AN ABSTRACT OF THE THESIS OF

Margaret E. Ruby for the degree of Master of Science in Forest Science presented on April 30, 2001. Title: Forest Macro-Arthropods as Potential Indicators of Ecosystem Conditions in Western Idaho: An Analysis of Community Composition, Biological Diversity, and Community Structure.

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Adaptive ecosystem management is a new paradigm for managing federal forests which requires regular monitoring of ecosystem function and diversity to measure the effects of management. Managers need new strategies and tools to help them assess their progress in maintaining healthy, productive and biologically diverse forests. Biomonitoring of select forest macro-arthropod species can provide useful information on the effects of management on forest biodiversity and ecosystem function.

The purpose of this study was threefold: (1) to inventory the macro-arthropod community and important environmental variables in the Bear Creek and Indian Creek study area within the Payette National Forest (PNF) in Western Idaho; (2) to compare measures of community composition, diversity, and structure in forest macro-arthropod communities between patches of different sizes and treatment; and (3) to assist PNF managers in their ecosystem management efforts by providing principles to guide the use of macro-arthropods as indicators of changing forest conditions.

Transects with pitfall traps were used to collect macro-arthropods at 22 sites in the Bear Creek and Indian Creek study area during the summer of 1994. Five forest patch types in *Abies grandis* habitat types were sampled. Intact forest

patches of 100 or more hectares, and large patches of 50-100 hectares, ranged in age between 50 and 250 years old with multistoried structure. Small patches up to 10 hectares were remnants or fragments of formerly intact forest isolated by logging. A plantation patch was 15 years old with patchy understory and forb cover. Clearcut patches had little or no overstory, and variable understory, and forb layers.

At each transect, soil samples were collected and six environmental descriptor variables were analyzed according to patch treatment and patch size. These site descriptors were: basal area (ft^2/acre); percent canopy cover for the overstory, understory; and forb layers; litter depth (cm), and percent soil moisture content. Differences detected using an ANOVA and T-tests are discussed in the Results section.

Arthropod community composition, diversity, and structure were described according to relative abundance, and four measures of diversity. They were also described by membership in seventeen orders and/or super-families; ten functional groups; two disperser classes (long or short distance); and three species indicator classes.

A total of 5455 macro-arthropod individuals, representing 17 orders and/or super-families and 219 species were collected in the Bear Creek and Indian Creek study area. While macro-arthropod fauna relative abundance did not vary significantly by treatment (ANOVA $p<0.3$), it did vary significantly by patch size (ANOVA $p<0.03$). Fauna relative abundance was 35% greater in clearcut patches than in large patches (T-test $p<0.09$). Fauna relative abundance in small patches was twice that of intact (T-test $p<0.03$) and large (T-test $p<0.02$) patches.

Taxonomic diversity (number of genera/taxa) of beetle, ant, and bug taxa differed significantly according to treatment type(each ANOVA $p<0.05$). For the top four taxa (beetles, ants, spiders, and bugs), taxonomic diversity was highest in the plantation and clearcut patches. Ants and bugs had their highest taxonomic diversity in the plantation patch (separate T-tests $p<0.05$) while the taxonomic diversity of beetles was highest in clear-cut patches (T-test $p<0.05$).

Beetle and ant taxonomic diversity varied significantly by patch size (each ANOVA $p<0.05$). For beetles and bugs, small patches were twice as diverse as intact patches (separate T-tests $p<0.04$) and 1.5 times that of large patches. Ant diversity was similarly distributed amongst the patch sizes, with significant differences between small and intact and between small and large patches (separate T-tests $p<0.05$).

Of the four species diversity measures employed, only two, α and JK1 (both measures of richness), were found to vary significantly by patch treatment and size. Evenness (E) and the Shannon Diversity Index (H') failed to detect differences in the majority of tests. Fauna α and JK1 differed significantly by treatment type (each ANOVA $p<0.05$). Richness in clearcut patches was nearly twice in intact and large patches, followed by plantation and large patches. Fauna α and JK1also differed significantly by patch size (each ANOVA $p <0.001$), with small patch fauna twice as rich as that in large and intact patches (separate T-tests $p <0.01$).

Of the top four functional groups, predators were the most abundant and had the highest taxonomic diversity (number of genera/functional group), followed by herbivores, fungivores and parasites.

Predators and herbivores showed increasing taxonomic diversity with decreasing patch size, from intact to large to small (ANOVA $p< 0.05$). Similarly, predators and herbivores exhibited increasing taxonomic diversity with increasing levels of management: from intact and large to plantation and clear-cuts (ANOVA $p< 0.05$). Predators and herbivores were most numerous in the managed and small patches. Fungivore taxonomic diversity was also highest in the small and managed patches, though neither patch size nor treatment differences were significant (ANOVA $p<0.85$). Parasite taxonomic diversity differed by patch size with highest generic diversity in the small patches (ANOVA $p<0.1$) and by treatment type with generic diversity highest in plantations and clearcuts followed in order by large and intact patches (ANOVA $p<0.1$) .

Twice as many genera were long distance dispersers as were short distance dispersers. Relative abundance of long distance dispersers varied significantly by patch treatment and patch size (each ANOVA $p<0.01$). Long distance dispersers were most numerous in clear-cut patches, followed in order by plantation, small, large, and intact patches. Relative abundance of short distance dispersers was not significantly different between treatment types (ANOVA $p<0.20$) but was significantly different between patch sizes (ANOVA $p<0.01$). Short distance dispersers were most numerous in small patches followed by plantation, large, and intact and least numerous in clearcut patches.

An indicator species analysis of 121 Bear Creek and Indian Creek genera (Dufrene and Legendre 1997), revealed sub-groups of species with 75 to 100 percent "perfect indication" or affiliation for specific patch types. When intact and large patches were pooled and analyzed against all treated patches (plantation and clearcut patches), a list of 36 genera with 75 to 100 percent "perfect affiliation" for intact or large patches was produced (MRPP $p<0.05$). Small patches had 42 indicators with 75 to 100 percent "perfect indication " when compared with the pooled intact and large patches (MRPP $p<0.1$).

Conclusions

Macro-arthropod community composition, diversity and structure did vary, usually significantly, by patch treatment and size. Useful measures of generic diversity include richness estimators α, β, and JK1. Examination of taxonomic diversity was also useful, especially for the more mobile arthropods. Pitfall traps provided copious data on the structure of the community in regards to predators and herbivores. Pitfalls, however, did not provide much information about the status of fungivores and parasites in the various different patches. Another trapping method such as the berlaise funnel, would likely provide more information about those functional groups which are likely operating at a finer scale of resolution than that tested by the pitfall trap. Employing both methods would provide a much better assessment of the community of arthropods living on the forest floor.

The indicator species analysis program also provided very useful lists of species which are affiliated with particular patch conditions. Taken together, these measures could be adopted for use by forest managers to allow them to assess and monitor the effects of a management regime on the structure and composition of macro-arthropod communities as part of a comprehensive adaptive management plan.

Forest Macro-Arthropods as Potential Indicators of Ecosystem Conditions in Western Idaho: An Analysis of Community Composition, Biological Diversity, and Community Structure.

by
Margaret E. Ruby

A THESIS

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Acknowledgments

I came to OSU and the Department of Forest Science to learn about forest ecology, sustainable forestry, and the tenants and applications of conservation biology. I am well pleased with my choice and believe I received an excellent education.

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Dedication

To Jonathan who cheered me on despite the hours and the costs.

Thanks for believing in me.

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INTRODUCTION

The management of public forests, especially federal forests under the stewardship of the United States Forest Service (USFS) and the Bureau of Land Management (BLM), has changed dramatically in the past half century. Public perception of the purpose and value of these forests has experienced an equally precipitous shift. In the 1950's, to meet rising demands for softwood in the post-World War II building boom, management emphasized timber production. On Forest Service lands, twice as much timber was cut between 1950 and 1966 as the entire preceding 45 years; by 1966, the annual cut had climbed to 12.1 billion board feet (Caldwell et al. 1992). As reforestation expertise accumulated, managers adopted a sustained-yield timber paradigm which emphasized regeneration harvest systems and reforestation to sustain the production of timber through time. Forests were considered simple systems, essentially tree plantations, where multiple rotations and harvests were planned, and where inputs and outputs could be controlled as needed.

This sustained-yield paradigm eventually evolved into a sustainable forestry model which promoted sustaining wildlife populations and recreational opportunities alongside the production of timber. More recently, the USFS and BLM have adopted paradigms of "adaptive ecosystem management" (For example, FEMAT 1993) to manage for multiple, sometimes competing goals, goods and services. Today's federal forests must balance wildlife habitat, recreational opportunities, resource extraction (ranging from timber to mushrooms and floral supplies (Costanza et al. 1992; Perrings et al. 1995), and ecological services (such as the provision of drinking water for municipalities).

The transition to adaptive ecosystem management in federal forests has been difficult for managers who must translate new ecosystem management mandates into specific on-the-ground management plans (Brown 1995), often in the context of shrinking budgets and staff levels (Seastedt 1996). Adaptive ecosystem management requires regular monitoring of ecosystem function and diversity to assess the effects of management. Managers need new, efficient strategies and tools to help them assess their progress in maintaining healthy, productive and biologically diverse forests (Amaranthus 1997). Biomonitoring of select forest macro-arthropod species can provide information on the effects of management on forest biodiversity and ecosystem functions.

The purpose of this study was threefold: (1) to inventory the macro-arthropod community and important environmental variables in the Bear Creek and Indian Creek study area within the Payette National Forest (PNF) in Western Idaho; (2) to compare measures of community composition, diversity, and structure in forest macro-arthropod communities between patches of different sizes and treatment; and (3) to assist PNF managers in their ecosystem management efforts by providing principles to guide the use of macro-arthropods as indicators of changing forest conditions.

LITERATURE REVIEW

Before Ecosystem Management

During the past 30 years, a synergistic interplay of social and political events, along with new scientific findings about forest ecosystems, have combined to evolve forest management from sustained-yield to adaptive ecosystem management.

First, findings among the scientific community prompted a growing concern among the U.S. public that humans were altering the earth's ability to sustain itself (e.g., Odum 1971). In the late 1960's, concerns that "timber on the national forest would soon be gone and with it the livelihoods of timber workers" moved Senator Lee Metcalf to convene a committee of university experts, chaired by Dean Bolle of the University of Montana School of Forestry, to assess the management practices of the Bitterroot National Forest The Bolle report was a scathing critique which found that "multiple use management, in fact, does not exist as the governing principle of the Bitterroot National Forest. . . .Consideration of recreation, watershed, wildlife, and grazing appear as afterthought" (as quoted in Caldwell et al. 1992).

These and many other concerns prompted the creation of new, powerful environmental laws which have profoundly affected the management of federal forests. The National Environmental Policy Act (NEPA) was adopted in 1969 and requires federal agencies to prepare environmental impact statements for proposed activities. The Endangered Species Act (ESA) was enacted in 1973 and requires the federal government to prepare conservation plans for threatened and endangered species, and to protect the ecosystems upon which those species depend (Snape 1996). The National Forest Management Act (NFMA) was adopted in 1976 and revised and strengthened in 1982. It requires federal agencies to recognize ecological inter-relationships, to provide for a diversity of plant and animal communities, and to provide habit "to insure viable populations will be maintained" of existing native vertebrate species. (as quoted in Caldwell et al. 1992).

Environmental organizations began to use these environmental laws during the 1980's to obtain protection for endangered species and associated habitats. Perhaps the most widely known example is that of the northern spotted owl and old-growth forests in the Pacific Northwest (PNW). Environmentalists successfully provoked judicial intervention in the management of PNW federal forests by suing various government agencies for failing to meet the requirements of these laws. In a series of decisions, the courts required the USFS and the BLM, in conjunction with the U.S. Fisheries and Wildlife Service, to halt logging in owl habitat until scientifically credible conservation plans were developed and implemented.

These and other legal rulings spawned new research efforts into the population viability of the northern spotted owls, as well as the habitat needs of hundreds of species associated with old growth forests. This work culminated in the report of the Federal Ecosystem Management Assessment Team (FEMAT) -- the first, largest, and most comprehensive of forest ecosystem analysis plans to date (FEMAT 1993).

