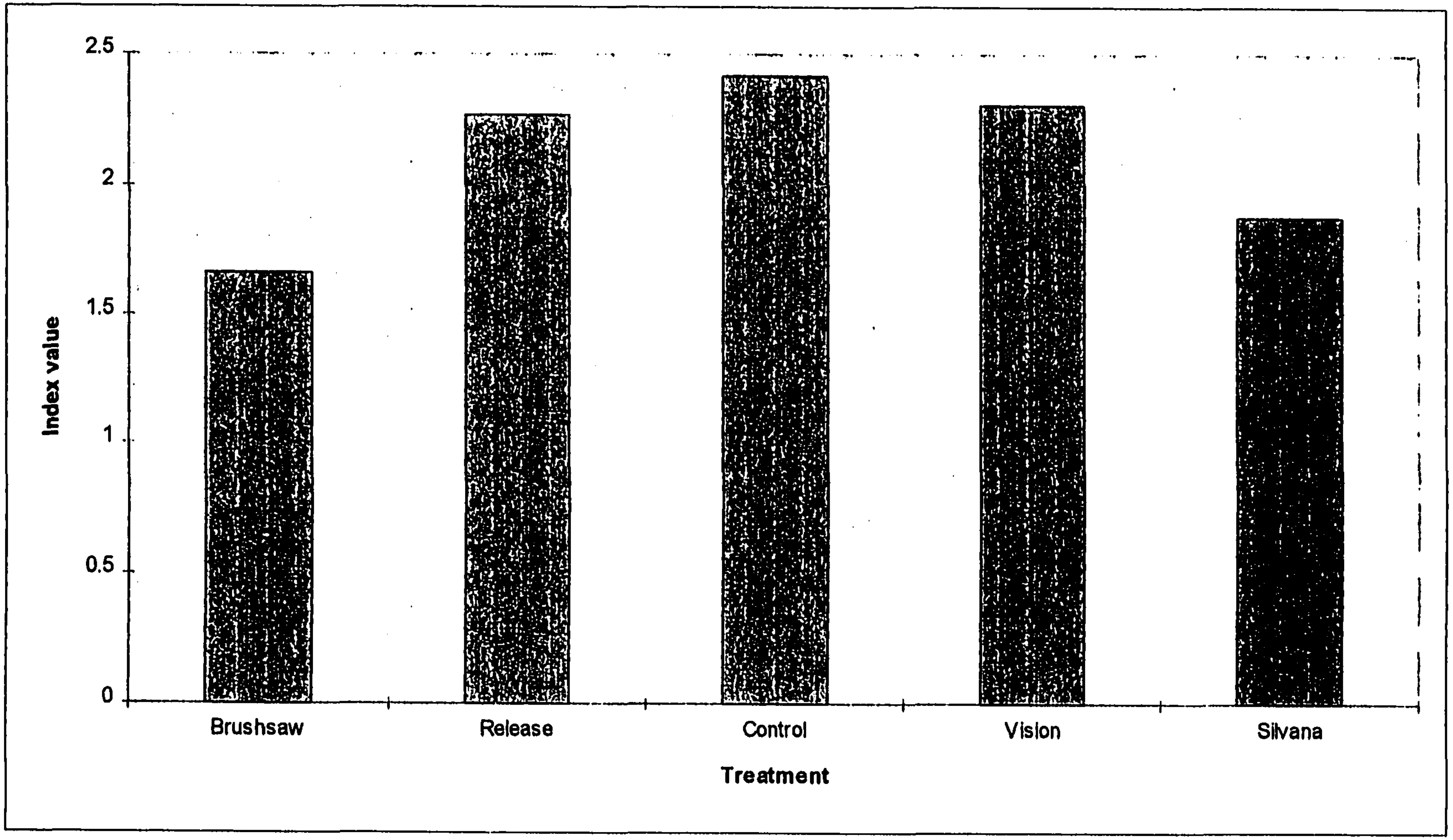

Figure 19. The biodiversity (using the Shannon-Wiener index of diversity) of 1994 carabid species in the five vegetation management treatments including the Control (untreated) plots, Fallingsnow Ecosystem Project

DISCUSSION

Carabidae Collected:

The 1993 carabid species results indicate differences in numbers for most species among the four blocks. This was consistently found for the majority of the data collected from this project, and clearly illustrates that the four blocks are not homogeneous in the type or amount of habitat they provide for various ground-dwelling insects and arthropods. Open-habitat carabid species such as *A. cupripenne* Say and *P. lucublandus* Say were both more prevalent in blocks 2 and 4, which contained fewer wet areas and were, in general, better drained than blocks 1 and 3 (Appendix X). Moreover, block 4 tended to contain, on average, less tall and medium shrubs than the other blocks (Bell *et al.* 1994). Conversely, *A. decentis* Say, a pronounced forest species, had fewer numbers in block 4 during both years of sampling. The fewer tall and medium shrubs in block 4 may not have provided enough shading for forest dwelling carabid species such as *A. decentis* Say, whereas an open-habitat species such as *P. lucublandus* Say may thrive in the relative openness of block 4.

C. emarginatus Say also showed prominent block differences, and this species had not been identified in the Thunder Bay area prior to this study. This species is an inhabitant of deciduous forests, and often occurs on moist soil among leaves as well as under logs (Lindroth 1961-69). Deciduous forests are common in the Quetico Section of the Great Lakes St.

Lawrence Forest Region southwest of Thunder Bay (Wickware and Rubec 1989). This species, which was previously known from as far north as the Rainy River District, may be living at the fringe of its range, or it may be common in recent cutovers that contain an abundance of deciduous cover such as aspen (*Populus tremuloides* Michx.), alder (*Alnus* spp.), and willow (*Salix* spp.). It is likely that *C. emarginatus* Say is common in the deciduous forests southwest of Thunder Bay, and is moving north as the deciduous forests also progress northward. This species has either remained in the cutblocks at low numbers since harvesting occurred, or it has slowly re-established in the cutblocks with the regeneration of early seral vegetation such as aspen, alder, and willow. Niemela *et al.* (1992) and Niemela *et al.* (1993) agree that forest species of Carabidae will often remain in post-harvest cutblocks in low numbers and slowly increase in number as suitable vegetation and soil conditions return.

H. laticeps Leconte also showed notable block differences with greater numbers in block 4. According to Lindroth (1961-69), *H. laticeps* Leconte has been found in sandy, upland woods. Although block 4 has clay soils, the in-block road and landing contains coarser material, which may be suitable for this species. In addition, much of block 4 is a hillside plateau in the northeast portion of the block. Although block 1 has mostly sandy soils, it is probably too wet for *H. laticeps* Leconte to occur in high numbers.

Many of the species collected over the two sampling years commonly occur in open habitats, but also can be found in forests indicating that many of them are generalists. These results agree with the observations of Baquette and Gerard (1993), who found that colonizing species were either generalist species (well fitted to colonization) or forest species generally associated with young spruce plantations (< 10 years). Similar conclusions also were made by den Boer (1985) indicating that rapid and large scale changes in the environment (e.g. clearcut logging) will favour opportunistic species, whereas most specialist species will die out. It is not known how many true "specialist" species existed in the study blocks prior to harvesting in the late 1980's, however, sampling of the adjacent mature forest surrounding the study blocks could provide such information. Pronounced forest species such as *A. decentis* Say may be more common in the adjacent mature stands, and may have either remained at low numbers in the cutblocks since harvesting or may have only recently re-established as the forest regenerates. Niemela *et al.* (1993) found that some forest generalists decrease after logging but do recover with forest regeneration.

Many adults of carabid species of rare occurrence were small (<5mm) in size relative to the most common carabids, which generally were larger in size. The smallest carabid adults including those of *A. subsulcatus* Dejean, *T. apicalis* Motschulsky, *B. obtusus* Leconte, *B. wingatei* Leconte, *B.*

muscicola Hayward, *B. mutatum* Gemm. & Harold, and *B. lugubris* Leconte were also the most rare in occurrence. The apparent rareness of these species may or may not reflect actual population numbers. This result may actually be a reflection of a difference in the susceptibility of the various species to pitfall trapping.

