AN ABSTRACT OF THE THESIS OF

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Title: Biodiversity in Managed Forests of Western Oregon: Species Assemblages in Leave Islands, Thinned, and Unthinned Forests.

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Deanna H. Olson | Richard A. Schmitz

Both leave islands, or green tree retention clusters, and thinning prescriptions have been proposed as alternative silvicultural strategies designed to sustain the structural and biological diversity of managed forests. However, the relationship of the physical structure of leave islands and thinned forests to their associated microclimates, flora, and fauna remain largely unknown. We evaluated habitat and biota after forest thinning from 600 to 200 trees per hectare with three sizes of leave islands. Specifically, we used analysis of variance, species occupancy pattern assessments, and community analysis methods to examine differences in habitat and vascular plant, arthropod, amphibian, and mollusk abundance and diversity with respect to thinning and leave island size in four western Oregon managed forest stands. We found multiple treatment effects of thinning and leave island size relative to microclimate and vascular plant diversity and ground cover. The microclimate and vascular plant species composition differed between thinned and unthinned forest while conditions within leave islands approximated conditions in unthinned forest. Proportions of exotic and early-successional species and species ground cover were higher in thinned forest than unthinned forest and higher in small leave islands than larger leave islands. Treatment effects on arthropod, amphibian, and mollusk density were mixed. Of 118 parameters analyzed, negative effects of thinning on faunal species were detected for five arthropod species, low-mobility arthropod captures, one salamander species, one salamander family (Plethodontidae), amphibian species richness, and one mollusk species. Of 83 parameters assessed, positive effects of leave island size were found for arthropod species richness, overall density, density within six functional group measures, and for six species groups. Treatment effects of leave island size were mixed for amphibians and mollusks with positive effects of leave island size for overall mollusk density, snail density, and density within three mollusk species groups. Indicator species analyses identified seven vascular plant and two arthropod species indicative of thinned forest, 0.2 ha and 0.4 ha leave islands. Assessments of species occupancy patterns revealed insights regarding the potential utility of managing the forest matrix for habitat heterogeneity. For example, 71 (19%) taxa occurred only in leave islands and 139 (37%) taxa occurred only in leave islands and unthinned forest. These patterns may indicate occurrences of rare species and do not necessarily indicate associations with these unthinned forest types. Community analyses highlighted the importance of addressing multiple spatial scales in forest management prescriptions by identifying distinct biotic assemblages occurring at forest type, study site, and mountain range scales. Our results suggest that leave islands may provide refugia for some low-mobility, ecologically sensitive species in managed forests of the Pacific Northwest.

Biodiversity in Managed Forests of Western Oregon:
Species Assemblages in Leave Islands, Thinned, and Unthinned Forests

by

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APPROVED:

Redacted for Privacy

Co-Major Professor, representing Wildlife Science

Redacted for Privacy

Co-Major Professor, representing Wildlife Science

Redacted for Privacy

Head of the Department of Fisheries and Wildlife

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Dean of the Graduate School

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CONTRIBUTION OF AUTHORS

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CHAPTER 1:

GENERAL INTRODUCTION

Forest lands comprise just over six percent of the global surface area and 29.6 percent of the total land area (FAO 2001) yet harbor nearly 65 percent of the world's terrestrial taxa (World Commission on Forests and Sustainable Development 1999). Population growth coupled with increasing demands on natural resources has generated concerns about the long-term sustainability of the world's forest resources. The forest resource demands of more than six billion global residents (US Census Bureau 2005) are supplied by a global forest land area of approximately 3.9 billion hectares (FAO 2001). Between 1990 and 2000, forest cover decreased by nearly 10 million ha (-0.26% annual rate of change; FAO 2001). In 2002, global forest resource consumption (woodfuel, industrial roundwood, and sawnwood) exceeded 3.7 billion m^3 (FAO 2004).

International concerns about population growth and sustainability are echoed in the United States. The US population of over 296 million (US Census Bureau 2005) consumed nearly 596 million m^3 of forest resources (FAO 2004) or 16% of global forest resource consumption. While nearly 25% of the total US land area is forested (FAO 2001), resource demands are not being met solely through domestic resource extraction. Rather, in 2002, nearly 7.5% of forest products consumed in the US were imported (FAO 2001).

Forest management paradigms are shaped by prevailing human objectives for forest stands and landscapes (Spies 1997). Current management paradigms are undergoing radical changes worldwide to ratify consumption-based approaches to sustainable forestry designs. Historically, forest management was a revenue-driven enterprise. Sustainable harvest levels were determined by tree growth and yield from economic standpoints (Haynes and Weigand 1997; Smith et al. 1997; Barnes et al. 1998). Forest management in the 21st century has undergone a paradigm shift away from this historical focus on resource extraction towards the broader, all-inclusive approach of ecosystem management (Kessler et al. 1992; Swanson and Franklin 1992; Grumbine 1994; Christensen et al. 1996). Conceptually, ecosystem management recognizes the complexity and interconnectedness of natural systems while acknowledging the social value of the intrinsic commodity resources. A central theme guiding this balancing act is the concept of sustainability. Among the principles of sustainability are the maintenance of ecological functions and biological diversity for future generations, evaluation and adaptation of social processes and governance structures, and integration and adaptability of ecological, economic, and social systems (Shannon and Antypas 1997). Thus, forest ecosystem management involves a precarious balance between maintaining ecosystem functions, processes, and biota and providing a constant source of wood production (Lélé and Norgaard 1996; Tappeiner et al. 1997a; Carey 1998; Lindenmayer and Franklin 2002).

Forest managers have developed a myriad of alternative silvicultural approaches to address concerns about this new view of forest sustainability. These include longer rotations (ecological vs. economic rotation age), uneven-aged management strategies, variable retention silvicultural prescriptions including structural retention methods such as aggregated and dispersed green tree retention, snag creation and retention, and management of the forest matrix.

Some of these alternative silvicultural strategies have been implemented on federal forest lands in the Pacific Northwest since the 1990's. For example, the 1994 Northwest Forest Plan introduced a comprehensive ecosystem management strategy for federal forest lands within the range of the northern spotted owl (*Strix occidentalis*; USDA and USDI 1994). A central component of the plan was a harvest guideline mandating structural retention during timber harvest on matrix land allocations. This guideline directed forest managers to permanently retain at least 15 percent of the green trees within each harvest unit. The plan specified that retained trees be both aggregated and dispersed. A second example of operational structural retention on Pacific Northwest forest lands is the Demonstration of Ecosystem Management Options Study on state and federal lands in Oregon and Washington. This study established a landscape-scale silvicultural experiment to test a broad range of green tree retention levels in both dispersed and aggregated spatial configurations (USDA 1996). The Augusta Creek landscape design (Cissel et al. 1998) provides a third example of sustainable forest management provided by a mix of rotations, harvest intensities, and frequencies matched to the natural disturbance regime. Conceptually, these examples of sustainable forest management strategies utilize innovative silvicultural approaches to address ecosystem management objectives. However, data supporting the operational effectiveness of these alternative silvicultural management approaches are few.

The USDI Bureau of Land Management (BLM) Density Management Study is an experimental study addressing the efficacy of some of these alternative silvicultural methods (Tappeiner et al. 1997b; Olson et al. 2002; Cissel et al. 2004). This study was established in 1994 at seven study sites in western Oregon. The study was designed to examine alternative forest thinning treatments to accelerate the development of late-successional habitat while simultaneously supplying timber for revenue. Sites were chosen based on forest age, forest structure, and several other criteria (Olson et al. 2002). These seven sites were thinned between 1997 and 2002 according to silvicultural prescriptions that specified the size, density, and configuration of forest treatments (Cissel et al. 2004). Study sites included unthinned controls (approximately 600 trees per hectare [tph]) and areas thinned to three densities: 100 tph, 200 tph, and 300 tph. Leave islands and patch cuts of three sizes (0.1, 0.2, and 0.4 hectare [ha]) were created within the thinned forest areas.

The concept of leave islands within this thinned matrix addressed forest structural heterogeneity and biodiversity concerns. A mosaic of forest structures was an intended outcome of the BLM Density Management Study because its objective was to accelerate development of old forest conditions which are similarly a mosaic of structures (Tappeiner et al. 1997a). Leave islands also may benefit biodiversity in several ways. Leave islands may be one such consideration to mitigate adverse effects of timber harvest because such aggregated tree retention can perform multiple roles relative to species' habitat in managed forests. First, legacy structural habitat features characteristic of mature forests can be preserved within leave islands in harvested stands (Lindenmayer and Franklin 2002). Such features include large dead wood, wolf trees, minority tree species, and complex forest structure (Franklin et al. 1981). Plant and animal species from multiple taxonomic groups are strongly associated with these mature forest structures (Marcot 1997), including arthropods (Parsons et al. 1991; Heyborne et al. 2003), amphibians (Pough et al. 1987; Carey 1989; Petranka et al. 1993; Blaustein et al. 1995; Petranka 1998), mollusks (Schumacher 1999; USDI 1999a), mammals (Carey 1989), birds (Carey 1989), fungi (Luoma 1988; Colgan et al. 1999), bryophytes (Lesica et al. 1991), lichens (Lesica et al. 1991; Neitlich and McCune 1997; Peck and McCune 1997), and vascular plants (Halpern 1988, 1989; Halpern and Spies 1995; Jules 1998; Halpern and McKenzie 2001). Second, leave islands also may ameliorate microclimate changes resulting from timber harvest and maintain forest interior conditions, including light, moisture, temperature, and humidity regimes (Barnes et al. 1998). Maintaining pockets of forest interior conditions within a managed forest matrix might prevent extirpation of forest-associated species, including those with ties to mature and old-growth forests. Leave islands may function as species lifeboats in remnant habitats or as stepping stones for dispersal by providing connectivity (Franklin et al. 1997; Lindenmayer and Franklin 2002). The lifeboat role of reserved habitat patches may apply particularly to low-mobility taxa or taxa sensitive to fine-grained habitat gradients. Species with limited capacity for movement or with extreme physiological limitations might be incapable of dispersing across an inhospitable harvested forest matrix (Gibbs 1998a, 1998b; Lindenmayer and Franklin 2002).