When presenting his plan for Oregon and Washington forests in 1993, President Clinton instructed federal agencies to work together, comply with environmental laws, and take an ecosystem approach to forest management (Caldwell et al. 1994). Beyond the controversy surrounding the northern spotted owl however, the PNW forest crisis precipitated the application of ecosystem management to natural resources elsewhere (Seastedt 1996).

While the current Bush administration has signaled a shift towards more emphasis on the extraction of natural resources, it will almost certainly do so within the current framework of laws. Hence, it will remain important for forest managers to continue managing natural resources on an ecosystems basis.

Ecosystem Management Defined

> We have come full circle in many ways. The new focus on ecosystem management has returned us to the systems models of energy flow, nutrient cycles, and food webs. . . As no mere quaint or anachronistic tale, the vision of the web of life provides a new mythos, a fresh root metaphor, for this era of forest ecosystem management. (Marcot 1997).

Recent research has demonstrated a direct link between above- and below-ground ecological processes in forest systems (Simard 1995; Perry 1994; Waring and Schlesinger 1985). In particular, changes in above-ground forest structure and species composition can alter flows of energy and nutrients both within and between above- and below-ground systems (Spies et al.1988; Simard 1995).

Ecosystem management has been defined as, "Any land management system that seeks to protect viable populations of all native species, perpetuate natural disturbance regimes on the regional scale, adopt a planning time-line of centuries, and allow human use at levels that do not result in long-term degradation (Noss and Cooperrider 1994). Grumbine (1994, 1997) identified ten ecosystem management themes. Key among them are ecological integrity, biological diversity (biodiversity), the importance of social and ecological scientific data, and adaptive management.

Biodiversity

Biological diversity, or biodiversity, is often defined as "the variety and variability among living organisms and the ecological complexes in which they occur" (OTA 1987). Another widely used definition is "the variety of all life and processes" (after Keystone Center definition).

Measurements of biodiversity depend upon the scale of examination. While Noss (1990) notes that diversity is often described at least in three scales: genetic, species and ecosystems, he notes the constraint imposed by higher levels of organization upon lower levels (i.e., global climate limits local disturbance regimes, which in turn constrain patterns of forest cover, which constrains the extant and diversity of litter dwelling arthropods). However, the question of interest dictates scale of examination.

At the level of a community or population, there are several useful measures. One is richness, designated by S or α which measures the number of different species (or genera) in a sample unit. Evenness, E is defined by McCune (1996) as E = H'/ln(S), measures how equitably the abundance (or total number of individuals) is distributed among the species. The Shannon diversity index, H', is a synthetic index of abundance and richness. McCune (1996) defines H' = - S (p_i $\cdot$ln(p_i)), where p_i= importance probability in column I (matrix elements are relativized by row totals). Derived from information theory, H' is relatively independent of sample size and rare species. Beta or β, also a measure of richness, examines species turnover along an environmental gradient. McCune (1996) defines $\beta = \alpha/\gamma$. Gamma or γ is the estimated total species richness across plots in a region. Whittaker called gamma "richness in a range of habitats" (as cited in McCune 1996).

Biological diversity is valued for many reasons. First, high levels of richness has been found to confer a level of redundancy (Walker 1995) or reliability (Naeem 1998; McCann 2000) to ecosystem functions. Where richness is high, more than one set of species may fulfill key functions, such as nutrient cycling. In situations of stress, such as drought or fire, diverse ecosystems are more likely to rebound due to redundancy (Franks and McNaughton 1991). Second, humans as a species generally value other forms of life (biophilia) and seek solace or recreation in various forms of it. Many scientists join religious leaders in stating we have an ethical duty to protect all species (Catholic Bishop's Pastoral Letter 2001; Soule 1985; Perry 1994). Third, evolutionary potential is inherent in biodiversity. If climate model predictions of shifting weather patterns are realized, more diverse (rich) communities are more likely to persist and flourish under new conditions (McCann 2000). Fourth, genetic advances show the importance of preserving as many forms of life as possible. Many new plant and animal applications are found daily in nature and this wealth potential should be protected.

Ecosystem Health

Leopold called "land health" nature's capacity for self renewal. Callicott (1992) notes Leopold's definition is both dynamic and functional. Costanza (1992) defines ecosystem health as "a measure of the overall performance of a complex system that is built up from the behavior of its parts." However, there are difficulties associated with the use of the term ecosystem health. Ehrenfeld (1992) summarized them, stating that ecosystem health is: (1) of necessity different for each system; (2) best as general definition; (3) hard to detect, as differences between normal fluctuations and induced stress may be subtle; and (4) difficult to measure or as not all functions and processes are directly related.

Biological and Ecological Integrity

Biological integrity has been defined as by Karr and Chu (1995) as "the capacity to support and maintain a balanced, integrated, adaptive biological system having the full range of elements (genes, species, and assemblages) and processes (mutation, demography, biotic interactions, nutrient and energy dynamics, and metapopulation processes) expected in the natural habitat of a region".

Karr defines ecological integrity as " the sum of physical, chemical and biological integrity" (Karr and Dudley 1981; Karr 1996). Ecological integrity has summarized by the Global Integrity Project (Pimentel et al. 2000) as having four attributes: (1)system health or successful functioning of the community; (2) the capacity to withstand stress; (3)an undiminished 'optimum capacity', and (4) the continued ability for ongoing change and development, unconstrained by human interruptions.

Recent research has shown that intact or undisturbed ecosystems with high species richness are less susceptible to stress than ecosystems with lower richness values (Naeem et al. 1994). For a recent review see McCann (2000). This functional redundancy (or reliability) of diverse ecosystems is believed to confer stability and resiliency (Naeem 1998;McCann 2000). Resiliency is the ability of a system to maintain structure and patterns of behavior in the face of disturbance (Holling 1986). A review by McNaughton (1994) summarized the stabilizing effect of biological diversity (richness) on ecosystems. He reviewed grasslands studies in Yellowstone National Park (Frank and McNaughton 1991), in the Serengeti (McNaughton 1983), and in New York state (Hurd and Wolf 1974) which demonstrate clear relationships between increased resistance to community composition change due to biological diversity in the face of a perturbation or stress.

Most ecosystems can function with some reduced biodiversity, but full diversity appears to be important for the survival of communities in fluctuating environments, such as habitat conversion and climate change (Naeem 1998; Walker 1995). Thus species redundancy may be essential to the long-term persistence of a community (Schulze and Mooney 1994).

It is difficult to directly assess the importance of the individual components of biological integrity. A hypothetical method would be to remove a species, guild (a group defined by a common role or function, such as predator or detritavore) or process from the ecosystem and see what happens. However, such experimentation is a sort of 'Russian roulette' which could contribute to the decline or extinction of the species in question and could risk ecosystem failure. If the species removed is a "keystone" species (one that exerts disproportionate influence to its numbers), structural or functional change in an ecosystem could result (McCann 2000;

Schultze and Mooney 1994). Such thresholds can be difficult to pinpoint in advance -- but when an important threshold is breached, the results can include a restructuring of energy and nutrient flows and the establishment of new communities, landscape patterns and natural disturbance regimes (Perry et al. 1990; Perry and Amaranthus 1997; Noss and Cooperrider 1994).

Why Measure Macro-Arthropods?

Nearly 89% of Earth's described animal species are insects, by far the most diverse of the described biotic elements on earth (Noonan 1988). *Carabidae*, one of the larger insect families, has about 40,000 described species -- more than ten times the richness of all known mammals (Noonan 1985). Arthropods, of which insects are a class, are sensitive to environmental change and have short life cycles, especially compared to longer lived vertebrates. Arthropods are small and easily collected by non-experts, and new methods of identification to order, family, and genus make it possible for rapid classification by an expert-led team.

In addition, ground dwelling arthropods are integral participants in the above-and-below ground ecological processes which shape forested ecosystems (Christiannsen et al. 1989a; Christiannsen et al. 1989b). As predators, herbivores, detritivores, and fungivores, arthropods influence productivity and the cycling of nutrients and energy (Cromack, Jr. et al.,1977; Matson and Addy 1977; Thieve 1977; Anderson et al. 1983; FEMAT 1993; Seastedt and Crossley, Jr. 1984; and Schowalter et al. 1991). Some arthropods also provide a biological control of 'pest' species through predation and parasitization (Thieve 1977; Campbell and Torgersen 1982; and Bull et al. 1995).

High species diversity (richness) and a multiplicity or redundancy of functions in ecosystems have been hypothesized to be part of a complex of many, 'weak' signals which has been found to confer stability to ecosystems (Shultze and Mooney 1994;).

Litter dwelling arthropods have been hypothesized to play an indicator role in assessing aspects of health and biological integrity of forests (Seastedt and Crossley, Jr.,1984; FEMAT 1993; Kremen et al. 1993; Berg et al.1994, Noss). For example, a reduction in the relative abundance of detritivores could foreshadow a decline in the availability of nitrogen and phosphorus -- two essential macro-nutrients affected by detritivore feeding (Seastedt and Crossley, Jr., 1984). Arthropods found only in primary forests may serve as sensitive indicators of changing conditions systems (Niemelä et al. 1993; Lattin and Moldenke 1990; and Spence 1990). Further, the science of island biogeography predicts that small populations of species in isolated habitats, such as forested mountain islands, are sensitive to change and may also serve as indicators of conditions (Darlington 1943; MacArthur and Wilson 1963, 1967).

Food web dynamics studies have shown that functional group interactions can and do affect forest composition and health (Kimmins 1987; Seastedt and Crossley, Jr., 1984; Schowalter 1991). One relatively well-studied example is that of the western spruce budworm (*Choristoneura occidentalis* Freeman), an important defoliator in Western forests. A suite of bird, ant, and parasitic wasp species is known to prey on and parasitize the budworm at different life stages and is now recognized as ån important beneficial bio-control agent (Campbell and Torgersen 1982; Youngs 1983). State and federal land management agencies have adopted programs to study and promote the welfare of these bird and insect species as a means of reducing economic losses due to defoliation (Bull et al.1995).

Forest management practices alter forest structure at the stand and landscape scales and are known to influence habitat for wildlife species such as birds (McGarigal and McComb 1995) and mammals (Noss and Cooperrider 1994). Madson (1997) found correlation between abundance and Some arthropod communities have been shown to respond to structural changes at the stand scale (Heliölä 2001). Niemelä et al. (1993), found interior forest carabid beetles disappeared or decreased in abundance with clearcutting. While many mature forest populations recovered with forest regeneration, some mature forest specialists did not recover, even in the oldest stands.

Monitoring and Choice Indicators

Noss (1999) argues it makes sense to monitor species' populations directly. The goal should be to identify a suite of species each representative of necessary elements which must be present for a region to retain its biota. Noss lists seven such species types. First are area-limited species with large home-ranges or low population densities. Second, are dispersal-limited species such as flightless insects which require patches in close proximity. Third, are resource-limited species, which require elements in short supply in managed landscapes such as snags, nectar sources, and fungi. Fourth, are process-limited species which require conditions created by ecological processes such as fire, flooding, and wind throw. The rate, level and timing of such events can be crucial. Fifth, are keystone species which exercise a disproportionately large impact on an ecosystem for their abundance or biomass. Sixth, are narrow endemic species with a restricted geographic range (e.g., often less than 50 000 km^2). Finally, Noss lists special cases, species which are important for other reasons. There may be a genetically distinct population, or a popular "flagship" species in which the public is interested.

Questions of Interest

Can forest managers use measures of arthropods (such as composition, abundance, diversity, and community structure) to assess aspects of forest integrity at the scale of the stand and landscape? Which measures are most indicative of specific forest conditions? How important is the patch size context? How do arthropod communities differ with treatment history? Which elements of forest structure correlate most strongly with arthropod community patterns?

Objectives

The purpose of this study was threefold: (1) to inventory the macro-arthropod community and important environmental variables in the Bear Creek and Indian Creek study area within the Payette National Forest (PNF) in Western Idaho; (2) to compare measures of community composition, diversity, and structure in forest macro-arthropod communities between patches of different sizes and treatment; and (3) to assist PNF managers in their ecosystem management efforts by providing principles to guide the use of macro-arthropods as indicators of changing forest conditions.

Predictions

Levels of environmental variables will vary according to patch treatment and size. Intact and large patches will have more structural diversity and therefore higher values for basal area (ft^2/acre), percent canopy cover, litter depth and percent soil moisture than will the treated and small patches (Seastedt and Crossley, Jr., 1984; Kimmins 1987; Perry 1988; Velasquez-Martinez 1990). The plantation will have higher values than the un-burned clearcut, which will have higher values than the burned clearcuts.