Generally, large carabid species tend to move more quickly and cover more ground in less time than smaller species, thus their chances of being trapped are greater. Data collected from this study supports this notion as species such as *P. lucublandus* Say and *P. coracinus* Newman were trapped most frequently in both sampling years. Refseth (1980) concurs that larger species move faster and are trapped more frequently than smaller species. Therefore, pitfall traps may introduce bias because of the differential susceptibility for trapping of various carabid species (Greenslade 1964, Luff 1975, Adis 1979, Halsall and Wratten 1988, and Topping and Sunderland 1992). Spence and Niemela (1994) agree that, in general, large bodied species are relatively common in pitfall traps while small bodied species are relatively more common in litter washing.

The lifestyle and habits of some of the small carabid species may also have contributed to their rareness in pitfall traps. *B. muscicola* Hayward is usually found under leaves in moist deciduous forests and is a known predator of mosquito eggs (Lindroth 1961-69). Thus, this species is frequently near pools of water, whereas, very few of the Fallingsnow pitfall traps were located immediately adjacent to pools. Thiele (1977) also recognizes that many small carabid species are predators of insect eggs and plant seeds within the soil. Since many of these species are not actively searching for food above ground, the chances of trapping them in a pitfall is reduced. In addition, the smaller body size of these species allows them to exploit niches in the soil and litter layers that many of the larger Carabidae avoid and are unable to expoit.

Small carabids were not the only rare species to have been trapped in low numbers. *C. limbatus* Say and *C. maeander* Fischer were also rare in occurrence in the traps. These are both large (20-25mm) species. *C. maeander* Fischer is a hygrophilus species, often associated with bogs, while *C. limbatus* Say is found in moist deciduous woods and also is often found near water (Lindroth 1961-69). *C. maeander* Fischer was trapped in a wet, downslope area in block 1, while *C. limbatus* Say was collected in 1994 in the Vision treatment plot of block 2 where dense deciduous cover occurred prior to treatment. It is difficult to say if *C. limbatus* Say had taken up residence in the Vision treatment or if it had been trapped as a tourist en route to a more suitable habitat. The trap where the one individual was caught was not far from the block edge and it is possible that this beetle was merely a tourist heading towards the forest edge.

The literature is conflicting about the varying susceptibility of carabid species to pitfall trapping based on daily rhythms. Greenslade

(1964) found that pitfall traps contained significantly higher numbers of nocturnal carabid species than diurnal species when compared with quadrat counts. In contrast, Halsall and Wratten (1988) found no differences in capture rate of nocturnal and diurnal species. The use of pitfall traps in this study may not have biased the sample towards nocturnal species, however, the use of a roof overtop the pitfall trap may have biased the sample towards trapping fewer day-active carabids. Baars (1979) found that day-active carabid species are caught less in traps with dark roofs, whereas night active species showed no difference in numbers caught under dark or light coloured roofs.

The general increase from 1993 to 1994 in the number of individuals of open-county species is probably more a reflection of natural population fluctuations and/or the warmer, drier weather conditions of 1994 contributing to increased insect activity, and not a reaction to the vegetation management treatments. However, it is possible that the vegetation management treatments indirectly caused an increase in carabid activity. The removal of vegetation cover would allow more sunlight to penetrate to the soil surface, thus increasing soil temperatures and decreasing moisture. Accordingly, microclimate and microhabitats would be changed for many species causing them to migrate to a more suitable habitat (Thiele 1977). Therefore, increases in numbers trapped of some species may be a reflection of a mass migration to more favourable habitats. However, statistical analyses of five carabid species do not support this theory.

Post-treatment: 1994

The vegetation management treatments, alone, had very little effect on the carabid species. Block differences were evident in 1994 as they were in 1993 indicating that natural variation between the blocks as outlined on page 68 influenced the presence and abundance of many species of Carabidae.

Although *P. adstrictus* Say was not tested for treatment effects (due to the low numbers trapped in both sampling years), this species did exhibit a notable difference in numbers between the various treatments. In both years of samping, *P. adstrictus* Say was trapped in the lowest numbers amongst this genus. Intergeneric competition is not thought to be responsible for this species low numbers. Competition does not play a large role in carabid species niche differentiation (Thiele 1977, Loreau 1986). The early seral stage conifer plantations may not have provided *P. adstrictus* Say with its optimum habitat. Since this species is common in northern coniferous forests (Lindroth 1961-69) and not deciduous forests, it is likely a forest species that was present in the area of study in relatively low numbers before and after harvesting. The vegetation management treatments combined with the warmer, drier weather conditions of 1994 may have created an environment where soils were too dry and vegetation cover was too sparse for this species to thrive. The fact that most of the *P. adstrictus* Say individuals were trapped in the Control (untreated) plots in 1994 adds validity to this explanation.

A. thoreyi Dejean also appears to have been influenced by the vegetation management treatments, however, this species was also not statistically tested due to the low numbers trapped. *A thoreyi* Dejean was most often trapped in the Vision treatment in 1994. Since A. thoreyi Dejean is a hygrophilus species, most often occurring at the margin of standing, small waters or marshes in rich organic soil and riparian vegetation cover (Lindroth 1961-69), this result was not expected. Again, an increased catch of this species in an unlikely treatment such as the Vision treatment may be an indication that conditions within this treatment were too hostile for this species.

The larger numbers trapped of *A. thoreyi* Dejean in the Vision treatment may be a reflection of increased mobility due to migration to a favourable habitat with adequate food supplies and shelter. Baars (1979b) refers to this type of migration as "directed movement". Moreover, the Vision treatment reduced vegetative cover to the greatest degree, thereby, reducing the amount of ground level obstacles such as grass shoots, and other plant stems. Refseth (1980) found that habitats with an open field layer permitted greater speed of movement which resulted in greater trapping frequencies.

Like *A. thoreyi* Dejean, *P. coracinus* Newman also seemed to be influenced by the treatments although the statistical analysis was not significant. *P. coracinus* Newman was most frequently trapped in the Vision treatment in 1994. *P. coracinus* Newman is a forest species but is also known to occur in meadows and fields (Lindroth 1961-69). This species may have also been migrating to more suitable habitats where vegetative cover and food was abundant. Grum (1971) found that increased mobility is correlated with hungry carabid beetles, therefore, increased catches of *P. coracinus* Newman may be associated with their search for food. As with *A thoreyi* Dejean, increased trapping of *P. coracinus* Newman in the Vision treatment may also be a result of increased trapping efficiency due to decreased vegetative cover .

P. pensylvanicus Leconte also demonstrated this same trend, however, the difference in numbers trapped between treatments was not as marked. Conversely, low numbers trapped of *P. lucublandus* Say in the Vision treatment may indicate lower mobility of this species due to an abundance of food and a suitable microhabitat. However, *P. lucublandus* Say, an open-country species, did exhibit its highest numbers trapped in the Silvana Selective treatment indicating that the difference in impact on microhabitats between the Vision treated plots and the Silvana Selective treated plots was remarkable for this species.

While the vegetation management treatments did not show significant effects on any of the carabid species tested, the 1993 catch of *A. gratiosum* Mann., *P. coracinus* Newman, and *P. lucublandus* Say was related to the 1994 catch of these species. This result shows that traps containing large numbers of these species in 1993 continued to have large numbers in 1994. It can be concluded that for some carabid species, pitfall traps placed in the same sampling sites over two consecutive years does not negatively impact these populations. Moreover, this result indicates that the distribution of carabid species is patchy, and that microhabitats containing healthy populations of these species in 1993 continued to produce healthy populations in 1994 despite the application of the vegetation management treatments. Niemela (1990) and Niemela *et al.* (1992) determined that ground-beetles show non-random spatial distributions both within and between habitats, and that ground-beetles tend to occur in aggregations associated with particular microhabitat types.

Most of the carabid species trapped in the Fallingsnow study likely hibernate as adults, and mating and egg laying occurs in the spring. The treatments occurred in the fall of 1993 (August to October) while the many carabid species were still active, however, the herbicide treatments did not produce a perceptable effect until the following spring. Conversely, the manual brushsaw treatment and the Silvana Selective treatment changed the landscape by immediately removing the mid- and upper-vegetation layers. In addition, the Silvana Selective treatment would have caused the most ground-level disturbance of all the treatments, possibly impacting on ground-beetle microhabitats and causing direct mortality. If migration was to occur from the herbicide treatments because of changes in microhabitat, it would not occur until the spring of 1994. However, the alteration of habitat was immediate in the brushsaw and Silvana Selective treatments. This may have caused some species to migrate to less disturbed microhabitats. However, the addition of woody debris on the ground may have created additional suitable microhabitats for many carabid species.