In the BLM Density Management Study, both forest structure and known biota were considerations in designation of leave islands. Leave islands were often placed over legacy forest elements (e.g., wolf trees, hardwood trees) to retain and enhance structural diversity. Similarly, at some sites, leave islands were placed over known locations of species diversity or rare species occurrence (i.e., vascular plant, lichen, bryophyte, fungi, mollusk species), to retain apparent "hotspots" of biota (Neitlich and McCune 1997; Olson et al. 2002).

Several rationales were used to determine the sizes of leave islands implemented in this BLM study. First, gap and leave island sizes were matched. Data on naturally-occurring old-forest canopy gaps show they occur in a range of sizes, including areas of 0.1-0.4 ha. Gaps resulting from small-scale (0.2-1.0 ha; Spies and Turner 1999) fires create spatial heterogeneity in old-growth forests. Hence, after gap formation, subsequent young forest patches would emerge following succession and species composition of such islands are relevant considerations. Also, minimum size recommendations greater than 0.12 ha have been made for forest "clumps" based on the poor growth form and slow regeneration growth resulting from edge effects permeating forest islands below this size threshold (Oliver and Larson 1996). One study documented the size of diversity hotspots for lichens to occur in 0.4 ha patches (Neitlich and McCune 1997). Small patch sizes are particularly relevant for low-mobility species which may have critical life history functions or subpopulations at small spatial scales. In this BLM study, size constraints of leave islands also stemmed from the treatment unit area per study site, and the complex layout of multiple leave islands, clearcut gaps, and riparian buffers within a thinned forest matrix (Olson et al. 2002; Cissel et al. 2004).

In a retrospective study, we examined the effect of combined dispersed and aggregated green tree retention on habitat components and species in young managed forests. We utilized four of the existing Density Management Study sites, including Bottomline (43°46'20" N, 123°14'11"W) and Green Peak (44°22'00"N, 123°27'30" W) in the Coast Range, and Delph Creek (45°15'56"N, 122°9'33" W) and Keel Mountain (44°31'41" N, 122°37'55" W) in the Cascade Range. We investigated the response of habitat conditions and multiple taxa to moderate thinning and to leave islands of three sizes embedded in the thinned forest stands, ages 50-70 years. Specifically, we compared the microclimate and abundance and diversity of vascular plants, arthropods, amphibians, and mollusks within five types of forest: unthinned forest (approximately 600 tph), thinned forest (approximately 200 tph), and leave islands of three sizes (0.1, 0.2, and 0.4 ha) embedded in the thinned forest matrix.

Our analyses address several questions. First, we compare the habitat elements and biota between thinned and unthinned forest units to document the response of these forest components to dispersed tree retention. Simply, does thinning of young managed stands to a moderate level of 200 tph affect habitat, species abundances, and species diversity measures? Second, we fold leave islands into the analyses to address the potential effect of aggregated tree retention within a matrix of dispersed green trees on forest habitat conditions or components of biotic diversity. In these second analyses, our null hypothesis is that there is no difference in forest structure or species abundance or diversity with forest type (thinned, unthinned, and three leave island sizes within the thinned matrix). We further address the role of these five forest types for biota by conducting Indicator Species Analysis, Blocked Multi-Response Permutation Procedure, and by documenting species occupancy by forest type. Are there species or species-groups that are indicators of thinned forest, leave islands, or unthinned forest? Lastly, we characterized environmental drivers shaping species assemblages in five forest types using the community analysis method, nonmetric multidimensional scaling. Chapter 2 describes these analyses and integrates our findings across analyses. This is the first study to provide such a comprehensive analysis of multiple taxa relative to combined dispersed and aggregated green tree retention.

A research synthesis and a discussion of management implications of our findings are presented in Chapter 3. The central theme of this chapter is an evaluation of joint thinning and leave islands as stand-level matrix management tools for achieving forest sustainability objectives. Results from this study demonstrate the utility of an integrated silvicultural approach for sustaining forest biodiversity.

CHAPTER 2:

BIODIVERSITY IN MANAGED FORESTS OF WESTERN OREGON: SPECIES ASSEMBLAGES IN LEAVE ISLANDS, THINNED, AND UNTHINNED FORESTS

INTRODUCTION

Forest management in the 21st century has undergone a paradigm shift away from a focus on resource extraction towards the broader, all-inclusive approach of ecosystem management and environmental sustainability (Kessler et al. 1992; Swanson and Franklin 1992; Grumbine 1994; Christensen et al. 1996). Conceptually, ecosystem management recognizes the complexity and interconnectedness of natural systems while acknowledging the social value of the intrinsic commodity resources. Thus, forest ecosystem management and sustainability involve a precarious balance between maintaining ecosystem functions, processes, and biota and providing a constant source of wood production (Lélé and Norgaard 1996; Tappeiner et al. 1997a; Carey 1998).

Forest managers have a myriad of silvicultural methods for integrating and sustaining these diverse forest resource objectives during timber harvest, including uneven-aged strategies such as partial cutting and structural retention (e.g., Lindenmayer and Franklin 2002). These management strategies represent a significant departure from traditional even-aged management and its intensive timber harvesting methods such as clearcutting which removed entire stands during harvest (Tappeiner et al. 1997a). New forest management strategies are notable in that their focus is not only on what is removed during timber harvest but also on what is left behind in the managed forest matrix (Lindenmayer and Franklin 2002).

Sustainable "matrix management" involves careful silvicultural prescriptions designed to balance an array of management objectives, including maintaining habitat for biodiversity. Crucial forest structures, conditions, and processes can be retained by uneven-aged management techniques, variable retention harvest systems, extended rotations or cutting cycles, and structural retention (USDA and USDI 1994; Franklin et al. 1997; Smith et al. 1997; Lindenmayer and Franklin 2002) to benefit multiple species groups (e.g., Carey et al. 1999a, b). Green tree retention within harvested forest stands is one such structural retention strategy designed to maintain both floral and faunal components of native forests (Franklin and Spies 1991; Franklin 1993). Retained trees can be either spatially dispersed or aggregated (i.e., leave islands or patch reserves).

Thinning to result in spatially dispersed structures can have both positive and negative effects on resident plant and animal species. Thinning can alter the abundance and composition of multiple taxonomic groups, including amphibians (Dupuis 1995, 1997; Aubry 2000; Grialou et al. 2000), arthropods (Spence et al. 1997; Lindo and Visser 2004), birds (Chambers et al. 1999), small mammals (Carey 2000), fungi (Amaranthus et al. 1990; O'Dell et al. 1992; Amaranthus et al. 1994), lichens (Peterson and McCune 2001), and vascular plants (Bailey and Tappeiner 1998; Bailey et al. 1998; Thysell and Carey 2001). Species associated with early-successional or disturbed habitats may benefit from the structural changes and habitat conditions produced by forest thinning, while adverse effects may be detected for taxa associated with late-successional or undisturbed habitats. Maintaining the persistence of species adversely affected by forest thinning may require special consideration during timber harvest.

Leave islands may be one such consideration to mitigate adverse effects of thinning because such aggregated tree retention can perform multiple roles relative to species' habitat in managed forests. First, legacy structural habitat features characteristic of mature forests can be preserved within leave islands in harvested stands (Lindenmayer and Franklin 2002). Such features include large dead wood, wolf trees, minority tree species, and complex forest structure (Franklin et al. 1981). Plant and animal species from multiple taxonomic groups are strongly associated with these mature forest structures (Marcot 1997), including arthropods (Parsons et al. 1991; Heyborne et al. 2003), amphibians (Pough et al. 1987; Carey 1989; Petranka et al. 1993; Blaustein et al. 1995; Petranka 1998), mollusks (Schumacher 1999; USDI 1999a), mammals (Carey 1989), birds (Carey 1989), fungi (Luoma 1988; Colgan et al. 1999), bryophytes (Lesica et al. 1991), lichens (Lesica et al. 1991; Neitlich and McCune 1997; Peck and McCune 1997), and vascular plants (Halpern 1988, 1989; Halpern and Spies 1995; Jules 1998; Halpern and McKenzie 2001). Second, leave islands also may ameliorate microclimate changes resulting from timber harvest and maintain forest interior conditions, including light, moisture, temperature, and humidity regimes (Barnes et al. 1998). Maintaining pockets of forest interior conditions within a managed forest matrix might prevent extirpation of forest-associated species, including those with ties to mature and old-growth forests. Leave islands may function as species lifeboats in remnant habitats or as stepping stones for dispersal by providing connectivity (Franklin et al. 1997; Lindenmayer and Franklin 2002). The lifeboat role of reserved habitat patches may apply particularly to low mobility taxa or taxa sensitive to fine-grained habitat gradients. Species with limited capacity for movement or with extreme physiological limitations might be incapable of dispersing across an inhospitable harvested forest matrix (Gibbs 1998a and 1998b; Lindenmayer and Franklin 2002).

The value of retaining both spatially dispersed and aggregated green trees has come to the forefront of forest management in the U.S. Pacific Northwest's Douglas-fir region as persistence of rare species has been integrated into forest management plans. Many of these species are sensitive to the physical disturbance and resulting habitat alterations associated with timber harvest. While traditional management approaches centered on intensive forestry practices designed to maximize wood production and timber harvest, the 1994 Northwest Forest Plan introduced an ecosystem management approach on nearly 10 million hectares of federal forest lands (USDA 1993; USDA and USDI 1994). Central to the Northwest Forest Plan was the allocation of 80% of the federal land base to forest reserves. This management approach represented a major paradigm shift from one dominated by timber production to one emphasizing long-term forest sustainability. However, fine-scale strategies to retain multiple forest resources including a diverse biota were applied to federal lands designated for regeneration timber harvests. Biota with limited distributions and dispersal capabilities were a particular concern. Rare old-forest dependent taxa such as fungi, lichens, bryophytes, vascular plants, terrestrial mollusks, amphibians, and arthropods were not well-protected by large reserves that were not coincident with the species' patchy occurrences (USDA and USDI 1994, 2001). In 2003, 304 of these species remained of concern, 179 of which were known from less than 20 sites, and most of which could be characterized as relatively low mobility organisms (USDA and USDI 2003). Strategies to maintain these rare species generally entailed the creation of protected areas at species localities (e.g., protection buffer provisions [USDA and USDI 1994] or species management recommendations [USDA and USDI 2003], often implemented by the creation of leave islands 0.1 ha or greater in size. The role of small-scale leave islands for such taxa and their habitats warrants investigation. Due to extensive forest thinning practices planned for the young managed stands in this landscape over the next several decades, the value of leave islands in thinned stands is a salient information need.