Macro-arthropods will differ by patch treatment and size according to measures of relative abundance, taxonomic diversity, species diversity, rareness, and membership in functional, disperser and indicator groups.

Overall relative abundance of macro-arthropods will be highest in the treated and small patches due to greater insolation and subsequently more energy available for primary production in these sites (Kimmins 1987).

Taxonomic diversity (number of genera/taxonomic group) of the four most abundant taxonomic groups (beetles, ants, spiders, and bugs,) will be highest in larger and older patches due to long-term stability of interior forest conditions in those patches.

Species richness, as measured by α and a jackknife estimator (JK1), will be highest in intact and large old growth patches due to greater niche diversification resulting from greater structural diversity and long term habitat stability. Richness will be lowest in the plantation patch, with increasing richness in the managed and small patches. Species evenness (E) will be lowest in the small and managed patches which will be dominated by a few abundant generalist species. Diversity as measured by the Shannon diversity index (H') will be low in clearcuts and high in intact and large patches.

Rare species (occurring in less than 3 sample units) will be more abundant in the older and larger patches than in the smaller and managed patches due to greater structural diversity and long term habitat stability (Lattin and Moldenke 1990; Niemelä et al. 1993). Generalist and pioneer species will be more abundant in the small and treated patches (Niemelä et al.1993).

Fungivores and detritivores will have more to eat and therefore will be more numerous in intact and large forest patches (Seastedt and Crossley, Jr., 1984). Because predators are mobile and require large territories and a wide prey base, predators will be more numerous in intact and large patches than in small and managed patches. Predators are the regulators of the system. Some predators are considered to be "keystone" in that their impact is much greater than their abundance (Noss and Cooperrider 1994; Schulze and Mooney 1994).

Dispersability is a function of forest structure. While long distance dispersing macro-arthropods will be present in all patch types, they will have higher relative abundance in small and treated patches. Flightless and other short distance dispersers will have higher relative abundance in intact and large patches (Lattin and Moldenke 1990; Niemelä et al. 1993).

Distinct subgroups of genera will be identified with strong affiliation or indication for specific patch types. These indicator classes will have distinct composition per patch treatment type and patch size.

MATERIALS AND METHODS

Bear Creek and Indian Creek Study Area

The study area is located in U.S. Forest Service (USFS) lands, in the Weiser and Council Districts of the Payette National Forest, and is situated within the Hornet Plateau subsection of the Blue Mountain Section in Western Central Idaho. The site spans a relatively warm and dry elevational range from 6000 to 7000 feet above sea level. Research was conducted in mixed conifer forests dominated by grand fir *(Abies grandis (Dougl.)Lindl.*), ponderosa pine (*Pinus ponderosa Doug.exLoud*), and douglas-fir (*Pseudotsuga menziesii (Mirb.) Franco*), with engelmann spruce (*Picea engelmannii*), and western larch (*Larix occidentalis Nutt.*) serving as important secondary species (Steele et al. 1981; Barrett 1994).

Aerial photos, thematic mapper satellite imagery, past and current management, fire history, and field trips to verify stand conditions were used to select the sites in the study area. My goal was to identify a forested watershed which contained large areas of intact forest, patches of different sizes, and areas of managed forest patches. I was unable to find any single site which met these criteria. Thus, I selected a study area which straddled the upper portions of Indian Creek and Bear Creek , adjacent tributaries of the Snake River. These paired watersheds contain multi-sized patches of unmanaged forest (save for periodic grazing by domestic ungulates), as well as forest patch stands in various stages of timber production. The two sites are assumed to be biologically and physically analogous to each other with similar grand fir *(Abies grandis)* habitat types, slopes, aspects, and elevational ranges (Steele et al. 1981). While this assumption can not be tested per se, an ANOVA examination failed to find a significant difference between the fauna of the five large patches located in Bear Creek and the three large patches in Indian creek.

We later established 5 additional transects at the Cuddy Mountain study area approximately 40 miles south west of the Bear Creek and Indian Creek study area.. Cuddy Mountain is a forested "mountain island" as defined by island biogeographic theory. This second study area was established in order to examine some of the precepts of the theory. Cuddy Mountain sites will be discussed in APPENDIX 1.

Table 1. Case history study design

Case History Study
Sampling Design

Bear Creek and Indian Creek Study Area
Payette National Forest, Idaho

Patch Treatments	**Patch Sizes**	
Indian Creek	Intact	100 hectares and greater
Intact (N=5)	Large	50 - 100 hectares
Large (N=3)	Small	10 hectares or less
Bear Creek	N = number of patch types	
Large (N=5)		
Small (N=3)		
Clearcut (N=3)		
Plantation (N=1)		

Stands and Patch Types

Five forest patch types were sampled (Table 1). Intact stands (100 hectares and larger) are dominated by a gappy overstory of mature (greater than 100 years old) and old (greater than 200 years old) trees. Intact stands have well developed co-dominant and/or understory and forb vegetation layers. Tree species composition is varied, but usually includes large old ponderosa pines and co-dominants of grand fir, douglas fir, western larch, and engelmann spruce. Intact stands have stable interior forest conditions characterized by higher soil moisture, and relatively high volumes of coarse woody debris. Except for sporadic grazing of domestic ungulates and periodic fire suppression activities, intact patch stands have not been actively managed or roaded (Steele et al. 1981; Barrett 1994). Five intact stands are located in Indian Creek.

The large patch stands (50 to 100 hectares) have the same structural elements as the intact patch stands: age-class, species composition, multistoried structure, and high values for litter depth, soil moisture and coarse woody debris. Five large patch stands are located in Bear Creek and three in Indian Creek.

Two medium patch stands (10 to 50 hectares) were established in patches with the same structure as intact and large. However, as 80 percent of medium patch pitfalls were vandalized, (in all likelihood by grazing domestic ungulates), this data set was discarded.

Small patch stands (up to 10 hectares) are remnants or fragments of formerly intact forest located between clearcuts in Bear Creek. Due to their size, much of the area within these patches exhibits edge conditions, particularly increased insolation. These stands have particularly well developed understory and forb layers. After the initial framentation or isolation from the former intact forest, small patches were not actively managed, although grazing by domesticated ungulates apparently occurs on a sporadic basis. Three small patch stands are located in Bear Creek.

Managed patch stands in the Bear Creek portion of the study area were established in the following management treatment types: one 15 year old ponderosa pine plantation and three clearcuts with different burn levels (one unburned, one patchy burned, and one high intensity burned). The plantation has an open overstory and a

patch understory and mineral soil. The unburned clearcut had moderate canopy cover in the understory and forb layers, with very little overstory canopy cover.

Field Methods

Transects 90 meters long were established in each stand or patch type. Every 90 meter transect had 10 sample units, dispersed at 10 meter intervals. There were 22 transects and a total of 220 sample units in the Bear and Indian study area. At each 10 meter point, sample units were randomly displaced five meters to the right or to the left of the transect. This was done to decrease linearity and to discourage "raids" of the pitfall traps by wildlife (Moldenke, personal communication). Samples of macro- arthropods and soils were collected and environmental descriptor data were noted at intervals along these transects. To avoid microclimate edge effects, transects were located at least 100 meters from any edge (Chen and Franklin 1992), except in the case of the small patch types, where transects were positioned equidistant from either patch edge. Streams, ravines, ridges and sumps were avoided.

Pitfall Trapping

Pitfall traps were set to measure the abundance, diversity and structure of the litter dwelling macro-arthropod community. Ten pitfall traps were set per transect, one at each ten meter interval according to standard pitfall methodology (Niemelä et al. 1986; Niemelä et al. 1990, Spence and Niemelä 1994). A one-quart

(950cc) clear plastic container with a bottom diameter of 4 inches and a top diameter of 5 inches was buried in the ground so that the open rim was level with the soil. An eight ounce cup (liquid ounce = 0.25 liter) containing approximately 50 cc of ethylene glycol was placed at the bottom of the yogurt container. A metal funnel with an opening diameter of one inch (24 mm) was placed so that the top rim would be even with the open rim of the larger container. This design was intended to prevent the escape of arthropods and to prevent entry by small forest vertebrates. A cover suspended 10 inches (25.4 cm) above the trap kept out rain and debris. Pitfall samples were collected two weeks after they were set.

Because some of the pitfall samples were damaged or destroyed by wildlife and or domestic ungulates during the first sampling, we conducted a limited second sampling a fortnight later in approximately one third of the transects. Samples were pooled and averaged per transect.

Macro-arthropod samples were stored in the collection cups until they were cleaned and sorted, after which they were weighed for biomass, cataloged, and placed in a synoptic collection (Martin 1977). All invertebrates were identified to family or genus level. Invertebrates were also categorized according to taxa, functional group membership and disperser capacity (Moldenke, personal communication July 8, 1994).

Soils

Forest soil samples were collected from the top 7-10 cm of soil at each sample unit according to standard collection procedures (Perry, personal communication July 8, 1994). Because the field sites were remotely located, soil samples were stored in doubled ziploc freezer bags, packed out, and stored in coolers and refrigerators until transport by truck to the Forest Research Lab at Oregon State University, Corvallis, Oregon.

Soils were sieved and homogenized in a splitter. Concentrations of mineralizable nitrogen (N) were determined following anaerobic incubation for 7 days at 40° C (Griffiths 1994). The methods and results for the mineralizable N are not discussed in this paper.

Environmental Descriptors

Data on forest composition and structure were taken within a 3 meter radius of each pitfall trap. Values were averaged per transect and per patch type.

Basal area (ft^2/acre) was estimated using a Spiegelrelaskop wedge prism at 20 meter intervals along each 90 meter transect. Values were averaged per transect and per patch type. Trees whose diameters were large enough to subtend the fixed critical angle were counted as 'in'. A basal area factor (B.A.F.), corresponding to the critical angle, was multiplied by the number of trees 'in' to achieve the total basal area in square feet per acre (Dilworth and Bell 1985).

Percent canopy cover for overstory, understory and forb or ground level vegetation was estimated ocularly. Litter depth measures (in centimeters) and content description were taken every 20 meters. Percent soil moisture content was measured in the lab where fresh and oven dried soil weights were obtained, and percent soil moisture was calculated.

Statistical Analysis Methods

I employed a series of parametric and non-parametric univariate and multivariate analysis techniques to assess the diversity, relative abundance, and structure of the arthropod community .

Data were analyzed using the PC-ORD for Windows, v3.17 suite of statistical analysis programs (McCune and Mefford 1997). In particular, I used the summary statistics package and the Dufrene and Legendre (1997) indicator species analysis package which combines information on species abundance in a particular patch type with faithfulness of occurrence in a particular patch type to produce an indicator value for each species per patch type. I then tested the significance of these indicator groups with the multiple response permutation procedure (MRPP), a parametric method for testing multivariate differences among preassigned groups. I also used the SAS system for Windows v.6.12 (SAS Institute 1989-1996) to test the hypotheses of 'no affect' of patch treatment and patch size on relative abundance, taxonomic diversity, species diversity, and community structure. This was done with an analysis of variance (ANOVA) which produced F-statistics and associated p-values, and a least square means analysis for patch means and confidence intervals and T-tests and p-values.

RESULTS

Patch Conditions

Soil samples were collected and six environmental descriptor variables were analyzed according to patch treatment and patch size: basal area (ft^2/acre); percent canopy cover for the overstory, understory; and forb layers; litter depth; and percent soil moisture content. Results include ANOVA and T-test detected differences between patch types per variable (Table 2).

Basal area (ft^2/acre) differed significantly by treatment (ANOVA $p<0.05$) with intact patch basal area (BA) twice that of large patches, and more than three times that of the plantation and clearcut patches (separate T-tests $p<0.01$). BA varied by patch size (ANOVA $p<0.1$), with intact patch volume twice that of large and small patches.

An ANOVA detected differences between treatments ($p<0.001$) and size ($p<0.05$) for overstory canopy cover, with highest values in large and intact patches. Understory canopy cover varied between treatments ($p<0.01$) and sizes ($p<0.1$) from a low of 5 percent in clearcuts to a high of 50 percent in the plantation patch. Forb canopy cover differed by patch treatment ($p<0.01$) but not by patch size ($p<0.26$), and ranged from a high of 70 percent for small patches to a low of 12 percent for clearcuts.