Notably low Shannon-Wiener diversity indices for the brushsaw and Silvana Selective treatments in comparison to the Control and the herbicide treatments indicates that the manual and mechanical removal of competitive vegetation had the greatest impact on carabid species. However, if I support the findings of Grum (1971) and Refseth (1980), I would conclude that the low diversity indices in the brushsaw and Silvana Selective treatments is a reflection of satiated species that do not need to move a great deal to find food. Lower mobility of carabid species, due to an abundance of suitable microhabitats provided by increased amounts of large and small organic debris within these treatments, may have lowered the number of individuals trapped in the brushsaw and Silvana Selective treatments.

Higher diversity indices in the both herbicide treatments may indicate hungry individuals in search of food, or increased mobility due to a more open habitat with fewer obstacles. Thus, more individuals of more species were trapped in these two treatments. The similarity in diversity indices between the herbicide treatments and the Control (untreated) plots indicates that carabid species were more affected by structural changes in the vegetation caused by the brushsaw and Silvana Selective treatments than by the chemical reduction of vegetation cover.

The expected result of the vegetation management treatments was to create a gradient of disturbance from low to high by which carabid species would separate themselves along the gradient. The Control (untreated) plots remained unchanged, therefore, this treatment was the least disturbed, while the Vision herbicide treatment removed the greatest percent vegetation cover or all the treatments, and therefore, sustained the greatest degree of disturbance (Bell *et al.* 1996 unpublished). The other three treatments should have been separated along the gradient between the extremes of no disturbance and greatest disturbance. However, this separation was not apparent, thus a clear separation of the effects of the vegetation management treatments did not occur. While the Vision treatment reduced woody and herbaceous vegetation more than any other, the brushsaw and Silvana Selective treatments also decreased deciduous cover (Bell *et al.* 1996 unpublished). The effects of the Release herbicide treatment was midway between the Vision herbicide treatment and the two mechanical methods in that it decreased deciduous tree and shrub cover, but retained the grass and much of the herbaceous layer.

The high diversity index found for the Control was not entirely expected. The literature indicates that diversity increases with increasing disturbance including disturbance caused by vegetation management (Lenski 1982 a and b, Parry and Rodger 1986, Jennings *et al.* 1986, Day and Carthy 1988, House 1988, Niemela *et al.* 1992, Niemela *et al.* 1993, and Duchesne and McAlpine 1994). However, the species present in the Fallingsnow blocks prior to the vegetation management treatments are likely generalists that colonized after the blocks were harvested. Species diversity in the blocks prior to the vegetation management treatments was likely near its peak in relation to the successional stage of the plantations. Thus, the Control plots continued to exhibit high species diversity after the vegetation management treatments occurred. Differences in species diversity between the treatments indicates that the vegetation management treatments did produce a slight, but distinct, effect on Carabidae.

Most of the species trapped in this study were either forest species adapted to young spruce plantations or generalists well adapted to colonization. The vegetation management treatments set back the vegetation in the blocks by a couple of years, but the amount of vegetation disturbance and soil disturbance was far less than produced by clearcut harvesting operation followed by mechanical site preparation. While logging operations followed by mechanical site preparation may virtually eliminate many plant species from an area, forest release treatments tend only to change plant species relative abundance (Lautenschlager 1991, 1993). By mid- to late-July, 1994, the vegetation in all treatments was lush indicating a quick recovery.

It is anticipated as vegetation recovers in each treatment and the forest grows from early seral into mature, the vegetation composition within each treatment may, in turn, have an effect on the carabid species composition. The Control plots will eventually become a shrub/hardwood forest and species associated with this forest type will be the most common in the Control plots. The extreme of this is the Vision treatment, which should eventually become a predominantly coniferous forest plantation. Consequently, forest species such as *P. adstrictus* Say should increase in number in all treatments. Open-country species will become less common, and will likely leave and colonize disturbed or open sites, or they might remain in low numbers occupying openings within the forest. Forest generalists and specialists will eventually become common as the forest matures, and species diversity will decrease (Jennings 1986, Niemela *et al.* 1992, Baquette and Gerard 1993, Niemela *et al.* 1993).

CONCLUSIONS: CARABIDAE COLLECTED

1. Between and within Block differences in Carabidae collected in 1993 and 1994 are a reflection of the block differences in soil type, moisture regime, drainage pattern, vegetation cover, microclimate and microhabitat.
2. *C. emarginatus* Say may be at the fringe of its range, or it may be a common species in recent cutovers that contain an abundance of early seral deciduous cover.
3. With the exception of *C. limbatus* Say and *C. maeander* Fischer, the majority of rare species were small bodied (<5mm). Commonness or rareness of carabid species in pitfall traps is a function of various factors such as size, locomotor ability, lifestyle and habits, and possibly daily activity rhythms.
4. Open-habitat species, forest species, and species without a preference for either open-habitat or forests comprised the majority of species indicating that most of the species trapped were either forest species adapted to young stands or generalists (well adapted to colonization).
5. Increased numbers of individuals trapped from 1993 to 1994 is a result, in part, of the warmer, drier weather conditions experienced in 1994. Natural population fluctuations of carabid species may also have been a factor in differences in the number of

individuals trapped between the years.

6. The vegetation management treatments did not significantly effect the carabid species indicating that the treatments did not significantly change the microhabitats suitable for Carabidae.
7. Large numbers trapped of *A. thoreyi* Dejean in the Vision treated plots in 1994 may be due to the dispersal of these species in a "directed movement" into more suitable microhabitats elsewhere. The lack of vegetation in the Vision treatment allows increased motility, and, thus, increased susceptibility for being trapped.
8. Low numbers of *P. lucublandus* Say in the Vision treatment may indicate lower mobility of this species due to an abundance of food and a suitable microhabitat.
9. The 1993 catch of *A gratiosum* Mann., *P. coracinus* Esch., and *P. lucublancus* Say significantly influenced the 1994 catch of these species, indicating that microhabitats supporting large numbers of these species continued to be successful after the vegetation management treatments occurred. This result supports the findings of Niemela (1990) and Niemela *et al.* (1992) who concluded that ground-beetles tend to occur in aggregations and were associated with particular microhabitat types.
10. Shannon-Wiener diversity indices in the brushsaw and Silvana Selective treatments imply a lower species diversity in these

treatments. However, these treatments may actually be similar in diversity to the other treatments, but lower mobility of individuals due to increased microhabitats and food supply may not be reflected by this statistic. The inability to reflect ecological processes has been a constant critism of the Shannon-Wiener diversity index.

11. I propose that changes in carabid species composition will occur through time as vegetation regenerates on each treatment. The most notable difference in species composition will occur in the Control (untreated) plots and the Vision herbicide treatment.
12. I propose that species diversity will decrease as vegetation regenerates and matures on the various treatments. Open-habitat species will decrease in number, and will either disperse and colonize elsewhere, or will be confined to smaller open patches within the forest. Forest generalists and specialists will increase in number as the forest ages.

RECOMMENDATIONS

Further ground-dwelling insect and arthropod studies within the Fallingsnow Ecosystem Project should concentrate efforts on one specific insect or arthropod Family. Since pre- and post-treatment species data exists on the ground-beetles (Coleoptera; Carabidae), it would be wise to continue this focus.

Interactions between the Carabidae and other biotic and abiotic factors including soils (moisture and temperature) and vegetation cover and structure would add a wealth of knowledge to the effects on Carabidae. Changes in microhabitats caused by large scale disturbances in vegetation cover and structure (*i.e.* alternate vegetation management treatments) should also be examined more closely. In addition, sampling of the mature stands adjacent to the existing blocks would provide additional information with respect to carabid diversity and changes in diversity associated successional changes in the vegetation.

Projects focusing on other taxa collected in this study would also be of interest in order to provide a multi-dimensional look at the effects of althernative vegetation managment on different epigeal insects and arthropods. Taxa that might be of interest to other researchers include the Araneae, Homoptera, Collembola, Formicidae (Hymenoptera), and Staphylinidae (Coleoptera).