In a retrospective study, we examined the efficiency of combined dispersed and aggregated green tree retention for species persistence in managed forests. Specifically, we investigated the response of habitat conditions and multiple taxa to moderate thinning and to leave islands of three sizes embedded in the thinned forest stands, ages 50-70 years. Habitat responses we examined included measures of microclimate (relative humidity, ambient temperature, and soil temperature) and forest structure (downed wood volume, canopy closure, trees per hectare, basal area, and diameter at breast height). Taxa we examined included dispersal-limited species potentially sensitive to changes in these habitat conditions: vascular plants, arthropods, terrestrial amphibians, and terrestrial mollusks. We characterized the microclimate, forest stand structure, and biota in five types of forest: unthinned forest, thinned forest and three sizes of circular leave islands (0.1 ha, 0.2 ha, and 0.4 ha).

Our approach to examining treatment effects of thinning and leave island size was multi-tiered. Using analysis of variance, we compared habitat and biota: 1) between thinned and unthinned forest; 2) among all five forest types; and 3) among three sizes of leave islands. Due to the species richness of vascular plants and arthropods, we also examined treatment effects on functional groups in these two taxonomic groups (i.e., association with forest seral stage or feeding groups). Using indicator species analysis and blocked multi-response permutation procedure analyses, we examined whether species assemblages were associated with each of the forest types. To incorporate rare species into our assessment, we examined species occurrences in the five forest types, tallying species richness of those only occurring in either thinned or unthinned forest types.

In addition, we examined vascular plant, arthropod, amphibian, and mollusk assemblages using multivariate community analysis methods to identify the primary environmental variables structuring these communities. We expected many plants and arthropods associated with early seral conditions to respond positively to the predicted increase in light and temperature in the thinned forest. Conversely, we expected many arthropod, amphibian, and mollusk species associated with late-seral or interior forest conditions to respond negatively to thinning and positively to areas of contiguous forest.

METHODS

Study Sites

We conducted our study in the Coast and Cascade Ranges of northwestern Oregon within the *Tsuga heterophylla* (western hemlock) vegetation zone (Franklin and Dyrness 1988). The maritime climate is relatively wet and mild with widely variable conditions depending on latitude, elevation, and location relative to mountain ranges (Franklin and Dyrness 1988). Annual precipitation occurs primarily during winter and averages 150-300 cm.

Four study sites were chosen from among the seven sites implemented for the U.S. Department of Interior Bureau of Land Management Density Management Study (Tappeiner et al. 1997b; Olson et al. 2002; Cissel et al. 2004). The Density Management Study was designed to examine alternative forest thinning treatments to accelerate late-successional habitat development while simultaneously generating timber for income. These four naturally-regenerated, 50-70 year-old stands were thinned between 1997 and 2000 according to silvicultural prescriptions that controlled for size, density, and configuration of forest treatments (Cissel et al. 2004). Each of these sites included unthinned controls (approximately 600 trees per hectare [tph]) and areas thinned to a moderate density, 200 tph. This density has been considered as an operational thinning prescription for these sites. Leave islands of three sizes (0.1, 0.2, and 0.4 hectare [ha]) were created within the 200 tph thinned area. Leave islands were not located randomly but were instead fit into available openings and were often placed over legacy forest elements (e.g., wolf trees, hardwood trees) or over known locations of species diversity (i.e., lichen species).

Site selection was not random but was based on two main criteria: 1) accurate implementation of 200 tph thinning treatments (i.e. thinned to less than or more than 200 tph) and 2) availability of all three leave island sizes in the 200 tph thinning treatment. The four study sites were managed by the Salem and Eugene BLM Districts and included Bottomline (43°46'20" N, 123°14'11"W) and Green Peak (44°22'00"N, 123°27'30" W) in the Coast Range, and Delph Creek (45°15'56"N, 122°9'33" W) and Keel Mountain (44°31'41" N, 122°37'55" W) in the Cascade Range (Figure 2.1). We examined five types of forest: unthinned forest (600 tph), moderately-thinned forest (200 tph), and three sizes of circular leave islands (0.1, 0.2, and 0.4 ha) embedded within the moderately-thinned forest. Three replicates (study units) of each type of forest were randomly selected at each of the four study sites (n=60 study units).

Data Collection

Data for habitat and biota were collected within a 20 x 20 m sampling area established at the center of each study unit (Figure 2.2). Each sampling area was comprised of four 100 m^2 (5 x 20 m) parallel transects, with transects aligned upslope. Habitat data corresponding to each study unit included geographic position (elevation, latitude, mountain range), topography (slope, aspect), forest stand

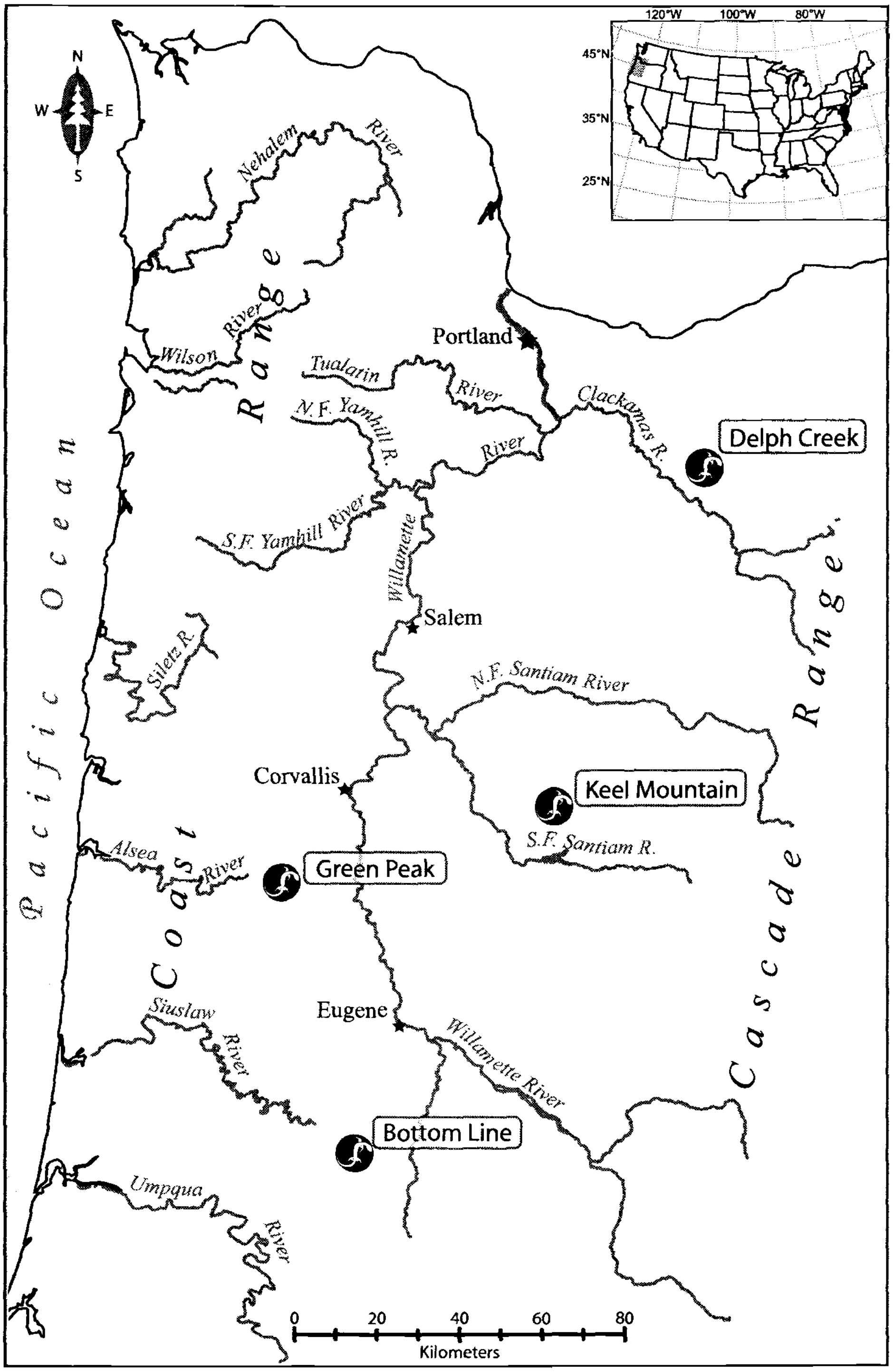

Figure 2.1. Location of four study sites within the study area of western Oregon. Mountain ranges, rivers, and major cities are displayed.

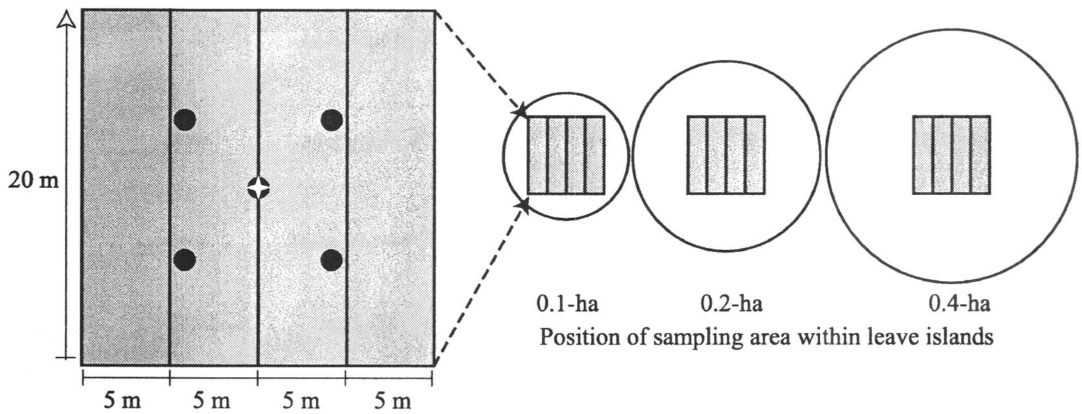

Figure 2.2. Schematic of sampling area showing four parallel transects sampled for vascular plants, amphibians, and mollusks. Five arthropod sampling plots (•) and one microclimate sampling point (+) are displayed.

structure, microclimate, heat load index (McCune and Keon 2002), soil moisture, substrate, and downed wood volume. Biotic data included abundance and diversity measures for vascular plants, arthropods, terrestrial amphibians, and terrestrial mollusks.