Litter depth varied significantly by patch treatment ($p<0.05$) with greatest depth in large (5.58cm) and intact (5.12cm) patches followed by plantation (3.17) and clearcut (1.85cm) patches. Litter depth was not significantly different by patch size ($p<0.84$) with greatest depth in large patches (5.58cm) and least in small patches (4.9cm)

Arthropod community composition, diversity, and structure was described according to relative abundance, four measures of diversity, and membership in:

Seventeen orders and/or super-families; ten functional groups; two types of disperser (long or short distance); and three species indicator classes. Results include ANOVA, T-test, and MRPP detected differences.

Table 2. Environmental descriptor measures. Summary values are means and ± standard errors (shaded) per patch type and were collected in1994 for the Bear Creek and Indian Creek Study Area.

	Intact		Large		Small		Plant		CC	
BA (ft^2/acre) [2*]	301[d 3]	46.07	161[b]	34.8	144[a]	68.5	88[b]	92.15	6[a]	53.2
[4] Over %CC [2**]	65[b]	4.77	70[b]	3.61	40[a]	7.02	50[b]	9.55	2[a]	5.51
[5] Under %CC [2*]	30[b]	5.21	30[b]	3.94	10[a]	6.84	50[b]	10.41	5[a]	6.01
[6] Forb %CC [2*]	50[b]	7.09	50[b]	5.36	70	9.74	50[b]	14.18	10[a]	8.19
Litter (cm) [2**]	5.12[b]	0.71	5.58[b]	0.53	4.90	1.16	3.17	1.41	1.85[a]	0.82

1. Values are means and ± standard errors (shaded) per patch type.
2. ANOVA tested significance levels: * $p<0.1$, ** $p<0.05$.
3. Per variable, values with different letters tested different with t-tests with significance levels of $p<0.1$ or better.
4. Estimated percent area cover of the overstory canopy layer.
5. Estimated percent area cover of the understory tree layer.
6. Estimated percent area cover of the forb and ground vegetation layer.

Abundance

A total of 5455 macro-arthropod individuals, representing 17 orders and/or super-families and 219 species were collected in the Bear Creek and Indian Creek study area during the summer of 1994. Indian Creek fauna numbered 1374 and Bear Creek fauna totaled 4081. The mean abundance of macro-arthropods per patch types was highest in small patches with a mean of 494 individuals (29%) followed by burned clearcut patches (26%) with a mean of 459 individuals (Figures 2 and 4). The 219 species were then reduced to 121 genera for the purposes of the community structure analysis. Of the 219 species found in the Bear Creek and Indian Creek study area, 135 species (or 62 percent) occurred less than three times in the samples. Bear Creek with four patch types totaled 192 species. Indian Creek with two patch types had 103 species.

While macro-arthropod fauna relative abundance did not vary significantly by treatment (ANOVA $p<0.3$), it did vary significantly by patch size (ANOVA $p<0.03$) (Figures 1 and 3). Fauna relative abundance was 35% greater in clearcut patches than in large patches (T-test $p<0.09$). Fauna relative abundance in small patches was twice that of intact (T-test $p<0.03$) and large (T-test $p<0.02$) patches.

Taxonomic Groups

Treatments differed significantly for taxonomic diversity (number genera/taxa) of beetle, ant, and bug taxa (each ANOVA $p<0.05$) (Figure 5). For the top four taxa (beetles, ants, spiders, and bugs), taxonomic diversity was highest in the plantation and clearcut patches. Ants and bugs had the highest taxonomic diversity in the plantation patch (separate T-tests $p<0.05$) while beetles taxonomic diversity was highest in clearcut patches (T-test $p<0.05$).

Beetle and ant taxonomic diversity were significantly different by patch size (separate ANOVA p values <0.05) (Figure 6). For beetle and bugs, small patches were twice as diverse as intact patches (separate T-tests $p<0.04$) and 1.5 times that of large patches. Ant diversity was similarly distributed amongst the patch sizes, with significant differences between small and intact and small and large patches (separate T-tests $p<0.05$).

Species Diversity

Of the four species diversity measures employed, only two, α and JK1 (both measures of richness), were found to vary significantly by patch treatment and size (Figures 7-10). Evenness (E) and the Shannon Diversity Index (H') failed to detect differences in the majority of tests. Fauna α and JK1 differed significantly by treatment type (each ANOVA $p<0.05$). Richness in clearcut patches was nearly twice in intact and large patches, followed by plantation and large patches. Fauna α and JK1 also differed significantly by patch size (each ANOVA $p<0.001$), with small patch fauna twice as rich as that in large and intact patches (separate T-tests $p<0.01$). Summary diversity measures α, JK1, E, H, beta and gamma, can be found in Table 3.

Functional Groups

Of the top four functional groups, predators were the most abundant and had the highest taxonomic diversity (number of genera/functional group), followed by herbivores, fungivores and parasites.

Predators and herbivores exhibited increasing taxonomic diversity with increasing levels of management: from intact and large to plantation and clear-cuts (ANOVA $p< 0.05$) (Figure 11). Similarly, predators and herbivores showed increasing taxonomic diversity with decreasing patch size (Figure 12), from intact to large to small (ANOVA $p< 0.05$). Predators and herbivores were most numerous in the managed and small patches. Fungivore taxonomic diversity was also highest in the small and managed patches, though neither patch size nor treatment differences were significant (ANOVA $p<0.85$). Parasite taxonomic diversity differed by patch size with highest generic diversity in the small patches (ANOVA $p<0.1$) and by treatment type with generic diversity highest in plantations and clearcuts followed in order by large and intact patches (ANOVA $p<0.1$) .

Disperser Groups

Twice as many genera were long distance dispersers as were short distance dispersers. Relative abundance of long distance dispersers varied significantly by patch treatment and patch size (each ANOVA $p<0.01$) (Figures 13 and 14). Long distance dispersers were most numerous in clear-cut patches, followed in order by plantation, small, large, and intact patches. Relative abundance of short distance dispersers was not significantly different between treatment types (ANOVA $p<0.20$) but was significantly different between patch sizes (ANOVA $p<0.01$). Short distance dispersers were most numerous in small patches followed by plantation, large, and intact and least numerous in clearcut patches.

Indicator Species

An indicator species analysis of 121 Bear Creek and Indian Creek genera (Dufrene and Legendre 1997), revealed sub-groups of species with 75 to 100 percent "perfect indication" or affiliation for specific patch types. When intact and large patches were pooled and analyzed against all treated patches (plantation and clearcut patches), a list of 36 genera with 75 to 100 percent "perfect indication" for intact or large patches was produced (MRPP $p<0.01$) (Figure 15). Small patches had 42 indicators with 75 to 100 percent "perfect indication " when compared with the pooled intact and large patches (MRPP $p<0.1$) (Figure 16).

Table 3. Summary diversity measures.

	N[1]	α^2	β^3	γ^4	E[5]	H'[6]	JK1[7]
Bear Creek	11	41.5	4.43	186	0.765	2.77	270
Large	5	34.2	2.60	89	0.746	2.59	128.2
Small	2	61.0	1.46	89	0.755	3.09	117
CC	3	53.7	1.94	104	0.744	2.94	144
Plantation	1	46.0	1.59	73.1	0.838	3.20	73.1
Indian Creek	8	31.9	2.98	97	0.846	2.89	141.6
Intact	4	27.8	2.17	63	0.840	2.74	90.8
Large	3	37.4	1.86	70	0.855	3.09	97.3
B &I							
Large	8	35.34	3.34	118	0.787	2.78	173.1
All	19	38.8	5.56	211	0.788	2.813	302.9

1. N is the number of transects per patch types.
2. α or S is mean trap richness per patch type.
3 $\beta = \gamma/\alpha$. A measure of richness, examines species turnover along an environmental gradient. McCune (1996).
4. γ or gamma is the estimated total species richness across plots in a region (Whittaker as cited in McCune 1996).
5. E or Evenness, E is defined by McCune (1996) as E = H'/ln(S), measures how equitably the abundance (or total number of individuals) is distributed among the species.
6. H' or the Shannon diversity index. H', is a synthetic index of abundance and richness. McCune (1996) defines $H' = - S\ (p_i \cdot \ln(p_i))$, where p_i= importance probability in column I (matrix elements are relativized by row totals).
7. JK1or First order jack knife estimate is defined $Jack_1 = S + r1(n-1) / n$. where s is the observed number of species, r1 = the number of species occurring in one sample unit, and n=the number of sample units.

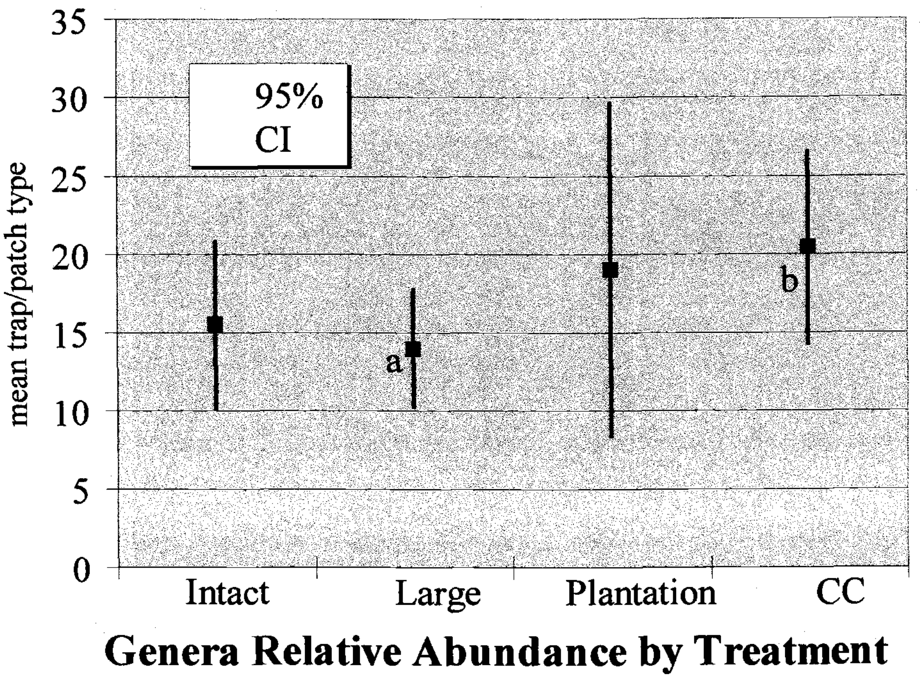
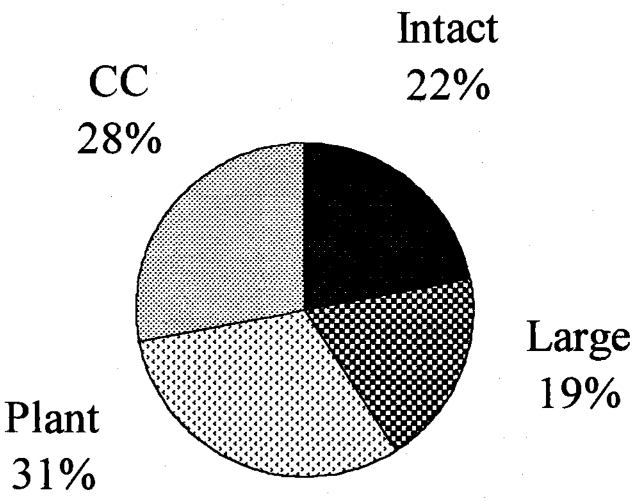


Figure 1.. Genera relative abundance by treatment. Values are means and 95% confidence limits. Fauna relative abundance was not significantly different by treatment type (ANOVA $p<0.3$). Means denoted by different letters differed at $p<.05$.



% Relative Abundance per Trap by Treatment

Figure 2. Percent relative abundance per trap per treatment.