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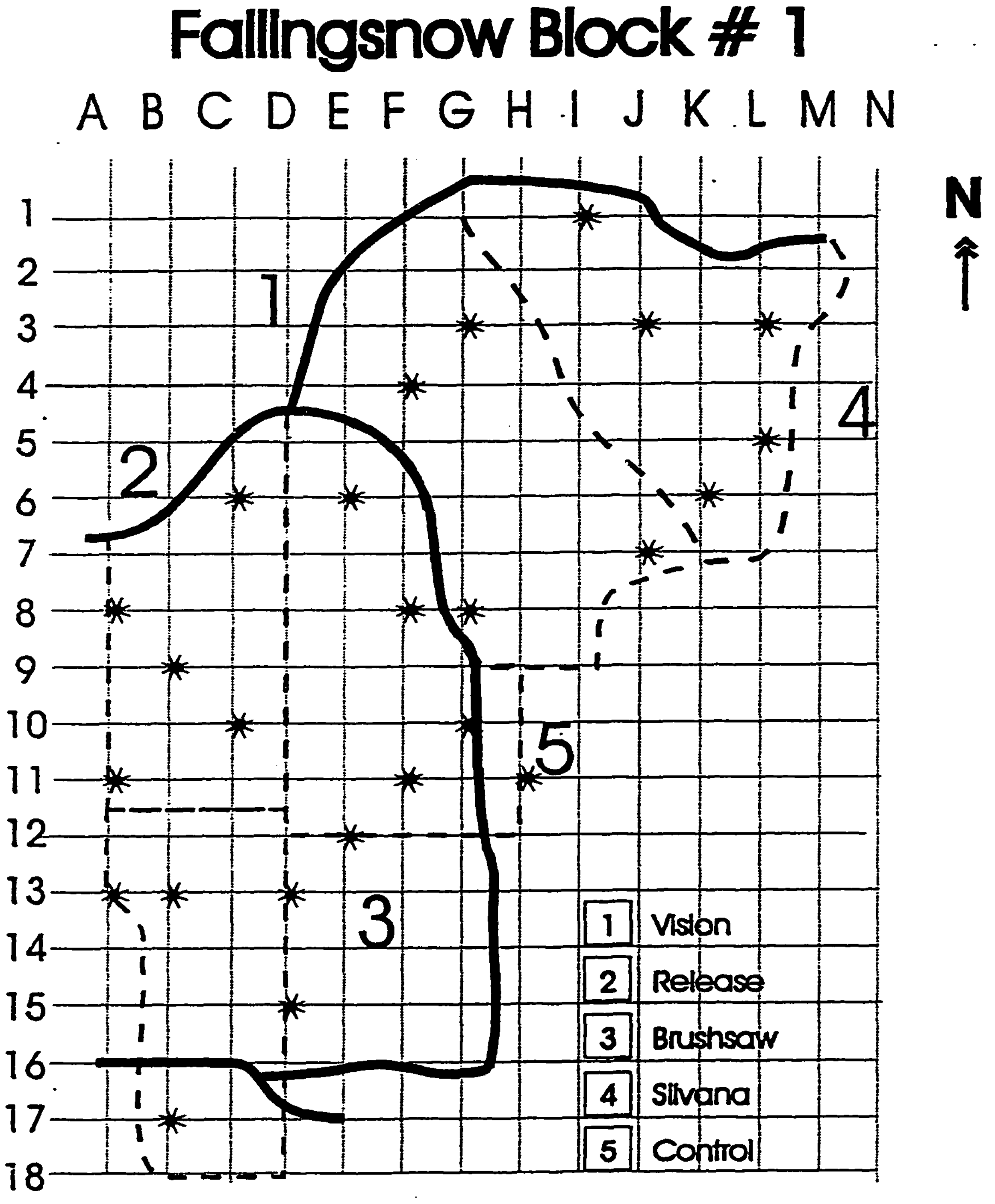
APPENDICES

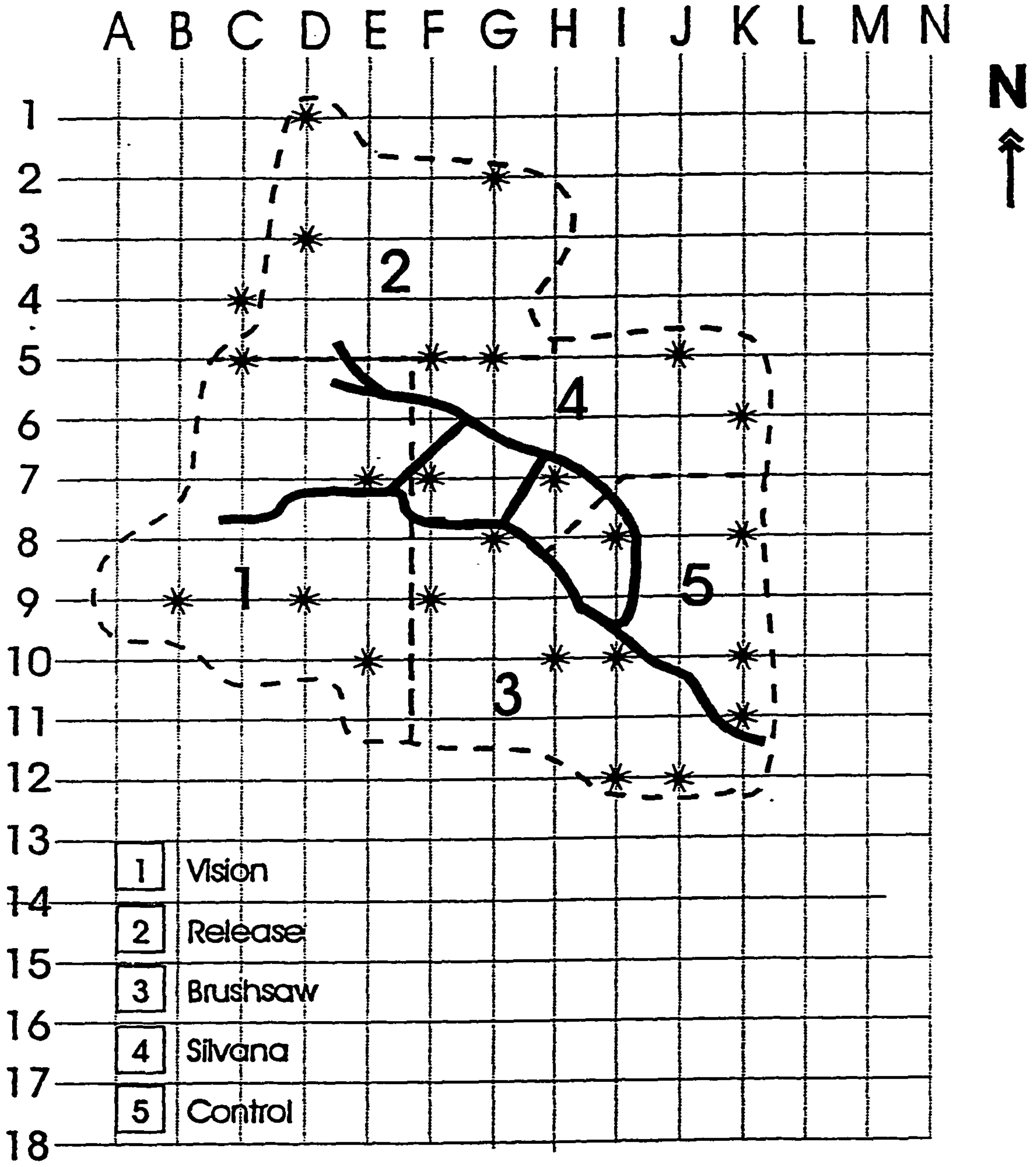
APPENDIX I

FALLINGSNOW STUDY BLOCKS, 1 TO 4, SHOWING PITFALL TRAP LOCATIONS (*)