Forest stand structure data for each sampling unit included canopy closure (percentage of 20 sampling points, five sampling points per transect using a vertical densitometer) and tree diameter at breast height (dbh; cm) for all trees in each sampling unit. We used these data to compute tree density (trees per hectare; tph) and basal area per ha (conifers and hardwoods; m^2/ha) per sampling unit. Microclimate data were collected during both spring and summer sampling seasons using automated data loggers (A.R. Harris GPSE Ltd. brand) to record ambient temperature, soil temperature, and relative humidity. One data logger was placed at the center of each study unit for a 10-day period in the spring during amphibian and mollusk sampling and in the summer during arthropod sampling. Data were collected simultaneously at all study units at a study site. We used input variables of slope, aspect, and latitude to derive an index of heat load for each study unit with the following equation: $\textit{heat load index} = \frac{1-\cos(\Theta-45)}{2}$ where Θ=aspect in degrees east of north (McCune and Keon 2002). This index ranges from 0 (coolest, northeast slope) to 1 (warmest, southwest slope). We measured soil moisture during both spring and summer sampling seasons by taking four samples of mineral soil from each study unit. Soil samples weighing approximately 60 g were taken at 10 cm depth and 2 m from the center of each sampling area in the direction of each sampling area corner. Soil moisture was determined using gravimetry with oven-drying in which each wet soil sample was weighed, dried in a 105°C oven, then re-weighed (Reynolds 1970a and 1970b). The gravimetric moisture content, or wetness (*w*), was then calculated using the equation: $w = \frac{(\textit{soil mass}_{wet} - \textit{soil mass}_{dry})}{\textit{soil mass}_{dry}}$. We used these four calculated *w* values to derive an average soil moisture value for each sampling unit.

Forest floor substrate was assessed in four 5 x 5 m sampling plots within two nonadjacent transects that were randomly chosen (n=eight per study site per study unit). We recorded the percent cover class (1-5%, 6-33%, 34-66%, and 67-100%) for each of 14 ground substrate categories, including total herbaceous cover (less than 10 cm in height), total shrub cover (greater than 10 cm in height), total moss cover, fallen epiphyte, intact stump or snag, decayed stump or snag, live tree bole, small (less than 5 cm diameter) or decomposed litter (including bark chip piles), intact coarse downed wood (greater than 5 cm diameter), decayed coarse downed wood (greater than 5 cm diameter), riparian or aquatic influence, exposed rock (rock greater than 7 cm diameter), exposed mineral soil, and other atypical substrates (e.g. deep concavity in ground, locally steep slope, root wad clump). Downed wood was classified by increasing degree of decay; decay classes 1 and 2 were defined as intact while decay classes 3, 4, and 5 were defined as decayed (after Maser et al. 1979; Maser et al. 1988). We computed the average ground cover for each of the 14 substrate categories using the assessments from the four sampling plots within each study unit.

Down wood surveys recorded pieces of dead and down wood within each of two nonadjacent transects per sampling area. Tallies of wood pieces measuring at least 1 m in length and 10 cm in diameter were recorded by type of piece (log, stump, snag, or rootwad), midpoint diameter, length (logs and rootwads) or height (stumps and snags), species, and decay class (Maser et al. 1979; Maser et al. 1988). Pieces of wood were recorded only if at least one-half (at least 0.5 m of length for logs and rootwads, at least 5 cm of diameter for stumps and snags) was contained within the sampled transect. Surveyors made visual estimates of the diameter and length or height of four pieces of downed wood then measured the diameter and length or height of every fifth piece of downed wood. These validation measurements were then used to compute a correction factor for each surveyor by comparing the surveyor's estimated dimensions with the measured dimensions for each fifth piece of wood (Hankin and Reeves 1988). This correction factor was used to adjust the dimensions of the visually estimated downed wood. These dimensions were then used to compute the estimated volume (m^3) of downed wood within each transect. We used this computed volume to calculate the estimated density (m^3/m^2) of downed wood per transect. These estimates were used in subsequent statistical analyses.

We conducted vascular plant sampling in two randomly assigned, nonadjacent transects, using a modified Daubenmire cover class method during Summer 2001 (Daubenmire 1959; USDI 1998). Along each vascular plant transect, eight rectangular quadrats were established using 2.5 x 5 m sampling frames. All vascular plants observed within each quadrat were identified to species (Hitchcock and Cronquist 1973; Halse, pers. comm.). For each species, we recorded percent ground cover class (1-5%, 6-33%, 34-66%, or 67-100%). Each plant species was then categorized within three sets of functional groups, including plant origin (native or exotic), seral class (early- or late-successional), and vertical stratum (herb, shrub, or tree; USDA NRCS 2004; Pabst, pers. comm.; Vance, pers. comm.).

Arthropods were sampled by collecting five, circular, 1m^2 samples of all forest floor litter and the top 1 cm of forest soil from each sampling area during Summer 2002. One sample was taken from the center of each study unit and additional samples were taken 5 m from the center in the direction of each sampling area corner. Arthropods were extracted from litter samples using Berlese-Tullgren funnels (Brydon and Fuller 1966), then identified to the finest possible taxonomic level (Parsons et al. 1991; Arnett 2000; Moldenke, pers. comm.). Each arthropod taxon was then categorized within three sets of functional groups, including mobility classes (low, medium, or high), associations with forest seral stage (early- or late-successional), and feeding groups (plant sucker, plant chewer, shredder, fungivore, detritivore, xylivore, micropredator, macropredator, parasitoid, cadaver feeder, dung feeder, and unknown; Parsons et al. 1991; Moldenke, pers. comm.).

Amphibian and mollusk sampling was conducted on the remaining two nonadjacent transects in each sampling area. We used garden claws to search all substrate and cover objects within two 5 x 20 m belt transects per sampling area during Spring 2002. Substrate was searched to a depth of 3-5 cm. Captures were identified to species (amphibians: Leonard et al. 1993, Heyer et al. 1994, Corkran and Thoms 1996, USDI 1999b; mollusks: Schumacher 1999, USDI 1999a, Hohenlohe, pers. comm.).

Data Analyses

Treatment Effects of Thinning and Leave Islands-

We used analysis of variance to test whether mean habitat or biotic measures differed between and among forest types ($\alpha<0.10$; SAS version 9.1, SAS Institute 2004). We applied the Shapiro-Wilk statistic to test all data for normality. Data with unequal variances or non-normal distributions were transformed using a natural log (x+1) transformation (Ramsey and Schafer 2002). Measures that could not be adequately transformed were not analyzed. The statistical design involved two treatments applied at each of the four study sites. The first, a forest density treatment (hereafter, whole plot) had two levels: thinned and unthinned. These two levels were the statistical “whole plots”. The second, a leave island treatment, was applied only within the thinned whole plot and had three levels: 0.1 ha, 0.2 ha, and 0.4 ha leave islands. We used site as a blocking factor for all analyses.

Our first research question examining treatment effects of thinning on habitat and biota was analyzed as a randomized complete block design (PROC GLM procedure, SAS Institute 2004). Treatment means were calculated using the three replicate sampling units of the thinned and unthinned whole plots at each site with the comparison occurring at the whole plot level (n=8). We refer to the analysis of the second research question comparing habitat and biotic responses among all five types of forest using a modified split-plot as an integrated analysis. Since this study design involved a leave island treatment nested only within the thinned whole plot treatment, the comparison among the three leave island sizes, thinned, and unthinned sampling units occurred at the split-plot level (n=20; PROC MIXED procedure, SAS Institute 2004). Means were calculated using the three sampling units of each forest type. Finally, we conducted a focused analysis of the treatment effect of leave island size analyzed as a generalized randomized block design (PROC GLM procedure, SAS Institute 2004). This analysis compared treatment means of the three sizes of leave islands nested within the thinned whole plot (3 replicates x 3 leave islands sizes x 4 sites; n=36). For integrated and leave island analyses indicating differences in at least two of the treatment means, pairwise comparisons were then conducted to determine which pairs of treatment means were different (α=0.10). We used Bonferroni adjusted p-values to account for multiple comparisons and to control experiment-wise error.

These three statistical approaches differed in several ways. Each analysis used different sample sizes, calculations of treatment means, and different subsets of the data as a result of tests of normality. Further, the integrated analyses utilized a user-specified covariance matrix which assigned a common correlation to all sampling units within the thinning treatment at each site. Thus, neither the thinned-unthinned analysis nor the focused leave island analysis was redundant to the integrated analysis because the underlying data differed. We compared concurrence of results across analysis approaches to highlight differences in findings.

Microclimate analyses included comparing treatment means for average, minimum, maximum, average daily minimum, average daily maximum, and range of relative humidity, ambient temperature, and soil temperature (Chen et al. 1993). Additional habitat analyses examined measures of soil moisture and measures of forest stand structure, including canopy closure, trees per hectare, average diameter at breast height, and basal area per hectare.

Vascular plant analyses included measures of species richness, species diversity, and percent ground cover for individual species and for the three sets of functional groups, including plant origin, seral class, and stratum. Analyses for arthropods, amphibians, and mollusks compared overall density, density of individual species and some species groups, and measures of species richness and species diversity. For arthropods, we also compared treatment means for densities of the three sets of functional groups, including mobility classes, associations with forest type, and feeding groups.

Analyses of individual species were constrained by species abundances since most species we censused were extremely rare (Appendices A and B). Occupancy varied across forest types and study sites, restricting the analyses to the more common taxa. Individual arthropod, amphibian, and mollusk species were selected for analysis by their abundance. Species with more than 30 overall captures for fauna and more than 0.5% average ground cover for vascular plant species were analyzed.