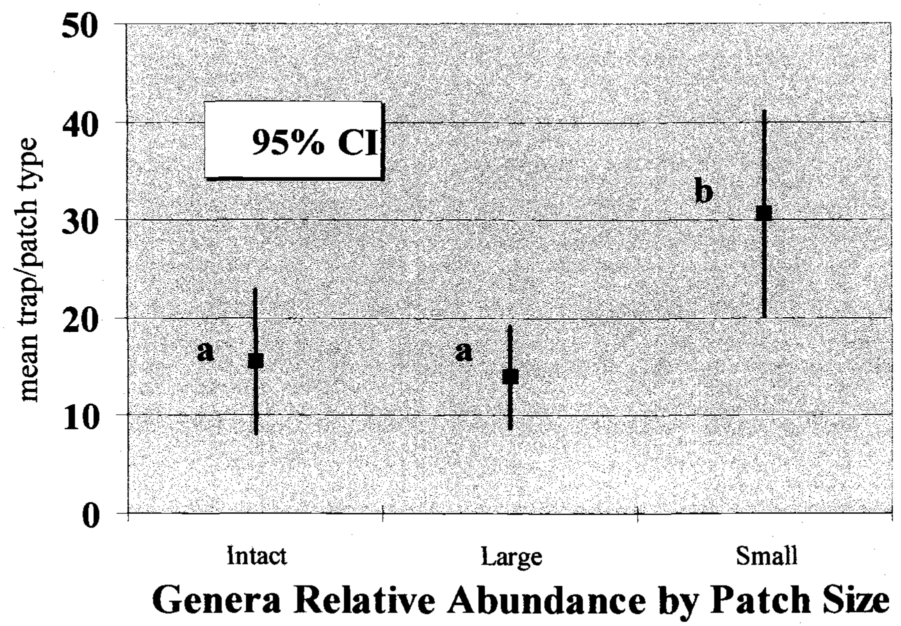


Figure 3. Genera relative abundance by patch size. Values are means and 95% confidence intervals by patch size (ANOVA $p < 0.03$). Means denoted by different letters differ in T-Tests at $p < 0.05$.

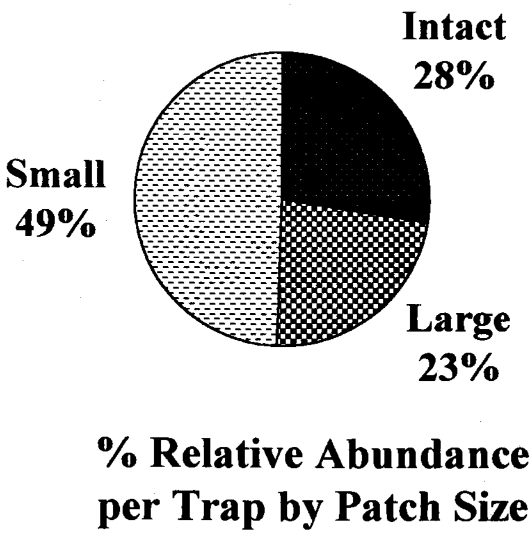


Figure 4. Percent relative abundance by patch size.

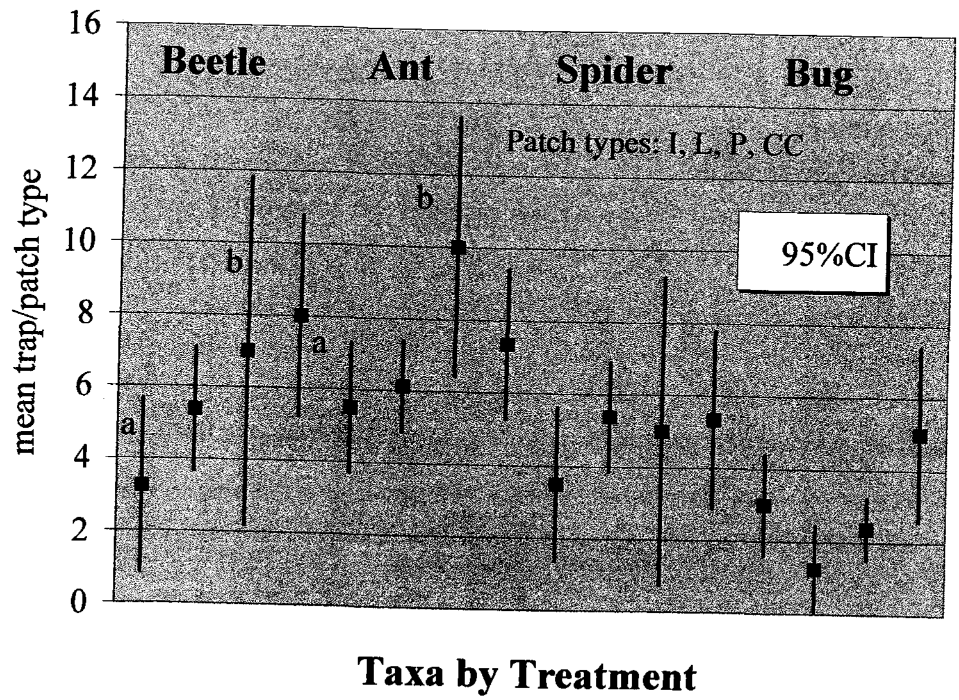


Figure 5. Taxa by patch treatment. Taxonomic diversity (number genera/taxa) was significantly different per each taxa (beetles, ants, spiders, bugs) (each ANOVA p<0.03). Means denoted by different letters differ in T-tests at p<0.05.

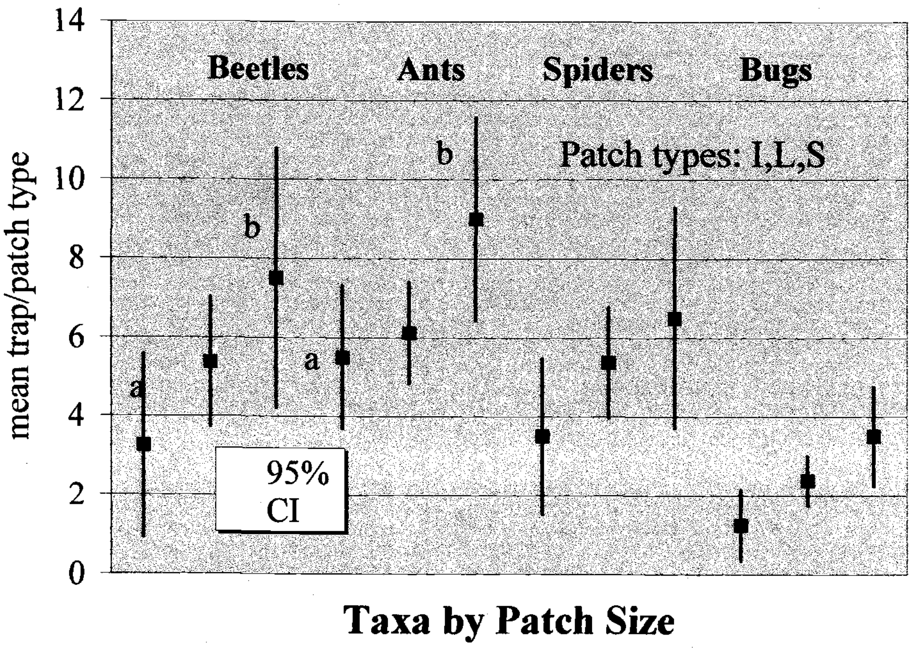


Figure 6. Taxa by patch size. ANOVA detected significant differences for taxonomic diversity per patch type: Beetles (F value=2.89, p=0.0981), Ants (F value=3.19, p=0.0807), and Bugs (F value=5.58, p=0.0212. No significant difference per patch size was detected for Spiders (Fvalue=2.27, p=0.1491). T-tests detected p<0.05 differences between means denoted by different letters.

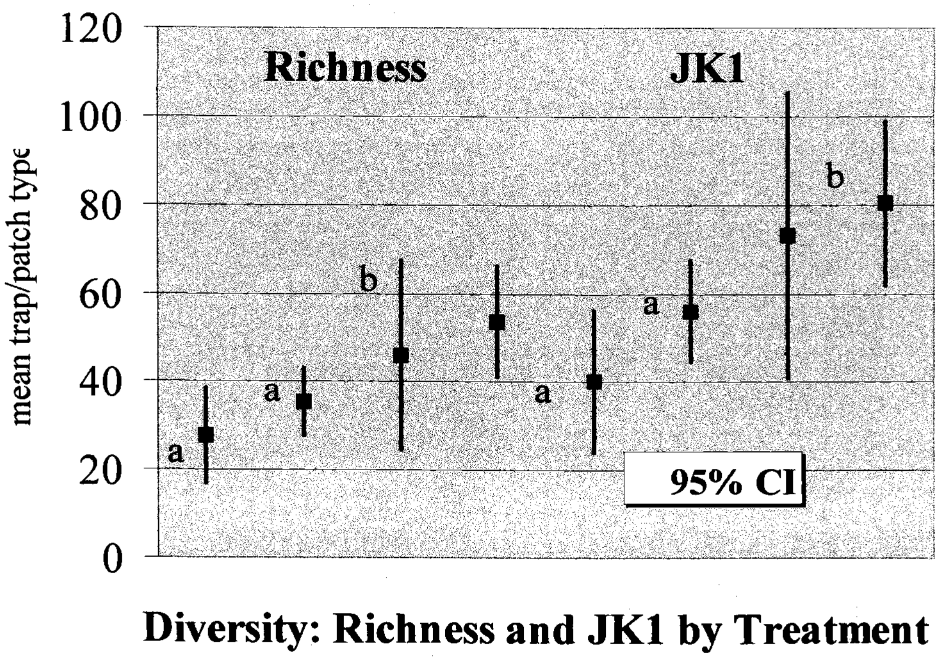


Figure 7. Richness and JK1 by treatment.

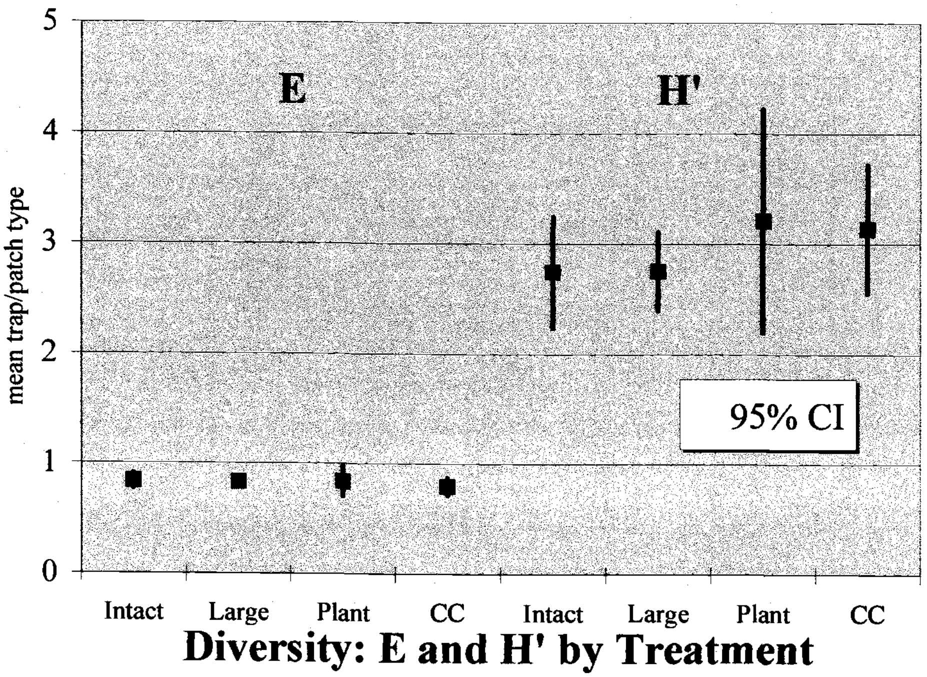


Figure 8. E and H' by treatment.