April 29,1994

Fallingsnow Block # 2



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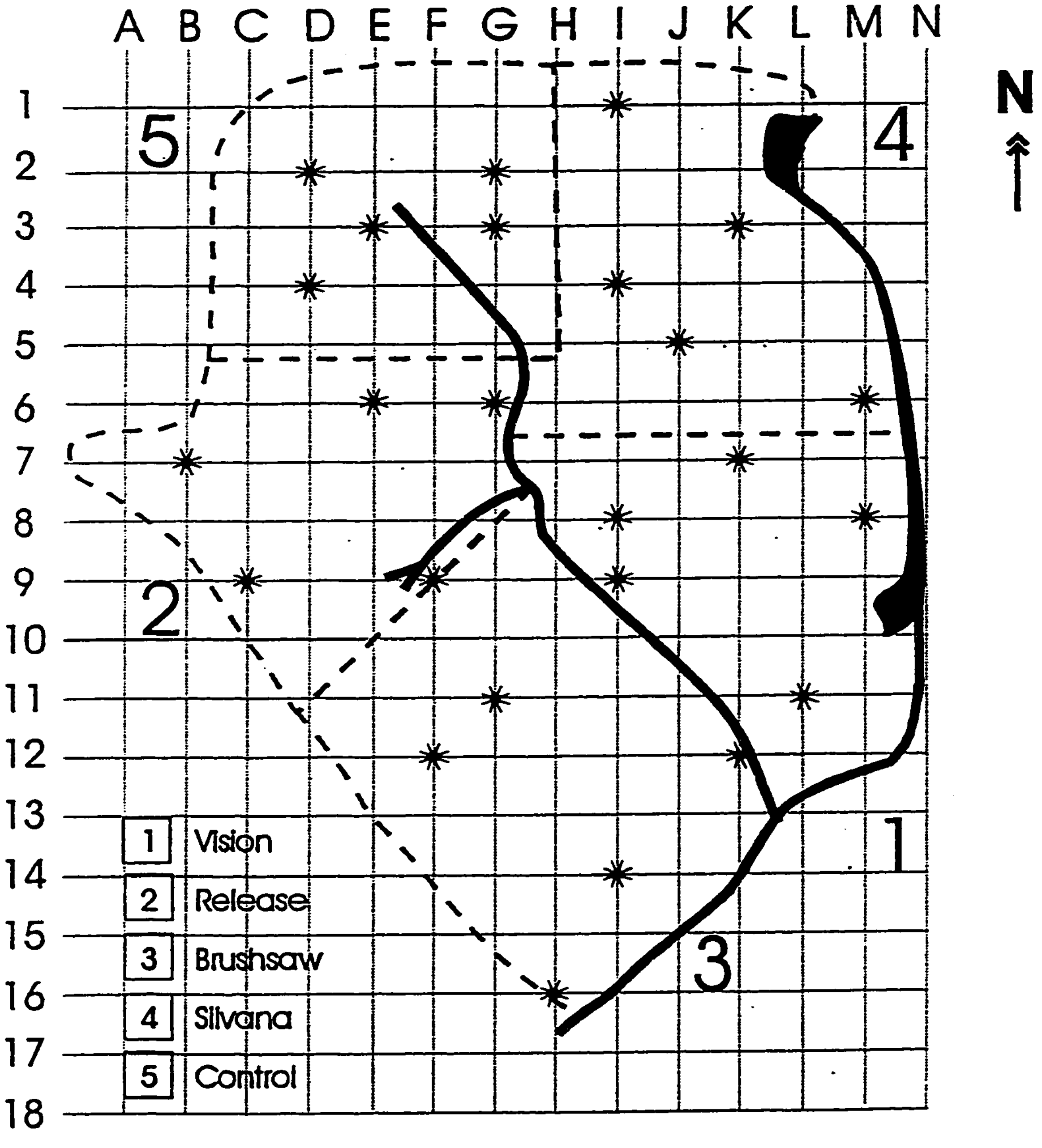

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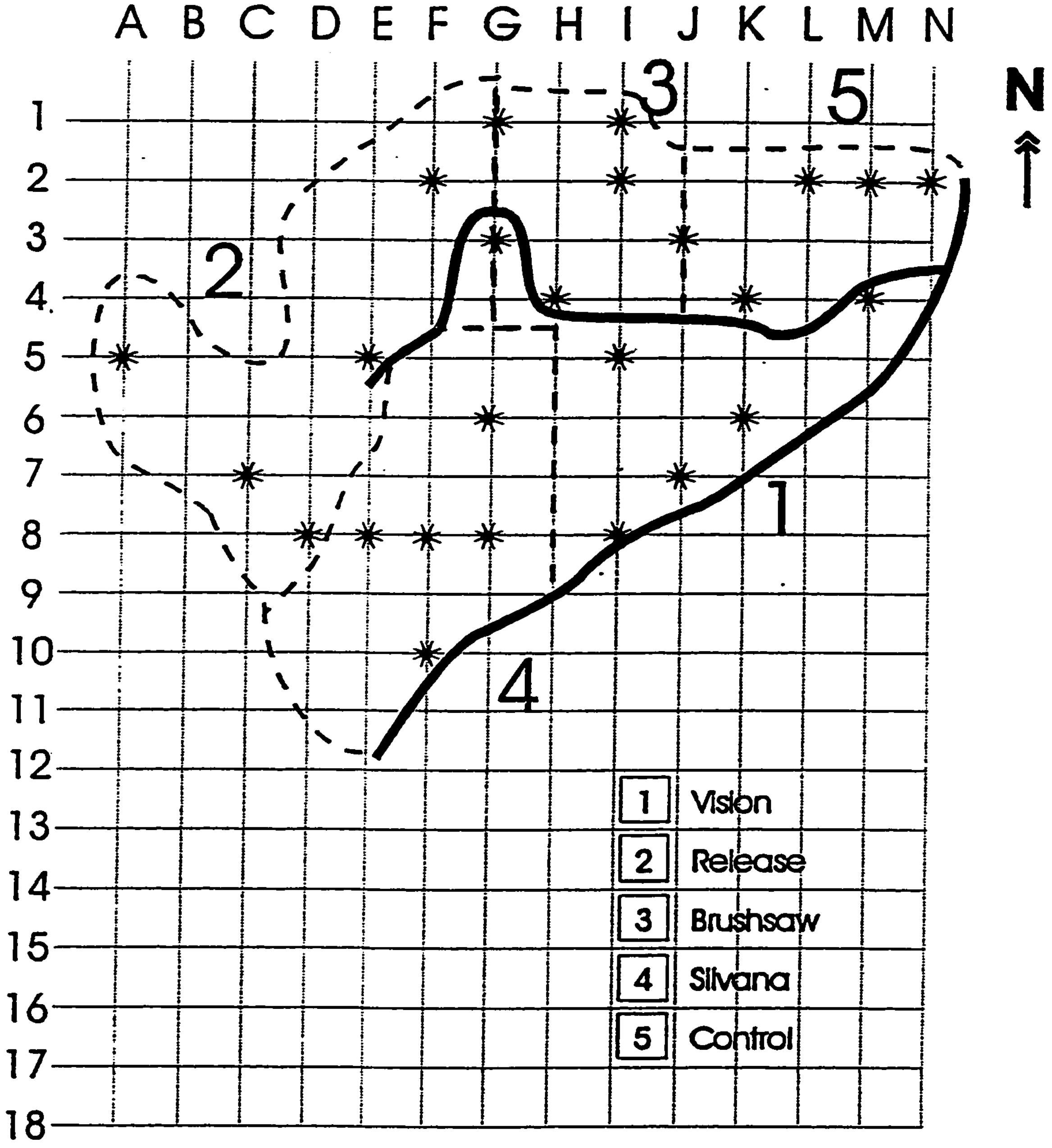


APPENDIX II

TOTAL NUMBERS BY BLOCK FOR INSECT AND ARTHROPOD ORDERS CAPTURED IN PITFALL TRAPS, FALLINGSNOW ECOSYSTEM PROJECT (1993 and 1994)

	1993				1994			
Order Block	1	2	3	4	1	2	3	4
Acari	253	2067	1078	558	1357	2263	2871	1008
Araneae	996	1099	954	1074	1813	1760	1775	1065
Coleoptera	855	1113	926	764	845	1780	1286	1021
Collembola	29	120	162	59	413	232	661	347
Diplopoda	114	309	25	84	36	60	22	68
Diptera	1485	2649	1794	882	1168	2049	1259	748
Gastropoda	178	195	118	47	102	152	161	63
Hemiptera	11	11	1	26	44	24	102	236
Homoptera	55	59	112	165	172	130	194	252
Hymenoptera	474	782	712	1079	1470	1510	1926	2366
Lepidoptera	9	13	8	20	21	43	40	87
Orthoptera	34	322	157	138	156	194	80	203
Opiliones	83	68	25	20	145	129	47	46