Indicator Species Analyses-

We used indicator species analysis (ISA) to characterize species assemblages characteristic of each of the five types of forest. ISA describes how well each species differentiates among groups (Dufrene and Legendre 1997). Indicator values (IV) are calculated for each species within each group by combining information about the concentration of species abundance and faithfulness of occurrence in a particular group. Indicator values range from zero (no indication) to 100 (perfect indicator). A perfect indicator for a particular group is present in all sampling units for the group and occurs exclusively in that group. ISA produces indicator values for all species in a group based on the standards of a perfect indicator. The statistical significance of indicator values was tested using a Monte Carlo randomization with 1000 permutations. All species data (including common and rare species) was used in ISA analyses for each taxon. Taxa not identified to the species level were collapsed to the genus or family level (hereafter, species group), summed, then analyzed (Appendices A and B). All community analyses were conducted using PC-ORD version 4.27 (McCune and Mefford 1999).

Blocked Multi-Response Permutation Procedure Analyses-

Blocked multi-response permutation procedure (MRBP) is a non-parametric technique providing a multivariate test of differences between *a priori* groups (Mielke 1984; Mielke and Berry 2001). After blocking by site, we used MRBP with a Euclidean distance measure to test the null hypothesis of no community differences among the five groups of interest: unthinned forest, thinned forest, and 0.1 ha, 0.2 ha, and 0.4 ha leave islands. All species data was used in MRBP analyses for each taxon; thus, both common and rare taxa were incorporated in analyses. Taxa not identified to the species level were collapsed to the genus or family level (hereafter, species group), summed, then analyzed (Appendices A and B).

Occupancy Patterns-

Species occupancy within the five forest types also was assessed in order to gauge patterns among all species sampled, including rare species not analyzed statistically. We tallied species richness per taxon per forest type (Appendices A and B) and qualitatively compared: 1) species occurring only in thinned forest; 2) species occurring only in thinned forest and leave islands; 3) species occurring only in unthinned forest; 4) species occurring only in unthinned forest and leave islands; 5) species occurring only in leave islands; and 6) species occurring in thinned, unthinned, and leave island forest types. Insights into the value of habitat heterogeneity for rare species might be gained if they were to occur in categories 2, 3, 4, 5, or 6.

Community Analyses-

We used non-metric multi-dimensional scaling (NMS) to ordinate sample units in species space to provide a graphical representation of vascular plant, arthropod, amphibian, and mollusk community relationships with environmental variables (Kruskal 1964; Mather 1976). Correlations between ordination axes and environmental variables also were examined to determine the important drivers of community structure and composition for each taxonomic group (McCune and Grace 2002). We used the "slow-and-thorough" autopilot mode of NMS with the Sørensen distance measure and random starting configurations. Final stress for the best of 40 runs with real data was evaluated with a Monte Carlo test of significance using 50 runs with randomized data to assess whether NMS was extracting stronger axes than expected by chance alone. Final instability was assessed by examining scree plots showing stress versus iteration number. Joint plot overlays were used to display environmental variables on the ordination based on linear correlations (Pearson's r) and rank correlations (Kendall's tau) of the variables with the ordination axes. The coefficient of determination between distances in the ordination space and distances in the original n-dimensional space using Sørensen distances represented the variance (r^2) accounted for by each ordination axis. Ordinations were then rigidly rotated to maximize the loading of the strongest gradients in community variation on a single axis.

We methodically and sequentially inspected all species and environmental data matrices prior to conducting community analyses to determine if any data transformations were necessary. Specifically, we log-transformed variables with skewness greater than one or ranging over an order of magnitude, deleted rare species occurring in less than 5% of sample units, and deleted outlying data points with standard deviations greater than 3.0 (McCune and Grace 2002). Such data adjustments of community data matrices are often performed to improve statistical assumptions of normality, linearity, or homogeneity of variance (McCune and Mefford 1999). For the species data matrices, we deleted all rare species occurring in less than 5% of sample units to reduce noise in the data set. Next, we log-transformed species data columns with a skewness greater than 2.0 and/or order of magnitude difference between the minimum and maximum values.

RESULTS

Forest stand structure and microclimate data showed a range of values across all sampling units. Elevation ranged between 290 and 756 m. Ground slope ranged from 0 to 54%. Canopy closure ranged from 20 to 100%. Average dbh ranged from 32.5 to 70.4 cm. Trees per hectare ranged from 74 to 744. Total basal area ranged from 12 to 84 m^2/ha with conifer basal area ranging from 12 to 84 m^2/ha and hardwood basal area ranging from 0 to 12 m^2/ha. Downed wood density ranged from 0.0015 to 0.2573 m^3/m^2. Microclimate data values ranged from 10.1 to 35.9°C for ambient temperature, from 14.5 to 21.5°C for soil temperature, and from 63 to 100% for relative humidity. Soil moisture data values ranged from 9.3 to 27.1%.

We identified a total of 120 vascular plant species: 83 herbaceous species, eight subshrubs, 20 shrubs, and nine trees (Appendix A). Of these, 104 were native species, 12 were exotic, and four were of unknown origin. Finally, 62 were late-successional species, 57 were early-successional species, and one was unknown. *Polystichum munitum* (Western swordfern) was the most abundant species and comprised 15.7% of all ground cover. Treatment effects were examined for 26 vascular plant species (Figure 2.3a), two diversity measures, and measures of percent ground cover within three functional groups (three stratum classes, two origin classes, and two associations with forest successional stages; Table 2.1).

In soil litter samples, we captured 30,447 arthropods within 289 taxa (Appendix B). *Geophilomorpha* (soil centipede) was the most abundant species group with 2,982 captures (9.8% of captures). Treatment effects were examined for 80 arthropod species (Figure 2.3b), two diversity measures, total arthropod density, and density within three functional groups (three mobility classes, eleven feeding groups and two associations with forest condition; Table 2.1).

We captured 218 amphibians of seven species (Appendix B). *Ensatina eschscholtzii* (Ensatina) was the most abundant species with 129 captures across all treatments (59.2% of captures). Treatment effects were examined for three species (Figure 2.3c), the family Plethodontidae, total amphibian density, and two diversity measures (Table 2.1).

We captured a total of 3,608 mollusks of 12 taxa (10 species and 2 species groups; Appendix B). *Haplotrema vancouverense* (robust lancetooth) was the most

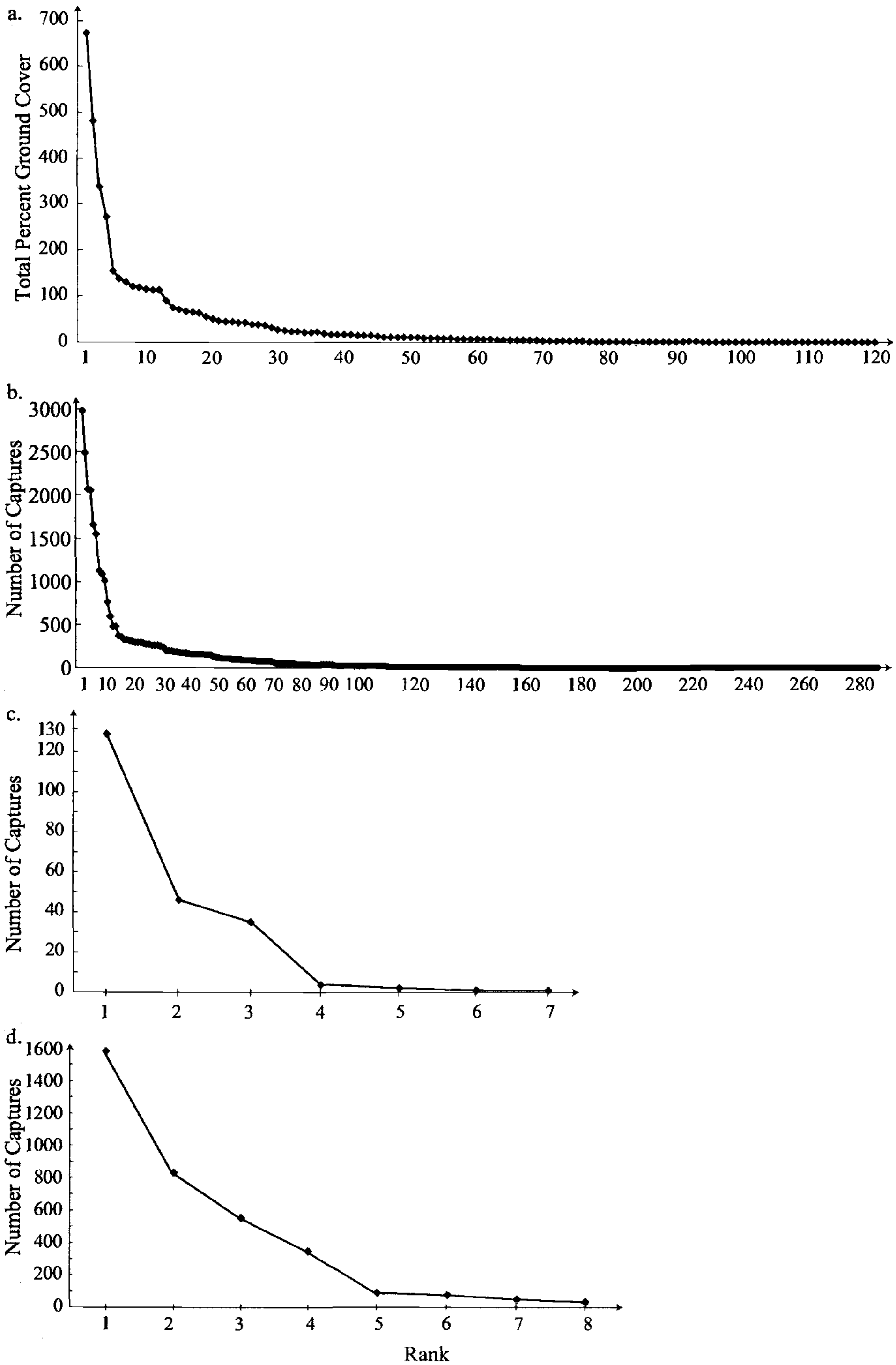

Figure 2.3. Rank abundance curves for a) vascular plants, b) arthropods, c) amphibians, and d) mollusks. Species names, ranks, taxonomic classifications, functional group assignments, site occurrences, and forest type occurrences are listed in Appendices A and B.