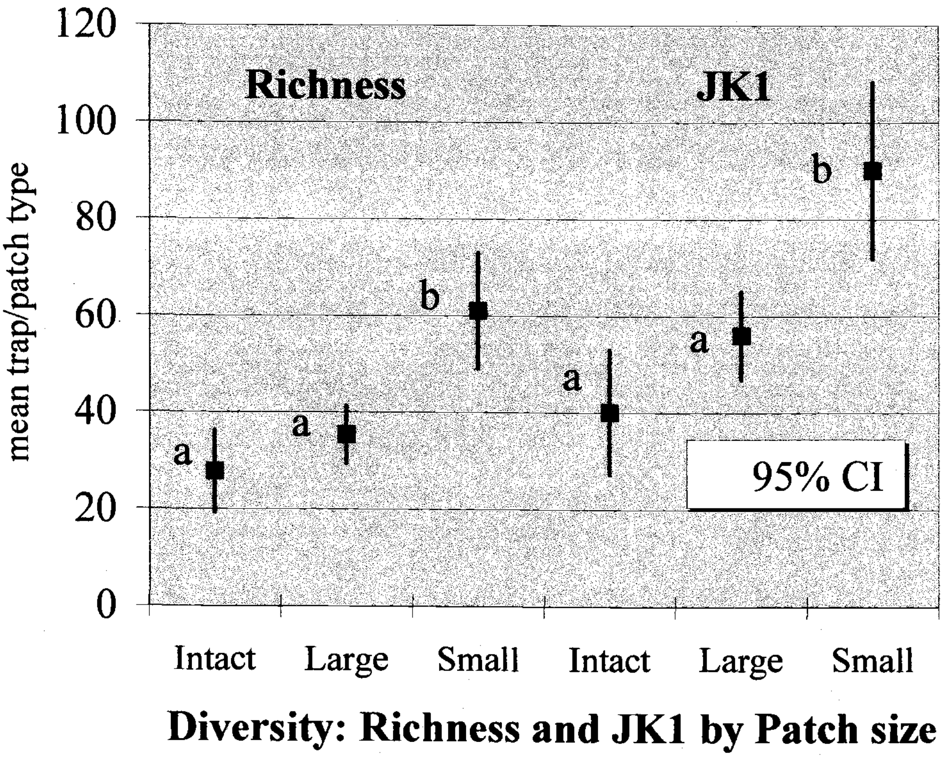


Figure 9. Richness and JK1 by patch size.

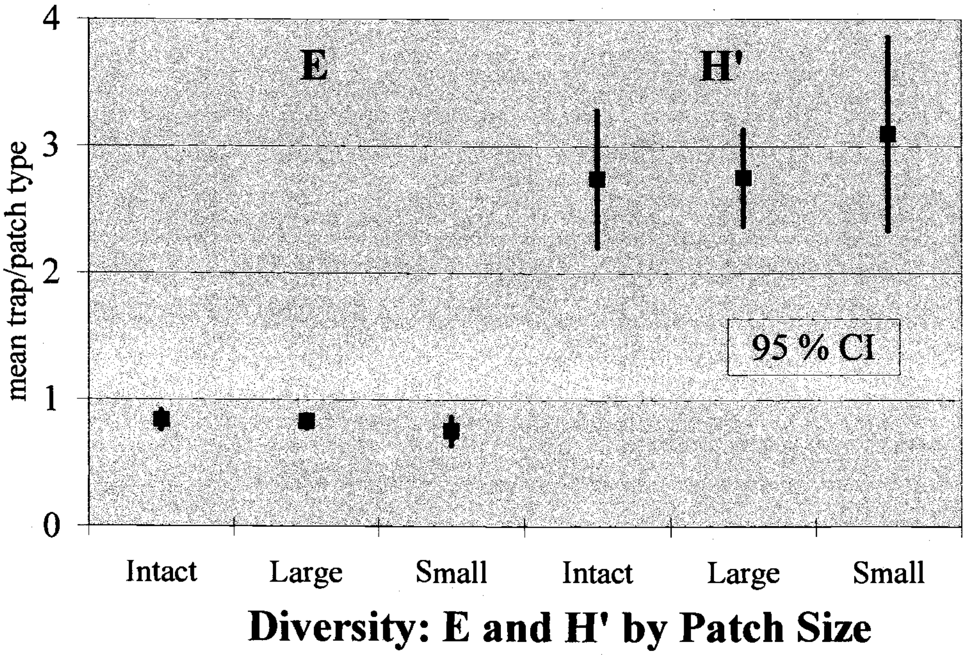


Figure 10. E and H' by patch size.

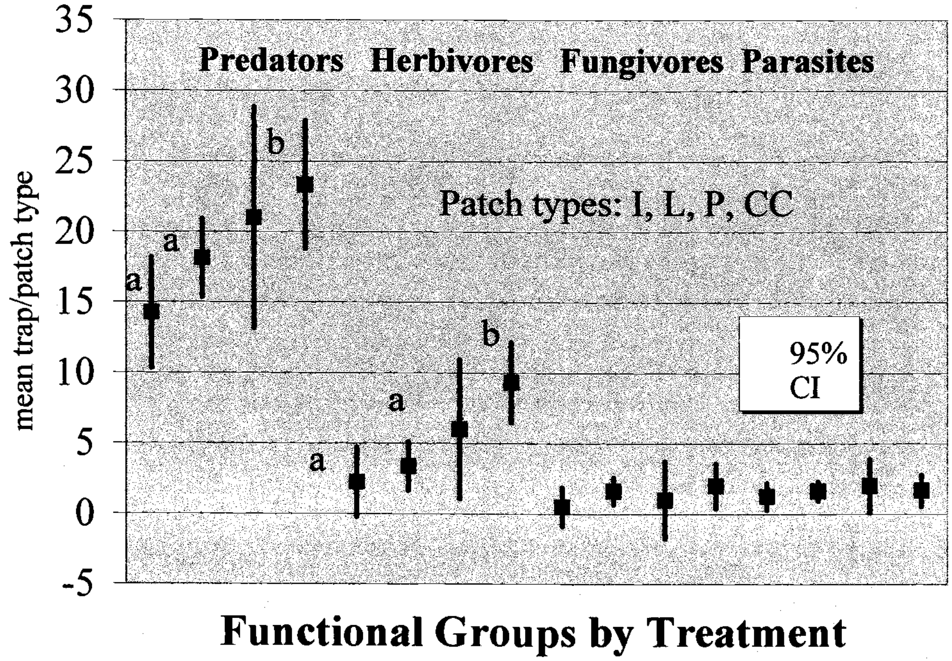


Figure 11. Functional groups by treatment.

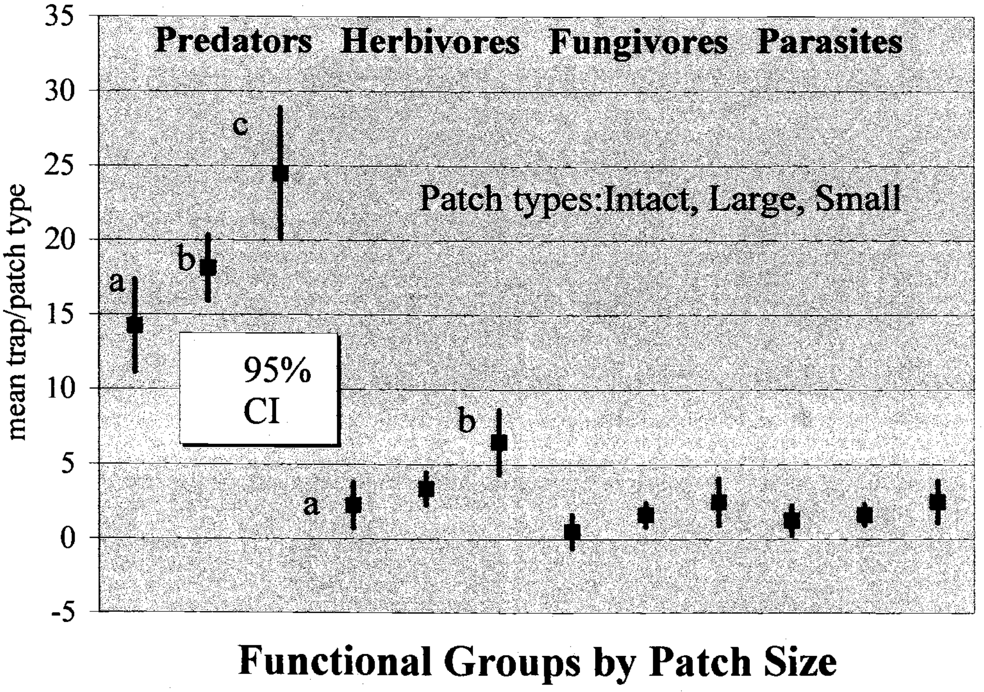


Figure 12. Functional groups by patch size.

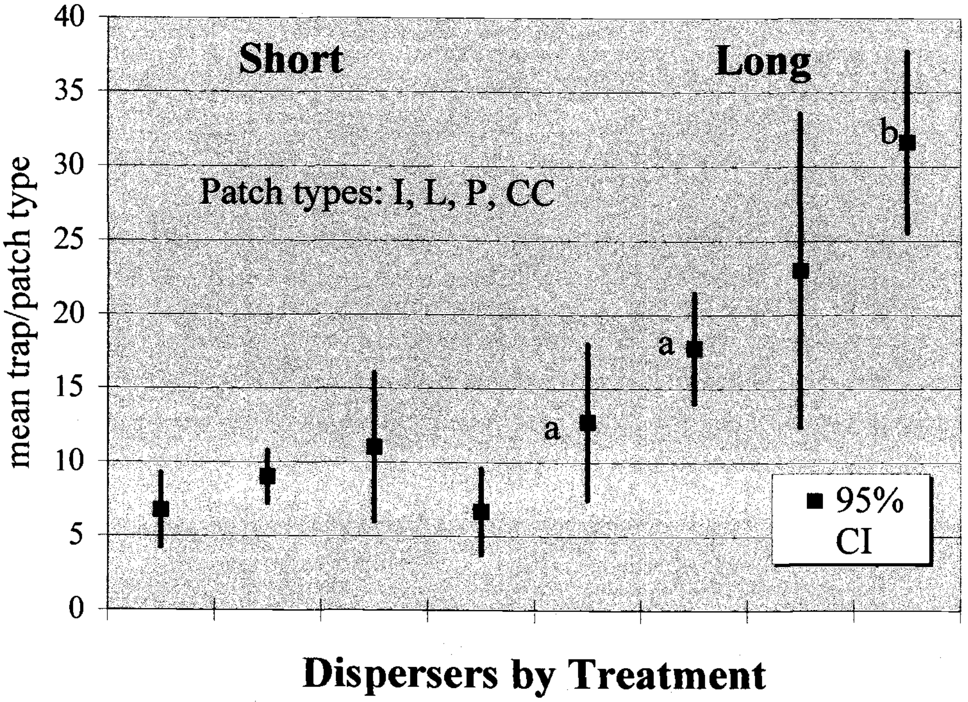


Figure 13. Dispersers by treatment.

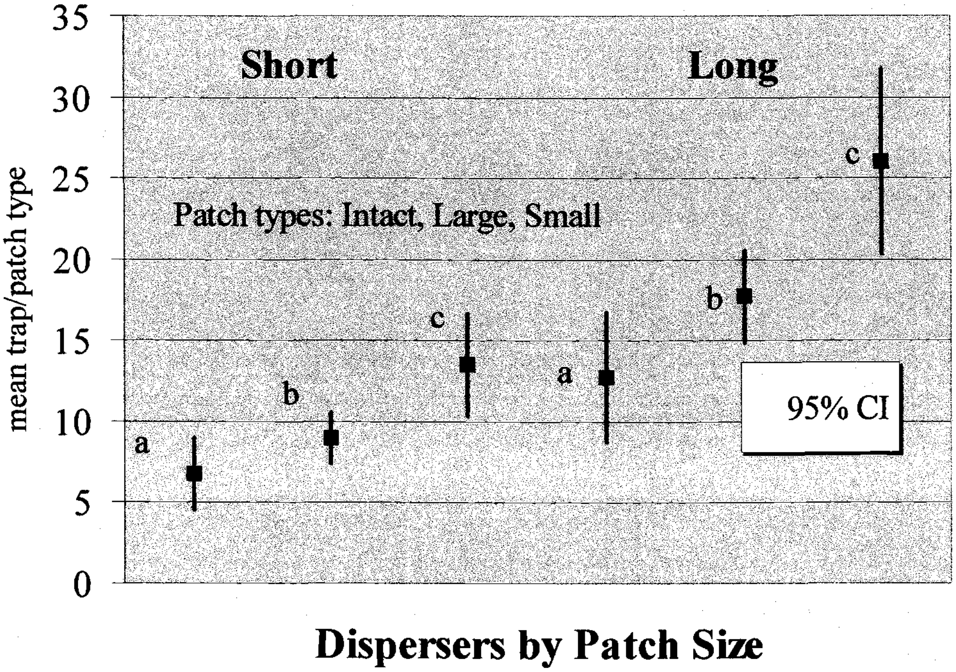


Figure 14. Dispersers by patch size.