APPENDIX III

LEAST SIGNIFICANT DIFFERENCE (LSD) TEST AND COVARIATE ANOVA (PRE-TREATMENT [1993] CAPTURES=COVARIATE) FOR TREATMENT AND TIME EFFECTS ON EPIGEAL INSECT AND ARTHROPOD ORDERS DURING THE FIRST (1994) POST-TREATMENT GROWING SEASON, FALLINGSNOW ECOSYSTEM PROJECT

ANOVA: COLEOPTERA (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	1.33943	0.446475	4.3169	0.0072
Treatment	4	0.713519	0.178380	1.7247	0.1531
Blk*Treat	12	1.26589	0.105491	1.0200	0.4395
93Coleop	1	0.365705	0.365705	3.5360	0.0638
Error	77	7.96370	0.103425		
Total	97	11.6552			

ANOVA: ARANEAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.642250	0.214083	4.1013	0.0094
Treatment	4	0.415619	0.103905	1.9906	0.1043
Blk*Treat	12	1.13306	0.094422	1.8089	0.0612
93Araneae	1	0.109644	0.109644	2.1005	0.1513
Error	77	4.01929	0.052199		
Total	97	6.22599			

ANOVA: ORTHOPTERA (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	1.44005	0.480015	3.8760	0.0123
Treatment	4	0.111952	0.027988	0.22599	0.9231
Blk*Treat	12	1.06377	0.088647	0.71580	0.7317
93Orthop	1	1.48418	1.48418	11.984	0.0009*
Error	77	9.53599	0.123844		
Total	97	14.9831			

ANOVA: HOMOPTERA (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.531411	0.177137	1.9477	0.1289
Treatment	4	1.94059	0.485148	5.3345	0.0008*
Blk*Treat	12	2.47210	0.206008	2.2652	0.0161*
93Homop	1	0.466384	0.466384	5.1282	0.0264*
Error	77	7.00273	0.090945		
Total	97	12.7128			

Expected Cell means of: Homoptera (log units)

Treatment	Expected cell mean	Cell count
Brushsaw	0.9293	18
Release	0.7440	20
Control	0.9071	20
Vision	0.5411	20
Silvana Selective	0.8488	20

LSD - HOMOPTERA (log units) * indicates significantly different treatments

	Treatments				
	Brushsaw	Release	Control	Vision	Silvana
Brushsaw				*	
Release				*	
Control				*	
Vision					
Silvana				*	

ANOVA: COLLEMBOLA (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	2.23577	0.745256	5.5929	0.0016
Treatment	4	0.710139	0.177535	1.3323	0.2655
Blk*Treat	12	2.22451	0.185376	1.3912	0.1885
93Collemb	1	0.000517	0.000517	0.00388	0.9505
Error	77	10.2603	0.133251		
Total	97	15.5817			

ANOVA: DIPLOPODA (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.321703	0.107234	1.0591	0.3715
Treatment	4	0.358086	0.089521	0.88416	0.4775
Blk*Treat	12	1.27405	0.106171	1.0486	0.4148
93Diplo	1	0.540290	0.540290	5.3362	0.0236*
Error	77	7.79630	0.101251		
Total	97	10.7895			

ANOVA: DIPTERA (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	1.10765	0.369216	3.1592	0.0294
Treatment	4	0.800233	0.200058	1.7118	0.1560
Blk*Treat	12	1.21663	0.101386	0.86751	0.5825
93Diptera	1	0.303549	0.303549	2.5973	0.1111
Error	77	8.99902	0.116870		
Total	97	13.7318			

APPENDIX IV

METEOROLOGICAL RECORDS INCLUDING PRECIPITATION, TEMPERATURE, AND TOTAL HOURS OF SUNSHINE FOR JUNE AND JULY, 1993 AND 1994; THUNDER BAY 'A', ONTARIO

Meteorological Criteria	June, 1993	Month and Year July 1993	June 1994	July 1994
Dry/Wet day Ratio	15/15 =1.00	13/18 =0.72	20/10 =2.00	18/13 =1.39
Total Precipitation (mm precipitation)	56.2	224.0	87.1	72.2
Normal rainfall values (mm)	84.0	79.9	84.0	79.9
Mean temperature (degrees Celsius)	12.8	16.8	15.4	16.2
Normal temperature (degrees Celsius)	13.9	17.7	13.9	17.7
Greatest rainfall in one day (mm)	19.6	41.1	26.7	34.8
Total hours of sunshine	219.8	189.4	258.9	252.2
Total hours of sunshine Normal values	259.6	297.1	259.6	297.1

reproduced in part from Environment Canada - Atmospheric Environment Service Monthly Meteorological Summaries from Thunder Bay 'A', Ontario

APPENDIX V

TOTAL NUMBERS BY BLOCK FOR COLEOPTERA FAMILIES CAPTURED IN PITFALL TRAPS, FALLINGSNOW ECOSYSTEM PROJECT (1993 and 1994)

	1993				1994			
Family Block	1	2	3	4	1	2	3	4
Carabidae	278	269	170	323	219	360	196	408
Chrysomelidae	1	5	9	6	8	43	10	3
Cicindelidae	0	1	1	29	-	-	-	-
Cryptophagidae	3	5	16	3	27	9	0	0
Curculionidae	1	7	3	32	5	9	9	60
Elateridae	3	20	12	23	32	57	64	19
Endomychidae	13	25	24	37	12	43	21	77
Histeridae	4	5	4	3	1	20	28	4
Lampyridae	32	34	23	21	19	22	24	28
Lathrididae	-	-	-	-	68	79	56	64
Leiodidae	125	187	329	135	214	291	111	62
Pselaphidae	92	4	16	4	-	-	-	-
Ptiliidae	0	9	50	0	1	21	62	1
Mycetophagidae	21	0	3	0	-	-	-	-
Nitidulidae	24	28	42	25	0	57	25	10

Phalacridae	28	8	3	1	-	-	-	-
Scarabaeidae	2	7	11	8	9	27	11	11
Scolytidae	98	9	9	4	-	-	-	-
Silphidae	74	182	60	57	78	177	178	64
Staphylinidae	32	83	90	35	105	547	364	130
Tenebrionidae	27	31	19	14	28	29	36	29

APPENDIX VI

LEAST SIGNIFICANT DIFFERENCE (LSD) TEST AND COVARIATE ANOVA (PRE-TREATMENT [1993] CAPTURES=COVARIATE) FOR TREATMENT AND TIME EFFECTS ON COLEOPTERA FAMILIES DURING THE FIRST (1994) POST-TREATMENT GROWING SEASON, FALLINGSNOW ECOSYSTEM PROJECT

ANOVA: CARABIDAE (square root units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	21.3832	7.12772	4.8184	0.0040
Treatment	4	2.63384	0.658460	0.44512	0.7756
Blk*Treat	12	20.9838	1.74865	1.1821	0.3110
93Carabid	1	1.27475	1.27475	0.86174	0.3562
Error	77	113.905	1.47928		
Total	97	163.718			

ANOVA: CURCULIONIDAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.439271	0.146424	3.1027	0.0314
Treatment	4	0.178642	0.044660	0.94634	0.4419
Blk*Treat	12	1.03986	0.086655	1.8362	0.0567
93Curcul	1	0.177649	0.177649	3.7643	0.0560
Error	77	3.63385	0.047193		
Total	97	6.31338			

ANOVA: ENDOMYCHIDAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	1.80939	0.603131	7.8119	0.0001
Treatment	4	0.335549	0.083887	1.0865	0.3692
Blk*Treat	12	1.63777	0.136481	1.7677	0.0688
93Endom	1	0.038923	0.038923	0.50414	0.4798
Error	77	5.94494	0.077207		
Total	97	10.1848			

ANOVA: ELATERIDAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.969738	0.323246	3.8194	0.0132
Treatment	4	0.325480	0.081370	0.96146	0.4336
Blk*Treat	12	1.81017	0.150847	1.7824	0.0660
93Elaterid	1	0.642327	0.642327	7.5897	0.0073
Error	77	6.51666	0.084632		
Total	97	10.8529			