Table 2.1. List of all ANOVA results (p-values) for habitat and biota, including thinned vs. unthinned forest analyses, integrated analyses (simultaneous comparison of all five types of forest), and leave island analyses. Forest types are abbreviated as follows: T=thinned forest, S=small (0.1 ha) leave islands, M=medium (0.2 ha) leave islands, L=large (0.4 ha) leave islands, and U=unthinned forest. Direction of treatment effects (Dir.) indicated for all significant analyses ($p<0.10$). Analyses not meeting ANOVA assumptions indicated with 'X'. For vascular plant analyses, * indicates percent of total vascular plant ground cover.

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	*p*	**Dir.**	*p*	**Dir.**	*p*	**Dir.**
HABITAT						
Relative Humidity (%):						
Spring average	0.0073	T<U	0.0208	T<L; T<U; S<L	0.0547	S<L; M<L
Spring minimum	0.0253	T<U	0.0072	T<U; S<U; M<U	0.0245	S<L; M<L
Spring maximum	0.3910		0.4558		X	
Spring range	0.0237	T>U	0.0026	T>U; S>L; S>U; M>U	0.0245	S>L; M>L
Spring average daily minimum	0.0186	T<U	0.0112	T<U; S<U; M<U	0.0618	S<L; M<L
Spring average daily maximum	0.4881		0.2635		X	
Summer average	0.3305		0.1039		X	
Summer minimum	0.0491	T<U	0.0042	T<L; T<U; S<L; S<U; M<U	0.0002	S<M; S<L; M<L
Summer maximum	X		0.4558		X	
Summer range	0.0757	T>U	0.0027	T>L; T>U; S>L; S>U; M>U	0.0002	S>M; S>L; M>L
Summer average daily minimum	0.0095	T<U	0.0010	T<M; T<L; S<L; S<U; M<U	X	
Summer average daily maximum	0.6050		0.5135		X	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	*p*	**Dir.**	*p*	**Dir.**	*p*	**Dir.**
Ambient Temperature (°C):						
Spring average	0.0420	T>U	0.0867	T>U	0.3810	
Spring minimum	0.9666		0.5981		0.0761	S<L; M<L
Spring maximum	0.2459		0.3145		0.1220	
Spring range	0.2838		0.3053		0.0561	S>L; M>L
Spring average daily minimum	0.9345		0.9815		0.8236	
Spring average daily maximum	0.0805	T>U	0.0909	T>U	0.0504	S>L; M>L
Summer average	0.0020	T>U	0.0020	T>M; T>L; T>U; S>U	0.1253	
Summer minimum	0.7074		0.4563		0.3526	
Summer maximum	0.0090	T>U	0.0023	T>M; T>L; T>U; S>U	0.0277	S>M; S>L
Summer range	0.0219	T>U	0.0026	T>M; T>L; T>U; S>U	0.0125	S>M; S>L
Summer average daily minimum	0.0152	T>U	0.7045		0.0524	S>M; S>L
Summer average daily maximum	0.9574		0.0028	T>M; T>L; T>U; S>U	X	
Soil Temperature (°C):						
Spring average	0.0849	T>U	0.1785		0.8756	
Spring minimum	0.5821		0.7265		0.9735	
Spring maximum	0.1762		0.2969		0.8631	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	*p*	**Dir.**	*p*	**Dir.**	*p*	**Dir.**
Spring range	0.3701		0.7131		0.8388	
Spring average daily minimum	0.1764		0.5058		0.8730	
Spring average daily maximum	0.0529	T>U	0.2348		0.9684	
Summer average	0.0124	T>U	0.0302	T>S; T>M; T>L; T>U	0.6116	
Summer minimum	0.0371	T>U	0.1504		0.6824	
Summer maximum	0.0031	T>U	0.0186	T>S; T>M; T>L; T>U	0.7682	
Summer range	0.2576		0.5160		0.9504	
Summer average daily minimum	0.0201	T>U	0.0601	T>L; T>U	0.5290	
Summer average daily maximum	0.0098	T>U	0.0241	T>S; T>M; T>L; T>U	0.7271	
Soil Moisture (%):						
Spring soil moisture	0.4562		0.5691		0.2095	
Summer soil moisture	0.3169		0.5099		0.5822	
Downed Wood Density Data (m^3 / m^2):						
Total density	0.5820		0.2677		0.6389	
Density in decay classes 1-2	0.6607		0.2415		0.2125	
Density in decay classes 3-5	0.3828		0.6702		0.7220	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
Forest Stand Data:						
Canopy closure (%)	0.0242	T<U	0.0027	T<S; T<M; T<L; T<U	X	
Average tree diameter at breast height (cm)	0.1651		0.0069	T>S; T>L	0.4173	
Trees per hectare	0.0454	T<U	0.0072	T<S; T<M; T<L; T<U	0.8007	
Basal area/hectare (m^2/ha)	0.0293	T<U	0.1003		0.5628	
Conifer basal area/hectare (m^2/ha)	0.0293	T<U	0.0999		0.4682	
Hardwood basal area/hectare (m^2/ha)	X		0.2804		X	
BIOTA						
Vascular Plants:						
Species richness	0.001	T>U	0.001	T>S; T>M; T>L; T>U	0.098	S>L; M>L
Shannon diversity (D)	0.009	T>U	0.022	T>M; T>L; T>U	0.732	
Total ground cover (%)	0.054	T>U	0.528		0.266	
Herb ground cover (%)	0.065	T>U	0.447		0.597	
Shrub ground cover (%)	0.844		0.539		0.169	
Tree ground cover (%)	0.063	T>U	0.347		0.898	
No. herb species	0.016	T>U	0.006	T>M; T>L; T>U	0.165	
No. shrub species	0.824		0.445		0.419	
No. tree species	0.444		0.401		0.341	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
% early-successional species ground cover (%) *	0.007	T>U	0.031	T>M; T>L; T>U	0.198	
% late-successional species ground cover (%) *	0.007	T<U	0.028	T<M; T<L; T<U	0.019	S<M; S<L
Early-successional species ground cover (%)	0.001	T>U	0.004	T>M; T>L; T>U	0.199	
Late-successional species ground cover (%)	0.904		0.866		0.441	
No. early-successional species	0.014	T>U	0.002	T>S; T>M; T>L; S>U	0.041	S>M; S>L
No. late-successional species	0.492		0.135		0.093	S<M; M>L
% early-successional species (%) *	0.018	T>U	0.005	T>M; T>L; T>U; S>U	0.049	S>M; S>L
% late-successional species*	0.013	T<U	0.003	T<M; T<L; T<U	0.028	S<M; S<L
% exotic species ground cover (%) *	0.013	T>U	0.002	T>S; T>M; T>L; T>U	0.363	
% native species ground cover (%) *	0.561		X		0.200	
Exotic species ground cover (%)	0.023	T>U	0.004	T>S; T>M; T>L; T>U	0.245	
Native species ground cover (%)	0.114		X		0.395	
No. exotic species	0.044	T>U	0.009	T>M; T>L; T>U	0.022	S>M; S>L
No. native species	0.030	T>U	0.027	T>L; T>U	0.214	
% exotic species*	0.030	T>U	0.029	T>M; T>L; T>U	0.042	S>M; S>L
% native species*	0.028	T<U	0.016	T<M; T<L; T<U	0.018	S<M; S<L
Acer circinatum ground cover (%)	0.450		0.153		X	
Adenocaulon bicolor ground cover (%)	0.163		X		X	
Campanula scouleri ground cover (%)	X		0.191		0.016	S>M; S>L