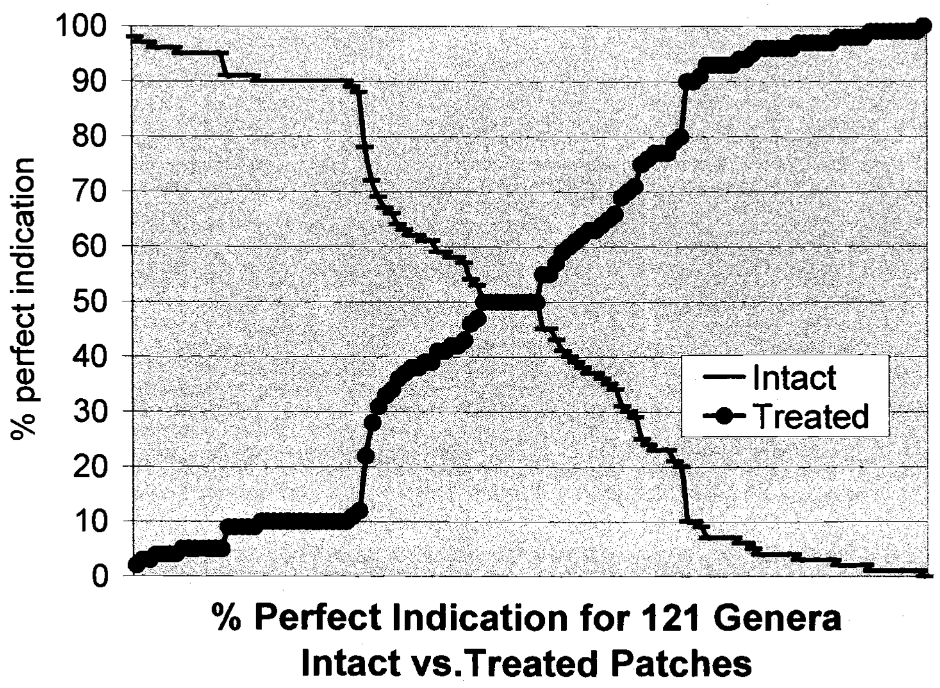


Figure 15. Percent "perfect indication" for intact & large vs. managed patches.

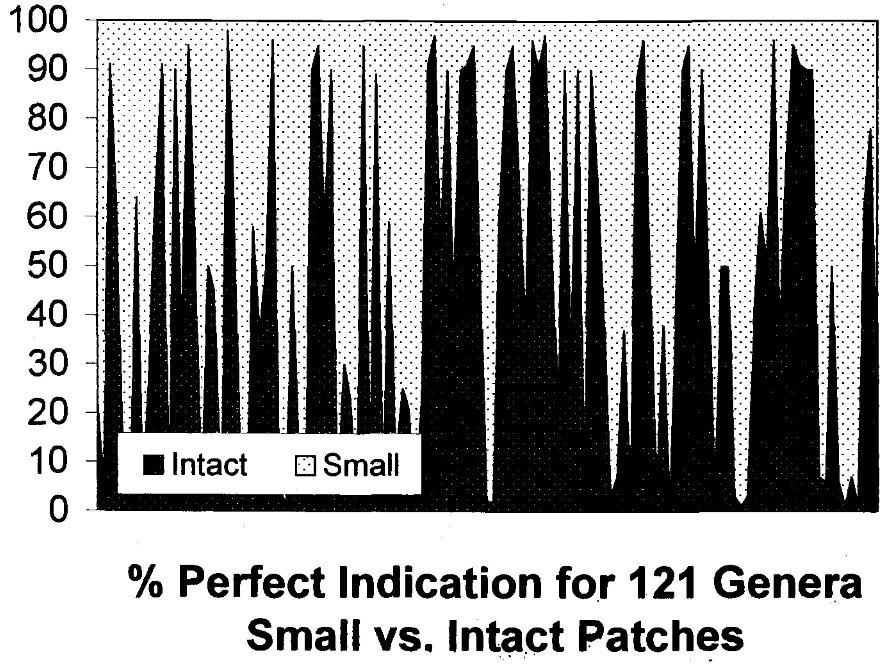


Figure 16. Percent "perfect indication" for small vs. intact and large patches.

DISCUSSION

An inventory of the macro-arthropod community and important environmental variables in the Bear Creek and Indian Creek study area was conducted during the summer of 1994. Macro-arthropod fauna were found to differ significantly between patch treatment and patch size for many variables. A strong pattern was observed throughout much of the data, that of increasing values (abundance, richness, taxonomic diversity, and numbers of long distance dispersers) with increased levels of management and decreased patch size. An important exception to this trend is that of the small distance dispersers which were least abundant in clearcuts. This trend of increasing values with increased levels of management and decreased patch size could be interpreted as a response to the increased flow of energy into the forb and litter layers in the form of solar insolation (Kimmins 1987; Perry 1994).

Patch Conditions

Intact and large patches were expected to have stable interior forest conditions characterized by higher basal area ft^2/acre, soil moisture, multiple canopy layers, and high values of litter depth. Other studies have found soil moisture to be correlated with high abundance of arthropods (Madson 1997; Griffiths and Swanson 1999). Multiple canopies provide for more and deeper litter layers for detritivores and more vegetation for herbivores (Seastedt and Crossley, Jr., 1984). Interior forest conditions often include high volumes of coarse woody debris which have been associated with high levels of beetles (Spies et al. 1988) and ants (Bull et al. 1995). Basal area (BA) and overstory canopy cover were greatest in the intact and large patches (Table 2).

In this study area, small patches had similar forest structure to the large and intact patches (Table 2), but due to their smaller size, much of these patch manifested edge effects (especially increased insolation).

The 15 year old pine plantation had a much greater understory canopy layer and forb layer than predicted. The forb layer canopy cover was much higher than predicted in small patches. Litter was greatest in large and intact patches as predicted and least in the burned clearcuts.

Taxonomic Groups

Due to the presumed stability of the habitat in the intact and large patches, I expected to see more diverse taxa present in these patches. That was not the case. Taxonomic diversity was highest for plantation and clearcut patches and in small patches.

Abundance and Species Diversity

Macro-arthropod richness was highest in the treated and small patches. In retrospect, perhaps my prediction of highest richness in intact and large patches (Niemelä et al. 1993; Noss and Cooperrider 1994) is applicable in general to arthropods, but not to the situation of the macro-arthropods at the litter level. Macro-arthropod richness, abundance, and structural diversity peak in clearcut, plantation, and small patches due to an increase in energy (available through increased insolation) cycled though the litter layer and below-ground communities in these managed and small sites. Increased insolation drives primary production at a furious rate in these sites.

E and H' did not vary as predicted probably due to high degree of richness of the macro-arthropod community in the Bear Creek and Indian Creek study area.

Functional Groups

My predictions of greater taxonomic diversity for predators, fungivores, and parasites in the intact and large patches (Seastedt and Crossley, Jr. 1984) were not borne out by the data. Instead, predators, fungivores and parasites joined herbivores (the one group which performed as predicted) in increased taxonomic diversity with decreased patch size and increased management.

One obvious next step would be to examine the lists of predators against the lists of indicator species for intact and large, versus treated, and versus small forest patches, to identify predators associated with those specific patch conditions as a first step towards determining whether any of these predators are keystone species (species whose impact is disproportionately greater than their numbers).

Disperser Types

As predicted, long distance disperser were more abundant in treated patches (clearcuts and plantation) than in large and intact patches. While short distance dispersers were least abundant in clearcuts as I predicted, they defied another prediction of highest abundance in intact and large patches (Lattin and Moldenke 1990). Instead they were most abundant in small patches, followed by plantation, large and intact patches than in the managed and small patches (Niemelä and Spence 1991). I also did not predict the two to one ratio of long to short dispersers. A next step would be to examine the degree to which there is overlap between the long distance dispersers and the pioneer and generalist communities on one hand and the short distance dispersers and interior forest obligates on the other (Niemelä and Spence 1991).

Indicator Species

I expected that some interior forest specialist species would be found in greater abundance in the intact sites, and found with decreasing abundance as patch size decreased from intact and large to small, and then be absent in the managed patches. As predicted, lists of indicator genera were generated for intact/large, plantation/clearcut and small patch types. As inference is limited to the Bear Creek and Indian Creek study area (Ganio, personal communication 3/8/01), these lists should not be projected a priori to apply in similar habitat types and conditions else where. However, these lists provide an excellent comparison point for future sampling and monitoring efforts.

Conclusions

In general, community structure as sampled by the pitfall is stable with predators, herbivores, fungivores, and parasites exhibiting the same pattern of increased taxonomic diversity with increased management and decreased patch size. Fungivores and parasites were poorly represented and may be better examined with other collection methods. Diversity was measured by four variables α, JK1, E and H'. Neither E or H' detected significant differences in the majority of cases. When α is high and H' is not, the diversity being measured is in rarer species, which I believe to be the case in the Bear Creek and Indian Creek study area (64 percent of fauna collected in the Bear Creek and Indian Creek study area were found to be rare (occurring in less than three samples)). E is often the inverse of α. When H' is high, and α is not, diversity is distributed in the middle range of the data.

While some genera were ubiquitous in nearly every patch type, others showed a clear affinity or indication of a particular set of patch conditions. Indicator genera were identified 75 to 100 percent "perfect indication" indicator values (Dufrene and Legendre 1999) for three different patch conditions: (1) 36 genera were associated with the interior forest conditions found in intact/large patches; (2) 46 genera were associated with small patches characterized by a unique combination of presumed high inputs of energy alongside high values for forest structural elements; and (3) 44 genera were associated with clearcut and plantation patches where energy inputs were presumed to be high, but structure was simplified (Figures 14, 15, and 16; Appendix 2).

Macro-arthropod community composition, diversity and structure did vary, usually significantly, by patch treatment and size. Useful measures of generic diversity include richness estimators α, β, and JK1. Examination of taxonomic diversity was also useful, especially for the more mobile arthropods. Pitfall traps provided copious data on the structure of the community in regards to predators and herbivores. Pitfalls, however, did not provide much information about the status of fungivores and parasites in the various different patches. Another trapping method such as the berlaise funnel, would likely provide more information about those functional groups which are likely operating at a finer scale of resolution than that tested by the pitfall trap. Employing both methods would provide a much better assessment of the community of arthropods living on the forest floor.

The indicator species analysis program also provided very useful lists of species which are affiliated with particular patch conditions. Taken together, these measures could be adopted for use by forest managers to allow them to assess and monitor the effects of a management regime on the structure and composition of macro-arthropod communities as part of a comprehensive adaptive management plan.

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APPENDICES

APPENDIX 1.

Indicator Species Value (% Perfect indication) for intact (includes intact and large patches), managed (includes plantation and clearcut patches), and small patch types.