ANOVA: LEOIDIDAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	2.90105	0.967015	5.2409	0.0024
Treatment	4	2.16392	0.540981	2.9319	0.0259*
Blk*Treat	12	1.23482	0.102902	0.55770	0.8689
93Leoidae	1	0.019705	0.019705	0.10680	0.7447
Error	77	14.2075	0.184513		
Total	97	20.6741			

Expected cell means of: Leoididae (log units)

Treatment	Expected cell mean	Cell count
Brushsaw	0.4573	18
Release	0.7633	20
Control	0.8365	20
Vision	0.5831	20
Silvana	0.4912	20

LSD - Leoididae (log units) * indicates significantly different treatments

	Treatment Brushsaw	Release	Control	Vision	Silvana
Brushsaw		*	*		
Release					
Control					*
Vision					
Silvana					

ANOVA: SILPHIDAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	2.87646	0.958819	4.1087	0.0093
Treatment	4	2.44861	0.612153	2.6232	0.0411*
Blk*Treat	12	4.01579	0.334649	1.4340	0.1690
93Silphidae	1	0.001133	0.001133	0.00486	0.9446
Error	77	17.9688			
Total	97	27.4314			

Expected Cell Means of: Silphidae (log units)

Treatment	Expected cell mean	Cell count
Brushsaw	0.1983	18
Release	0.5773	20
Control	0.4515	20
Vision	0.3119	20
Silvana	0.1527	20

LSD - Silphidae (log units) * indicates significantly different treatments

	Treatment				
	Brushsaw	Release	Control	Vision	Silvana
Brushsaw		*			
Release					
Control					
Vision					
Silvana		*			

ANOVA: STAPHYLINIDAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	3.33591	1.11197	6.1753	0.0008
Treatment	4	0.644970	0.161242	0.89546	0.4709
Blk*Treat	12	2.11716	0.176430	0.97980	0.4755
93Staphyl	1	0.275893	0.275893	1.5322	0.2195
Error	77	13.8652	0.180067		
Total	97	21.4103			

ANOVA: TENEBRIONIDAE (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.044012	0.014671	0.18027	0.9095
Treatment	4	0.174347	0.043587	0.53559	0.7100
Blk*Treat	12	0.877214	0.073101	0.89827	0.5524
93Teneb	1	0.003337	0.003337	0.04100	0.8401
Error	77	6.26628	0.081380		
Total	97	7.38316			

APPENDIX VII

TOTAL NUMBERS BY BLOCK FOR CARABIDAE SPECIES CAPTURED IN PITFALL TRAPS, FALLINGSNOW ECOSYSTEM PROJECT (1993 AND 1994)

	1993				1994			
Species Block	1	2	3	4	1	2	3	4
Ag. cupripenne	0	6	0	9	2	22	0	14
A. decentis	8	2	2	0	8	6	7	2
A. gratiosum	7	14	13	3	20	21	29	4
A. placidum	-	-	-	-	7	3	1	4
A. thoreyi	0	8	3	5	14	6	16	18
Am. impuncticollis	-	-	-	-	1	1	2	3
Ap. subsulcatus	-	-	-	-	4	13	2	15
Ch. emarginatus	-	-	-	-	1	11	3	5
Ha. laticeps	0	2	1	26	2	1	1	12
Pt. adstrictus	-	-	-	-	8	19	0	3
P. coracinus	24	48	41	79	45	61	53	72
P. pensylvanicus	4	12	23	27	39	23	9	43
Po. lucublandus	2	33	18	111	23	57	53	189
Sp. lecontei	3	5	10	5	-	-	-	-

Sy. impunctatus	4	33	23	15	33	77	13	12

APPENDIX VIII

LEAST SIGNIFICANT DIFFERENCE (LSD) AND COVARIATE ANOVA (PRE-TREATMENT [1993] CAPTURES=COVARIATE) FOR TREATMENT AND TIME EFFECTS ON SPECIES OF CARABIDAE DURING THE FIRST (1994) POST-TREATMENT GROWING SEASON, FALLINGSNOW ECOSYSTEM PROJECT

ANOVA: *A. gratiosum* (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.260378	0.086793	1.2428	0.3031
Treatment	4	0.256099	0.064025	0.91678	0.4608
Blk*Treat	11	0.600281	0.054571	0.78141	0.6569
93A.grat	1	0.483000	0.483000	6.9161	0.0111*
Error	55	3.84102	0.069837		
Total	74	5.83706			

ANOVA: *P. coracinus* (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.481563	0.160521	1.4619	0.2350
Treatment	4	0.269615	0.067404	0.61386	0.6544
Blk*Treat	11	0.870761	0.079160	0.72093	0.7136
93P.coracin	1	0.455274	0.455274	4.1463	0.0466*
Error	55	6.03912	0.109802		
Total	74	7.89517			

ANOVA: *P. lucublandus* (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	1.53693	0.512309	4.4255	0.0074
Treatment	4	0.368052	0.092013	0.79484	0.5337
Blk*Treat	11	1.33717	0.121561	1.0501	0.4174
93P.lucu	1	0.596539	0.596539	5.1531	0.0271*
Error	55	6.36698	0.115763		
Total	74	14.3474			

ANOVA: *P. pensylvanicus* (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.431566	0.143855	2.0212	0.1216
Treatment	4	0.125143	0.031286	0.43957	0.7794
Blk*Treat	11	0.508352	0.046214	0.64932	0.7786
93P. pensyl	1	0.031635	0.031635	0.44448	0.5078
Error	55	3.91450	0.071173		
Total	74	4.96930			

ANOVA: *S. impunctatus* (log units)

Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Block	3	0.017274	0.005758	0.07960	0.9708
Treatment	4	0.287931	0.071983	0.99511	0.4181
Blk*Treat	11	0.834525	0.075866	1.0488	0.4184
93S.impunc	1	0.048565	0.048565	0.67137	0.4161
Error	55	3.97851	0.072337		
Total	74	6.20196			

APPENDIX IX

SHANNON-WIENER BIODIVERSITY INDICES FOR POST-TREATMENT (1994) CARABID SPECIES IN THE VEGETATION MANAGEMENT TREATMENTS AND CONTROL (UNTREATED) PLOTS, FALLINGSNOW ECOSYSTEM PROJECT

$H = -\Sigma P_i \ln P_i$, where ln = natural log

Treatment					
Brushsaw		**Release**		**Control**	
P_i	$P_i \ln P_i$	P_i	$P_i \ln P_i$	P_i	$P_i \ln P_i$
0	----	0.067	-0.181	0.017	-0.069
0	----	0	----	0	----
0.018	-0.072	0.017	-0.069	0.042	-0.133
0.018	-0.072	0.033	-0.113	0.076	-0.196
0	----	0.1	-0.230	0.034	-0.115
0	----	0.017	-0.069	0.127	-0.262
0.036	-0.120	0.083	-0.207	0.017	-0.069
0	----	0.033	-0.113	0.059	-0.167
0.018	-0.072	0	----	0	----
0.036	-0.120	0.083	-0.207	0.042	-0.133
0	----	0	----	0.009	-0.042
0	----	0	----	0	----
0	----	0	----	0	----
0	----	0	----	0	----
0	----	0	----	0.009	-0.042
0	----	0	----	0	----
0	----	0	----	0	----
0	----	0	----	0.042	-0.133
0	----	0.033	-0.113	0.009	-0.042
0	----	0	----	0	----
0.145	-0.280	0	----	0.025	-0.092
0.200	-0.322	0.133	-0.268	0.102	-0.233
0.418	-0.365	0.267	-0.353	0.246	-0.345
0.109	-0.242	0.100	-0.230	0.127	-0.262
0	----	0	----	0	----
0	----	0	----	0.009	-0.042
0	----	0.033	-0.113	0.009	-0.042
	H=1.665		**H=2.266**		**H=2.419**

APPENDIX IX (CONTINUED)