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
Chimaphila menziesii ground cover (%)	0.290		X		X	
Claytonia sibirica ground cover (%)	0.163		0.228		0.048	S<L
Corylus cornuta ground cover (%)	X		0.140		0.282	
Disporum hookeri ground cover (%)	0.861		0.519		0.421	
Galium triflorum ground cover (%)	0.082	T>U	0.128		0.489	
Gaultheria shallon ground cover (%)	X		0.780		0.657	
Holodiscus discolor ground cover (%)	X		0.262		0.134	
Hypochaeris radicata ground cover (%)	0.097	T>U	X		X	
Mahonia nervosa ground cover (%)	0.451		0.717		0.121	
Oxalis oregana ground cover (%)	0.184		0.627		X	
Poaceae species ground cover (%)	0.029	T>U	0.026	T>M; T>L; T>U	0.070	S>M; S>L
Polystichum munitum ground cover (%)	0.467		0.421		0.842	
Pteridium aquilinum ground cover (%)	0.226		0.027	T>M; S>M	0.209	
Rosa gymnocarpa ground cover (%)	X		0.492		0.040	S>M; M<L
Rubus ursinus ground cover (%)	0.281		0.539		0.287	
Symphoricarpos albus ground cover (%)	X		0.197		0.021	S>M; S>L
Symphoricarpos mollis ground cover (%)	X		0.304		0.061	S>M; S>L
Trientalis latifolia ground cover (%)	0.153		0.367		X	
Trillium ovatum ground cover (%)	0.836		0.810		0.925	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	*p*	**Dir.**	*p*	**Dir.**	*p*	**Dir.**
Vancouveria hexandra ground cover (%)	0.463		0.533		X	
Vaccinum ovatum ground cover (%)	X		0.902		0.934	
Vaccinum parvifolium ground cover (%)	0.988		0.394		0.101	
Viola species ground cover (%)	0.431		0.492		0.617	
Arthropods:						
No. orders	0.900		0.906		0.387	
No. functional groups	1.000		0.344		0.039	S<L; M<L
Species richness	0.627		0.749		0.080	S<L; M<L
Shannon diversity (D)	0.424		0.725		0.608	
Low-mobility captures (n/m^2)	0.457		0.508		0.055	M<L
Mid-mobility captures (n/m^2)	0.694		0.421		0.156	
High-mobility captures (n/m^2)	0.761		0.303		0.024	S<L; M<L
No. low-mobility species	0.543		0.635		0.088	S<L; M<L
No. mid-mobility species	0.354		0.675		0.593	
No. high-mobility species	0.810		0.514		0.017	S<L; M<L
% low-mobility captures	0.089	T<U	0.442		0.319	
% mid-mobility captures	0.660		0.128		0.017	S<M; M>L
% high-mobility captures	0.533		0.673		0.325	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	*p*	**Dir.**	*p*	**Dir.**	*p*	**Dir.**
Disturbance-associated captures (n/m^2)	0.322		0.291		0.204	
LSOG-associated captures (n/m^2)	0.593		0.192		0.018	S<L; M<L
% disturbance-associated captures	0.431		0.597		0.663	
% LSOG-associated captures	0.313		0.157		0.051	S>M; M<L
Arthropod captures (n/m^2)	0.720		0.475		0.019	S<L; M<L
Cadaver feeder captures (n/m^2)	X		X		X	
Dung feeder captures (n/m^2)	X		X		X	
Fungivore captures (n/m^2)	0.464		X		0.464	
Macropredator captures (n/m^2)	0.145		X		0.559	
Micropredator captures (n/m^2)	0.542		0.485		0.542	
Parasitoid captures (n/m^2)	0.576		0.570		0.366	
Plant chewer captures (n/m^2)	0.437		0.843		0.907	
Plant sucker captures (n/m^2)	0.807		0.773		0.561	
Shredder captures (n/m^2)	0.390		0.903		0.937	
Slime-mold feeder captures (n/m^2)	X		X		X	
Xylivore captures (n/m^2)	X		0.571		0.799	
Acrotrichus captures (n/m^2)	0.339		X		X	
Actium captures (n/m^2)	X		X		X	
Agulla captures (n/m^2)	X		0.294		0.426	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	*p*	**Dir.**	*p*	**Dir.**	*p*	**Dir.**
Aleocharine black species captures (n/m^2)	0.878		X		X	
Aleocharine red species captures (n/m^2)	1.000		0.827		X	
Antrodiaetus captures (n/m^2)	0.179		0.333		0.025	S<L; M<L
Apochthonius captures (n/m^2)	0.930		0.346		0.081	M<L
Arctorthezia occidentalis captures (n/m^2)	0.030	T<U	X		0.399	
Atrechus captures (n/m^2)	0.604		X		X	
Batrissodes captures (n/m^2)	0.793		0.661		0.489	
Bdellozonium captures (n/m^2)	0.368		X		X	
Bollmannella captures (n/m^2)	0.620		X		X	
Brachyrhinus rugostriatus captures (n/m^2)	0.642		0.801		0.754	
Braconid species W captures (n/m^2)	X		0.355		0.276	
Bradysia captures (n/m^2)	X		X		0.280	
Byrrhid immature captures (n/m^2)	0.400		0.411		0.209	
Cantharid immature captures (n/m^2)	0.506		0.351		0.167	
Carabid immature captures (n/m^2)	0.814		0.363		0.010	S<L; M<L
Catopocerus sp A captures (n/m^2)	0.632		0.554		X	
Ceraphron sp B captures (n/m^2)	0.297		0.600		0.613	
Chironomid captures (n/m^2)	0.166		0.093		X	
Chordeumid captures (n/m^2)	0.311		0.503		X	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
Curculionid immature captures (n/m^2)	0.220		X		X	
Cybaeus captures (n/m^2)	0.461		0.446		0.463	
Cytilus alternatus captures (n/m^2)	0.075	T>U	0.310		0.591	
Elater 2HK captures (n/m^2)	0.658		0.668		0.554	
Elater sp 1 captures (n/m^2)	0.468		0.564		X	
Elaterid immature captures (n/m^2)	0.508		0.261		0.447	
Ellychnia captures (n/m^2)	0.967		X		X	
Fenderia capizii captures (n/m^2)	0.489		X		X	
Garypus captures (n/m^2)	0.594		0.169		X	
Geodercodes latipennis captures (n/m^2)	0.699		0.756		0.399	
Geophilomorpha captures (n/m^2)	0.648		0.024	T<L; S<M; S<L	0.098	S<M; S<L
Giant Geophilomorpha captures (n/m^2)	0.439		0.345		0.832	
Harpaphe haydeniana haydeniana captures (n/m^2)	0.899		0.884		0.150	
Hesperonemastoma captures (n/m^2)	0.402		0.693		X	
Hexura captures (n/m^2)	0.298		0.210		0.018	S<M
Ichneumonid captures (n/m^2)	0.200		0.343		X	
Julid ST captures (n/m^2)	0.525		0.527		0.295	
Lasius captures (n/m^2)	0.190		0.421		X	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
Ligidium gracile captures (n/m^2)	0.575		0.436		X	
Lioon simplicipes captures (n/m^2)	0.755		0.648		0.236	
Listemus formosus captures (n/m^2)	0.617		X		X	
Lithobid captures (n/m^2)	0.897		0.789		0.610	
Lophioderus captures (n/m^2)	0.546		X		X	
Lucifotychus impellus captures (n/m^2)	0.326		0.707		0.327	
Lygaeidae captures (n/m^2)	0.079	T>U	0.249		X	
Machilid captures (n/m^2)	0.733		X		X	
Megarofonus captures (n/m^2)	0.423		X		X	
Metanonychus captures (n/m^2)	0.660		0.664		0.269	
Microcreagis captures (n/m^2)	0.457		0.398		0.174	
Microcybaeus captures (n/m^2)	X		X		X	
Micropeplus captures (n/m^2)	X		X		X	
Micryphantid sp C captures (n/m^2)	0.790		0.204		X	
Micryphantid sp D captures (n/m^2)	0.670		X		X	
Myrmica captures (n/m^2)	0.089	T<U	0.107		0.289	
Nearctodesmus captures (n/m^2)	0.268		X		X	
Noctuid captures (n/m^2)	X		0.108		0.164	
Notiophilus sylvaticus captures (n/m^2)	X		0.367		0.134	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
Polyxenes captures (n/m^2)	0.531		X		X	
Pristoceuthophilus captures (n/m^2)	0.080	T<U	0.273		X	
Pselaphid immature captures (n/m^2)	0.504		X		X	
Pselaptrichus rothi captures (n/m^2)	0.417		0.335		X	
Pterostichus lanei captures (n/m^2)	0.818		0.996		X	
Ptillid adult captures (n/m^2)	0.856		X		X	
Scolopocryptops captures (n/m^2)	0.950		0.580		0.681	
Scutigerella captures (n/m^2)	0.830		X		X	
Scydmaenus captures (n/m^2)	0.693		X		X	
Scytonotus captures (n/m^2)	0.569		0.613		X	
Siro captures (n/m^2)	0.884		0.264		X	
Staphylinidae immature captures (n/m^2)	0.308		0.012	T<L; S<L; M<L	0.002	S<L; M<L
Staphylinidae sp AR captures (n/m^2)	0.228		0.403		X	
Steremnius carinatus captures (n/m^2)	0.020	T>U	0.148		0.835	
Striaria species captures (n/m^2)	0.151		X		X	
Tachinus sp B captures (n/m^2)	0.822		0.129		X	
Tachyporus sp A captures (n/m^2)	0.548		X		X	
Tenthredenid captures (n/m^2)	0.789		X		X	
Tipulid captures (n/m^2)	0.896		0.316		X	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
Trombidiid captures (n/m^2)	0.558		0.204		X	
Xysticus captures (n/m^2)	0.135		0.314		0.520	
Amphibians:						
Species richness	0.015	T<U	0.004	S>L; M>L; L<U	0.002	S>L; M>L
Shannon diversity (D)	0.193		0.308		X	
Amphibian captures (n/m^2)	0.241		0.010	T<S; T<M; S>L; M>L	0.448	
Plethodontid captures (n/m^2)	0.239		0.014	T<S; T<M; S>L	0.466	
Batrachoseps wrighti captures (n/m^2)	X		0.730		0.078	S>L; M>L
Ensatina eschscholtzii captures (n/m^2)	0.366		0.065	T<S	0.729	
Plethodon vehiculum captures (n/m^2)	X		X		X	
Mollusks:						
Species richness	0.940		0.997		0.787	
Shannon diversity (D)	0.885		0.996		0.949	
Mollusk captures (n/m^2)	0.122		0.311		0.050	S<L
Snail captures (n/m^2)	0.114		0.275		0.057	S<L
Slug captures (n/m^2)	0.583		0.907		0.887	

Table 2.1. (Continued)

	Analysis					
	Thinned vs. Unthinned		**Integrated**		**Leave Island**	
PARAMETER	***p***	**Dir.**	***p***	**Dir.**	***p***	**Dir.**
Ancotrema sportella captures (n/m^2)	0.238		0.362		0.079	S<M; S<L
Ancotrema sportella-Haplotrema vancouverense juvenile captures (n/m^2)	0.137		0.298		0.037	S<M; S<L
Ariolimax columbianus captures (n/m^2)	0.923		0.723		X	
Haplotrema vancouverense captures (n/m^2)	0.090	T<U	0.303		0.019	S<L
Monadenia fidelis captures (n/m^2)	X		X		X	
Vespericola columbianus captures (n/m^2)	0.175		0.350		0.131	

abundant species with 1,581 captures (43.8% of all captures). Treatment effects were examined for six species (Figure 2.3d), snail, slug, and total mollusk density, and two diversity measures (Table 2.1).

Treatment effects of thinning-

Thinning effects were detected for 24 of 45 (53.3%) habitat measures analyzed when comparing only thinned and unthinned forest ($p<0.10$; Table 2.1). Specifically, seven of 11 relative humidity, six of 12 ambient temperature, seven of 12 soil temperature, and four of five forest structure analyses were significant (Table 2.1). These measures of microclimate and habitat followed logical sequences of effects, with thinned forest consistently having higher temperatures, lower relative humidity, and greater ranges of microclimate conditions than unthinned forest. Treatment effects were not detected for any measures of soil moisture or downed wood density.

Thinning effects were shown for 30 of 155 (19.4%) biotic measures analyzed (Table 2.1). Almost half (21 of 43) of the plant analyses were significant, including two measures of diversity, one measure of ground cover, six measures of successional status, three measures of stratum, six measures of plant origin, and three species. Species richness, species diversity, and overall ground cover tended to be greater in thinned forest. Thinned forest had higher proportions of both early-successional and exotic species compared to unthinned forest while conversely, unthinned forest had higher proportions of both late-successional and native species. The three plant species with thinning effects had greater ground cover in the thinned forest units.