	Indicator Values (IV) - Intact Patch Types				**Indicator Values (IV) - Managed Patch Types**		
	Genera	Intact	Treated		Genera	Treated	Intact
1	Caecul	98	2	1	Pompil	100	0
2	Geophi	97	3	2	Anthop	99	1
3	Membra	97	3	3	BugX	99	1
4	Cercop	96	4	4	Chrysm	99	1
5	Machil	96	4	5	Eleode	99	1
6	Pityoh	96	4	6	Geocor	99	1
7	Tachin	96	4	7	Sphe	99	1
8	Bdelli	95	5	8	Vespac	99	1
9	Creoph	95	5	9	Vespul	99	1
10	Ensife	95	5	10	Apidae	98	2
11	Julid	95	5	11	Coelio	98	2
12	Linyph	95	5	12	Leiodi	98	2
13	Pseudo	95	5	13	LepiX	98	2
14	Tenthr	95	5	14	Rhynco	98	2
15	Agulla	91	9	15	AntX	97	3
16	Aphodi	91	9	16	Nabid	97	3
17	Geomet	91	9	17	Orthez	97	3
18	Ichneu	91	9	18	Phello	97	3
19	Therid	91	9	19	Scarab	97	3
20	Apoche	90	10	20	Spheco	97	3
21	Coleop	90	10	21	Agapos	96	4
22	Cymind	90	10	22	Bembid	96	4
23	Hemero	90	10	23	Cantha	96	4
24	HymnX	90	10	24	Dialic	96	4
25	Ligidi	90	10	25	Flea	96	4
26	Meloid	90	10	26	Polist	96	4
27	MillX	90	10	27	Cercer	95	5
28	MiteX	90	10	28	Trachy	94	6
29	Nicrop	90	10	29	Trombi	94	6
30	Pselap	90	10	30	Amara	93	7
31	Quediu	90	10	31	Evylae	93	7
32	Thomis	90	10	32	Osmia	93	7
33	Tipuli	90	10	33	Tortri	93	7
34	Fbeetl	89	11	34	VespiX	93	7

35	Philod	88	12	35	Cnovae	91	9
36	Xystic	78	22	36	Cicade	90	10
37	Taracu	72	28	37	Forufa	90	10
38	Lithob	69	31	38	Micari	80	20
39	Noctui	67	33	39	FoX	79	21
40	Aphid	66	34	40	Acridid	77	23
41	Antrod	64	36	41	Elater	77	23
42	Cmodoc	63	37	42	Geoder	77	23
43	Aleoch	62	38	43	Zacotu	76	24
44	WeeviX	62	38	44	Fosanq	75	25
45	Leuron	61	39	45	Mirid	71	29
46	Staph	61	39	46	Diapri	70	30
47	Fopaci	59	41	47	Apheno	69	31
48	Micryp	59	41	48	Aradid	66	34
49	Carabu	58	42	49	Tapino	65	35
50	Cybaeu	58	42	50	CaX	64	36
51	Beetle	57	43	51	Lygaei	63	37
52	Gnapho	54	46	52	Pardosa	63	37
53	Lasius	53	47	53	Polyde	62	38
54	Bollma	50	50	54	Pristo	61	39
55	CentiX	50	50	55	Spider	60	40
56	Chrysp	50	50	56	Notiop	59	41
57	Pogono	50	50	57	Hparas	57	43
58	Raphid	50	50	58	Bracon	55	45
59	Sabaco	50	50	59	Pteros	55	45
60	Scaph	50	50	60	Bollma	50	50
61	Stenop	50	50	61	CentiX	50	50
62	Tricop	50	50	62	Chrysp	50	50
63	Bracon	45	55	63	Pogono	50	50
64	Pteros	45	55	64	Raphid	50	50
65	Hparas	43	57	65	Sabaco	50	50
66	Notiop	41	59	66	Scaph	50	50
67	Spider	40	60	67	Stenop	50	50
68	Pristo	39	61	68	Tricop	50	50
69	Polyde	38	62	69	Lasius	47	53
70	Lygaei	37	63	70	Gnapho	46	54
71	Pardosa	37	63	71	Beetle	43	57
72	CaX	36	64	72	Carabu	42	58
73	Tapino	35	65	73	Cybaeu	42	58
74	Aradid	34	66	74	Fopaci	41	59
75	Apheno	31	69	75	Micryp	41	59
76	Diapri	30	70	76	Leuron	39	61
77	Mirid	29	71	77	Staph	39	61
78	Fosanq	25	75	78	Aleoch	38	62
79	Zacotu	24	76	79	WeeviX	38	62
80	Acridid	23	77	80	Cmodoc	37	63
81	Elater	23	77	81	Antrod	36	64
82	Geoder	23	77	82	Aphid	34	66

83	FoX	21	79	83	Noctui	33	67
84	Micari	20	80	84	Lithob	31	69
85	Cicade	10	90	85	Taracu	28	72
86	Forufa	10	90	86	Xystic	22	78
87	Cnovae	9	91	87	Philod	12	88
88	Amara	7	93	88	Fbeetl	11	89
89	Evylae	7	93	89	Apoche	10	90
90	Osmia	7	93	90	Coleop	10	90
91	Tortri	7	93	91	Cymind	10	90
92	VespiX	7	93	92	Hemero	10	90
93	Trachy	6	94	93	HymnX	10	90
94	Trombi	6	94	94	Ligidi	10	90
95	Cercer	5	95	95	Meloid	10	90
96	Agapos	4	96	96	MillX	10	90
97	Bembid	4	96	97	MiteX	10	90
98	Cantha	4	96	98	Nicrop	10	90
99	Dialic	4	96	99	Pselap	10	90
100	Flea	4	96	100	Quediu	10	90
101	Polist	4	96	101	Thomis	10	90
102	AntX	3	97	102	Tipuli	10	90
103	Nabid	3	97	103	Agulla	9	91
104	Orthez	3	97	104	Aphodi	9	91
105	Phello	3	97	105	Geomet	9	91
106	Scarab	3	97	106	Ichneu	9	91
107	Spheco	3	97	107	Therid	9	91
108	Apidae	2	98	108	Bdelli	5	95
109	Coelio	2	98	109	Creoph	5	95
110	Leiodi	2	98	110	Ensife	5	95
111	LepiX	2	98	111	Julid	5	95
112	Rhynco	2	98	112	Linyph	5	95
113	Anthop	1	99	113	Pseudo	5	95
114	BugX	1	99	114	Tenthr	5	95
115	Chrysm	1	99	115	Cercop	4	96
116	Eleode	1	99	116	Machil	4	96
117	Geocor	1	99	117	Pityoh	4	96
118	Sphe	1	99	118	Tachin	4	96
119	Vespac	1	99	119	Geophi	3	97
120	Vespul	1	99	120	Membra	3	97
121	Pompil	0	100	121	Caecul	2	98

	Indicator Values (IV) Small Patch Types	Small	Intact
1	Pompil	100	0
2	Anthop	99	1
3	BugX	99	1
4	Chrysm	99	1
5	Eleode	99	1
6	Geocor	99	1
7	Sphe	99	1
8	Vespac	99	1
9	Vespul	99	1
10	Apidae	98	2
11	Coelio	98	2
12	Leiodi	98	2
13	LepiX	98	2
14	Rhynco	98	2
15	AntX	97	3
16	Nabid	97	3
17	Orthez	97	3
18	Phello	97	3
19	Scarab	97	3
20	Spheco	97	3
21	Agapos	96	4
22	Bembid	96	4
23	Cantha	96	4
24	Dialic	96	4
25	Flea	96	4
26	Polist	96	4
27	Cercer	95	5
28	Trachy	94	6
29	Trombi	94	6
30	Amara	93	7
31	Evylae	93	7
32	Osmia	93	7
33	Tortri	93	7
34	VespiX	93	7
35	Cnovae	91	9
36	Cicade	90	10
37	Forufa	90	10
38	Micari	80	20
39	FoX	79	21
40	Acridid	77	23
41	Elater	77	23
42	Geoder	77	23
43	Zacotu	76	24
44	Fosanq	75	25
45	Mirid	71	29
46	Diapri	70	30
47	Apheno	69	31
48	Aradid	66	34
49	Tapino	65	35

	Indicator Values (IV) Small Patch Types	Small	Intact
50	CaX	64	36
51	Lygaei	63	37
52	Pardosa	63	37
53	Polyde	62	38
54	Pristo	61	39
55	Spider	60	40
56	Notiop	59	41
57	Hparas	57	43
58	Bracon	55	45
59	Pteros	55	45
60	Bollma	50	50
61	CentiX	50	50
62	Chrysp	50	50
63	Pogono	50	50
64	Raphid	50	50
65	Sabaco	50	50
66	Scaph	50	50
67	Stenop	50	50
68	Tricop	50	50
69	Lasius	47	53
70	Gnapho	46	54
71	Beetle	43	57
72	Carabu	42	58
73	Cybaeu	42	58
74	Fopaci	41	59
75	Micryp	41	59
76	Leuron	39	61
77	Staph	39	61
78	Aleoch	38	62
79	WeeviX	38	62
80	Cmodoc	37	63
81	Antrod	36	64
82	Aphid	34	66
83	Noctui	33	67
84	Lithob	31	69
85	Taracu	28	72
86	Xystic	22	78
87	Philod	12	88
88	Fbeetl	11	89
89	Apoche	10	90
90	Coleop	10	90
91	Cymind	10	90
92	Hemero	10	9
93	HymnX	10	90
94	Ligidi	10	90
95	Meloid	10	90
96	MillX	10	90
97	MiteX	10	90
98	Nicrop	10	90

	Indicator Values (IV) Small Patch Types	Small	Intact
99	Pselap	10	90
100	Quediu	10	90
101	Thomis	10	90
102	Tipuli	10	90
103	Agulla	9	91
104	Aphodi	9	91
105	Geomet	9	91
106	Ichneu	9	91
107	Therid	9	91
108	Bdelli	5	95
109	Creoph	5	95
110	Ensife	5	95
111	Julid	5	95
112	Linyph	5	95
113	Pseudo	5	95
114	Tenthr	5	95
115	Cercop	4	96
116	Machil	4	96
117	Pityoh	4	96
118	Tachin	4	96
119	Geophi	3	97
120	Membra	3	97
121	Caecul	2	98

APPENDIX 2.

Site Description

The research area is located in US Forest Service (USFS) lands, in the Weiser and Council Districts of the Payette National Forest, and is situated within the Hornet Plateau subsection of the Blue Mountain Section in Western Central Idaho. The site spans a relatively warm and dry elevational range from 6000 to 7000 feet above sea level.

I established 5 transects at the Cuddy Mountain study area approximately 40 miles south west of the main Bear Creek and Indian Creek study area. Cuddy Mountain is a forested "mountain island" as defined by island biogeographic theory. The second study area was established in order to examine some of the precepts of the theory.

Cuddy Mountain

Cuddy Mountain is a biogeographic "mountain island" located approximately 50 miles south and west of Bear and Indian Creeks. Biogeographic theory states that true islands and biogeographic islands will have distinct biota from that of contiguous areas (MacArthur and Wilson 1967). On its west side Cuddy Mountain rises up from the east bank of the Hells Canyon of the Snake River. To the South, X creek, a tributary of the Snake River, separates Cuddy Mountain from similar forested mountains. On its east side, Cuddy Mountain climbs up from lowland grasslands managed for grazing. To the north, the mountain rises gradually from patchy forest and grassland. The forests on Cuddy are not contiguous with those of Bear and Indian Creek. At the time data was conducted (Summer and Fall 1994), study area forests on Cuddy Mountain were intact mature and old forests, and excepting fire control and some grazing) were not actively managed. These forests of mixed conifer were dominated by large, old

Ponderosa pine, an important seral component of Grand fir habitat types. The study area had similar slopes, aspects and elevations to those found in the Bear Creek and Indian Creek sites.

Stands and Patch Types

The study area is located in U.S. Forest Service (USFS) lands, in the Weiser and Council Districts of the Payette National Forest, and is situated within the Hornet Plateau subsection of the Blue Mountain Section in Western Central Idaho. The site spans a relatively warm and dry elevational range from 6000 to 7000 feet above sea level. Research was conducted in mixed conifer forests dominated by grand fir *(Abies grandis (Dougl.)Lindl.)*, ponderosa pine (*Pinus ponderosa Doug.exLoud*), and douglas-fir (*Pseudotsuga menziesii (Mirb.) Franco*), with engelmann spruce (*Picea engelmannii*), and western larch (*Larix occidentalis Nutt.*) serving as important secondary species (Steele et al. 1981; Barrett 1994).

Intact stands (100 hectares and larger) are dominated by a gappy over-story canopy of mature (greater than 100 years old) and old (greater than 200 years old) trees. Intact stands have well developed co-dominant and/or under-story and shrub layers. Except for sporadic grazing of domestic ungulates in managed and un-managed sites and periodic fire suppression activities, these forests have not been actively managed or roaded. Five intact stands are located in Indian Creek.

A natural patch stand (<10 hectares) is a small patch of forest near to but separate from a larger forest area. The natural patch is bounded on all sides by grass or shrub habitat types. Called "stringers" or fragments, one natural patch is included in the Cuddy Mountain study area.

Hypotheses

Due to geographical isolation despite similar habitat types, Cuddy Mountain arthropod biota will be distinct from that in Bear and Indian:

- Because Cuddy Mountain forests are isolated, more rare (found in less than 5 percent of the pitfalls) species will be present (MacArthur and Wilson 1967; Darlington 1943; Noonan 1988).
- More flightless or short distance dispersing species were expected as compared to long distance dispersers due to interior forest conditions in these intact patches (Lattin and Moldenke 1990).