$H = -\Sigma P_i \ln P_i$, where ln = natural log

Treatment			
Vision		**Silvana Selective**	
P_i	**$P_i \ln P_i$**	**P_i**	**$P_i \ln P_i$**
0.015	-0.063	0.032	-0.110
0	----	0	----
0	----	0.021	-0.081
0.015	-0.063	0.021	-0.081
0.215	-0.330	0.074	-0.192
0.046	-0.141	0.074	-0.192
0.015	-0.063	0.021	-0.081
0.046	-0.141	0.012	-0.055
0	----	0	----
0.031	-0.108	0.085	-0.209
0.015	-0.063	0	----
0	----	0	----
0	----	0.012	-0.055
0.031	-0.108	0	----
0	----	0	----
0	----	0	----
0.015	-0.063	0	----
0.031	-0.108	0	----
0	----	0	----
0	----	0	----
0	----	0	----
0.123	-0.258	0.053	-0.155
0.2	-0.322	0.511	-0.343
0.138	-0.273	0.032	-0.110
0	----	0.012	-0.055
0.046	-0.141	0.021	-0.081
0.015	-0.063	0.021	-0.081
	H=2.308		**H=1.881**

APPENDIX X

CARABID SPECIES OF THE FALLINGSNOW ECOSYSTEM PROJECT:

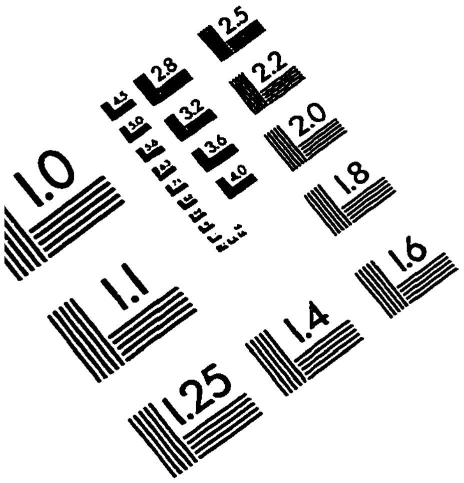
ECOLOGY (from Lindroth 1961-69)

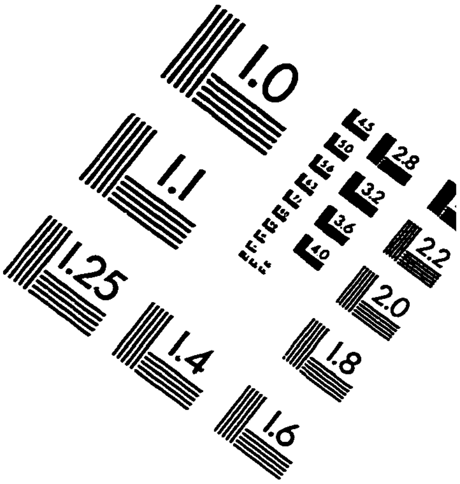
Species	Ecology
Agonum cupripenne Say	- in open country, often on gravel or sand, where the soil is not too dry and the vegetation is thin. Often near water but not confined to its vicinity. Seen running rapidly in bright sunshine. Hibernation as an adult.
A. decentis Say	- pronounced forest species, often found under bark
A. gratiosum Mannerheim	- less hygrophilus than relatives, eurytopic, open & moderately moist ground, peat, sphagnum, carices
A. placidum Say	- xerophilus species, occurring in open, usually sandy country, often on cultivated soil among weed vegetation, in sandpits. Hibernates as an adult, excellent flyer.
A. thoreyi Dejean	- hygrophilus species occurring at the margin of standing, often small waters or in marshes. Soil, more or less, soft, rich organic and vegetation eutrophic (i.e. *Typha latifolia*, carices, *Equisetum* spp.)
Amara impuncticollis Say	- open, moderately dry open country with rich, more or less, incoherent vegetation, usually of pronounced weed character; clearly favoured by human activity.
Apristus subsulcatus Dejean	- usually on river banks on dry sand and gravel distant from water.
Badister obtusus Leconte	- taken among leaves on rather moist soil in shaded position.
Bembidion muscicola Hayward	- usually under leaves in moist deciduous forests, often near pools and small lakes with *Carex* spp.. Easiest to collect in spring and during flooding. Predator of mosquito eggs.

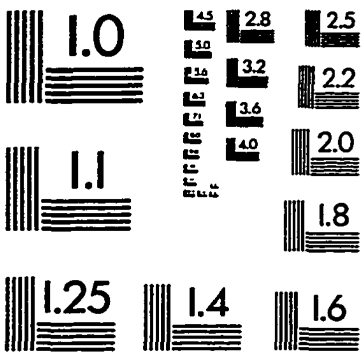
B. mutatum Gemm. & Harold	- open, moderately moist spots of fine sand (usually moraine) with tiny mosses or other very sparse vegetation
B. wingatei Leconte	- almost subterranean, occurring both under deep lying stones in open grassland and among leaves in shady deciduous forests.
Bradycellus lugubris Leconte	- shaded position, usually on humus mixed soil under bushes of *Alnus, Vibernum*, and *Acer* species. Also in wet meadows among heaps of grass. Adult hibernation.
Carabus maeander Fischer	- hygrophilus species, confined to open, more or less, moist ground with rich but moderately high vegetation. Often in *Carex* spp. bogs. Adult hibernation.
C. limbatus Say	- moist deciduous woods, often near water
Chlaenius emarginatus Say	- an inhabitant of deciduous forests, occurring on moist soil among leaves, under logs.
Cymindis cribricollis Dejean	- usually on dry, sandy moraine in open position.
Elaphrus clairvillei Kirby	- avoids exposed places and prefers shores half shaded by trees and bushes or with high, dense carex vegetation with bare spots of mud or organic detritus. Wet soft soil, but often in some distance from water. Adult hibernation.
Harpalus laticeps Leconte	- in sandy, upland woods. Good flight powers.
Notiophilus semistriatus Say	- open, gravelly, rather dry ground, often moraine, with thin, low vegetation.
Pterosticus adstrictus Say	- common in northern coniferous forests, but not a pronounced forest species, but prefers open country. Soil - dry to medium moisture.
P. coracinus Esch.	- in forests, and notably in wet coastal areas in open fields and meadows. Immatures in late summer.
P. pensylvanicus Leconte	- dead leaves and moss under bushes of alder, usually on gravel soil

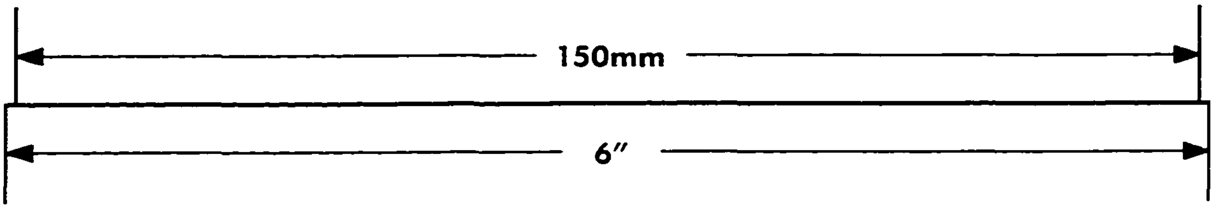
Poecilus lucublandus Say	- open country, moderately dry soils
Scaphinotus bilobus Say	- rare, demands little known. Found in dry gravel pit near Nipigon, Ontario
Spheroderus lecontei Dejean	- a forest species, prefers moist places with mosses and dead leaves (*i.e.* under deciduous bushes) often near water. Adult hibernation.
Synuchus impunctatus Say	- in open country and light forests, on rather dry ground (usually moraine) (*i.e.* usually among leaves under *Rubus* spp. and other bushes). Hibernation in larval stage. Adults appear around the end of May.
Trechus apicalis Motschulsky	- eurytopic species, usually occurring on meagre soil among dead leaves under bushes in, more or less, shady position. Sometimes in the drier parts of *Carex* spp. marshes, also in open grassland, under big stones. Adult and larval hibernation.

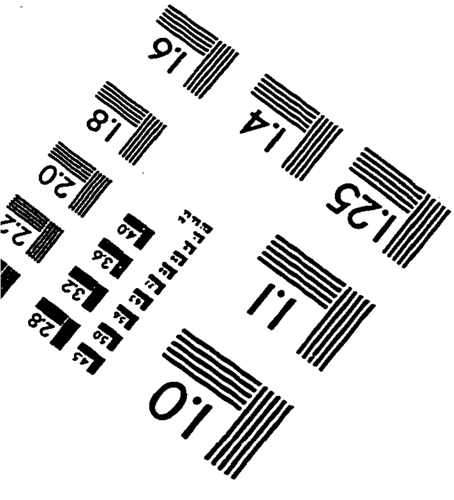
IMAGE EVALUATION TEST TARGET (QA-3)











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