Seven of 97 (7.2%) arthropod analyses showed effects of thinning, including one mobility measure and six species (Table 2.1). Densities of *Arctorthezia occidentalis*, *Myrmica*, and *Pristoceuthophilus*, and the percentage of low-mobility species captures were higher in unthinned forest than in thinned forest. Densities of *Cytilus alternatus*, *Steremnius carinatus*, and Lygaeidae were higher in thinned forest than in unthinned forest. *Myrmica* density was the only result that was not consistent with our predictions; we expected this disturbance-associated species to be more abundant in the thinned forest matrix.

Five amphibian analyses examined two diversity and three density measures (Table 2.1). Treatment effects were shown only for amphibian species richness, with richness of unthinned forest (mean=1.58; s.d.=0.167; n=8) exceeding that of thinned forest (mean=1.17; s.d.= 0.167; n=8).

Ten mollusk analyses examined two diversity measures and eight density measures (Table 2.1). Treatment effects were shown only for *H. vancouverense* density. Log-transformed densities of this species were higher in unthinned forest (mean=0.137; s.d.=0.05; n= 8) than in thinned forest (mean=0.074; s.d.=0.05; n= 8).

Integrated analyses comparing all forest types-

We found that the forest structure and microclimate of these managed second-growth forests varied with thinning and leave island size (Table 2.1). Forest structure differences followed our predictions for measures of canopy closure, trees per hectare, and basal area. Analyses did not detect statistical differences in downed wood density among the five forest types. For microclimate, measures of relative humidity, ambient temperature, and soil temperature varied along a gradient according to intensity of harvest from thinned forest, small through large leave islands, and unthinned forest. Microclimate conditions in 0.4 ha leave islands were most similar to unthinned forest while conditions in 0.1 ha leave islands were closely aligned with thinned forest. The 0.4 ha leave islands did not differ ($p>0.10$) from unthinned controls for any microclimate parameter examined, supporting our prediction that they best represent interior habitat in comparison to the smaller leave islands in this thinning context. Treatment effects on soil moisture were not evident for either sampling season.

Treatment effects were detected for 20 of 47 (42.6%) habitat measures analyzed (Table 2.1). Seven of 12 relative humidity analyses, six of 12 ambient temperature analyses, four of 12 soil temperature analyses, and three of six forest structure analyses were significant (Tables 2.1 and 2.2). Specifically, these included spring and summer relative humidity and ambient temperature measures, summer soil temperature, canopy closure, dbh, and trees per hectare. Direction of effects followed logical sequences with thinned forest having the lowest relative humidity, highest ambient and soil temperatures, lowest canopy closure, largest dbh, and fewest trees per hectare (Table 2.2). Average daily ranges of conditions (difference between minimum and maximum for microclimatic variables) were consistently greatest in thinned forest, progressively less in 0.1 ha, 0.2 ha, and 0.4 ha leave islands, and smallest in unthinned forest. Conditions in smaller leave islands (0.1 ha and 0.2 ha) were most similar to thinned forest while conditions in the largest leave islands

Table 2.2. List of all significant ANOVA analyses (p<0.10) and resulting pairwise comparisons (Bonferroni-adjusted p-values: * p<0.10, ** p<0.05, *** p<0.01) for integrated analyses comparing all five types of forest. Forest types are abbreviated as follows: T=thinned forest, S=small (0.1 ha) leave islands, M=medium (0.2 ha) leave islands, L=large (0.4 ha) leave islands, and U=unthinned forest. For vascular plant analyses, GC=ground cover and * indicates percent of total vascular plant ground cover.

								Pairwise Comparisons									
			Treatment Means					Thinned vs.				S vs.			M vs.		L vs.
PARAMETER	F	p	T	S	M	L	U	S	M	L	U	M	L	U	L	U	U
HABITAT:																	
Relative Humidity (%):																	
Spring average	5.03	0.021	82.211	82.912	83.848	85.353	85.582			**	*		*				
Ln Spring minimum	7.11	0.007	3.585	3.525	3.588	3.695	3.817				**			***		**	
Spring range	9.69	0.003	64.125	65.917	63.750	59.917	54.917				***		*	***		***	
Spring average daily minimum	6.19	0.011	62.678	63.158	64.675	67.893	70.867				**			**		*	
Summer minimum	8.37	0.004	35.750	32.583	36.083	41.417	42.333			*	*		***	***		*	
Summer range	9.50	0.003	64.000	67.417	63.917	58.583	57.417			*	**		***	***		**	
Summer average daily minimum	12.49	0.001	53.275	52.200	56.533	61.800	62.450		***	***			***	***		*	
Ambient Temperature (°C):																	
Spring average	2.88	0.087	7.522	7.295	7.358	7.146	6.890				*						
Spring average daily maximum	2.82	0.091	12.975	12.433	12.383	11.583	11.067				*						
Summer average	10.41	0.002	15.668	15.258	15.073	14.912	14.748		**	***	***			*			
Summer maximum	10.04	0.002	29.075	27.350	25.600	25.150	24.500		**	***	***			**			
Ln Summer range	9.60	0.003	3.103	3.019	2.942	2.904	2.858		**	***	***			**			
Summer average daily maximum	9.45	0.003	22.825	21.517	20.383	19.967	19.325		**	***	***			**			

Table 2.2. (Continued)

								Pairwise Comparisons										
			Treatment Means					Thinned vs.				S vs.			M vs.		L vs.	
PARAMETER	**F**	**p**	**T**	**S**	**M**	**L**	**U**	**S**	**M**	**L**	**U**	**M**	**L**	**U**	**L**	**U**	**U**
Soil Temperature (°C):																	
Summer average	4.40	0.030	13.543	12.932	12.929	12.767	12.778	*	*	**	**						
Summer maximum	5.23	0.019	15.025	14.367	14.367	14.200	14.225	*	*	**	**						
Summer average daily minimum	3.37	0.060	13.192	12.650	12.683	12.500	12.525			*	*						
Summer average daily maximum	4.78	0.024	13.992	13.325	13.300	13.167	13.167	*	*	**	**						
Forest Stand Data:																	
Canopy closure (%)	9.56	0.003	63.333	90.000	88.750	83.750	89.583	***	***	**	***						
Average diameter at breast height (cm)	7.21	0.007	46.708	39.267	42.617	38.525	42.492	***		***							
Trees per hectare	7.13	0.007	226.330	479.000	445.920	445.670	444.920	***	**	**	***						
BIOTA:																	
Vascular Plants																	
Ln Species richness	12.12	0.001	3.554	3.321	3.328	3.183	3.095	**	**	***	***					*	
Shannon diversity (D)	4.90	0.022	2.840	2.481	2.460	2.384	2.196		*	**	**						
Number of herb species	7.52	0.006	24.333	18.750	17.417	15.667	13.167		*	**	***						
% early-successional GC (%) *	4.38	0.031	38.758	30.545	18.493	19.882	17.765		**	*	*						
% late-successional GC (%) *	4.55	0.028	60.758	69.356	81.505	80.125	82.245		**	*	*						
Ln Early-successional species GC (%)	8.61	0.004	3.323	2.755	2.436	2.265	2.224		**	***	***						
Number of early-successional species	10.67	0.002	17.417	12.417	9.833	9.917	7.500	*	***	***				*			

Table 2.2. (Continued)

			Treatment Means					Pairwise Comparisons: Thinned vs.				S vs.			M vs.		L vs.
PARAMETER	**F**	**p**	**T**	**S**	**M**	**L**	**U**	**S**	**M**	**L**	**U**	**M**	**L**	**U**	**L**	**U**	**U**
% late-successional species *	9.41	0.003	51.806	60.734	67.718	65.388	71.382		***	**	***						
% early-successional species *	8.08	0.005	47.197	38.648	32.283	34.613	28.618		**	**	***			*			
Ln % exotic species GC (%) *	11.04	0.002	1.774	0.653	0.543	0.315	0.120	**	***	***	***						
Ln Exotic species GC (%)	8.71	0.004	1.684	0.575	0.416	0.249	0.099	**	**	***	***						
Number of native species	4.59	0.027	29.417	26.083	27.083	24.167	22.500			*	**						
Ln Number of exotic species	6.70	0.009	1.441	0.910	0.587	0.414	0.265		**	***	***						
% native species *	5.46	0.016	85.263	90.473	93.675	95.527	96.591		*	**	**						
% exotic species *	4.47	0.029	10.147	6.243	3.455	2.546	1.283		*	*	**						
Ln Poaceae species GC (%)	4.67	0.026	1.282	0.890	0.558	0.497	0.471		*	**	**						
Ln Pteridium aquilinum GC (%)	4.61	0.027	1.096	0.951	0.609	0.877	0.961		**			*					
Arthropods:																	
Ln Geophilomorpha captures (n/m^2)	4.79	0.024	1.891	1.770	2.323	2.396	2.010			*		*	**				
Ln Staphylinidae immature captures (n/m^2)	6.10	0.012	0.499	0.498	0.567	1.302	0.766			**			**		**		
Ln Chironomid immature captures (n/m^2)	2.79	0.093	0.298	0.147	0.159	0.472	0.163										
Amphibians:																	
Ln Species richness	8.69	0.004	0.679	0.838	0.906	0.472	0.895						***		***		**
Amphibian captures (n/m^2)	6.44	0.010	0.013	0.025	0.023	0.014	0.017	**	**				**		*		
Plethodontid captures (n/m^2)	5.80	0.014	0.011	0.024	0.022	0.014	0.015	**	**				*				
Ensatina captures (n/m^2)	3.25	0.065	0.007	0.014	0.011	0.010	0.011	**									

(0.4 ha) were most similar to unthinned forest (Table 2.2). Treatment effects were not shown for any measures of soil moisture or downed wood density.

Results of the integrated analyses paralleled the thinned-unthinned comparisons for habitat; for example, analyses of 17 parameters resulted in concurrence of significant differences between thinned and unthinned forest (Table 2.1). However, seven analyses detected differences in the thinned and unthinned analyses that were not also found by the integrated analyses. Specifically, in the previous analyses, four measures were significantly greater in thinned forest than unthinned forest, including measures of summer ambient temperature and spring and summer soil temperature. Conversely, three measures were significantly greater in unthinned forest than thinned forest, including summer relative humidity and measures of basal area/ha.

Of the 46 vascular plant measures examined (Table 2.1), 17 (37.0%) were significant ($p<0.10$), including two diversity measures, six exotic and native species measures, six early- and late-successional species measures, number of herbaceous species, and ground cover for two of 23 species investigated (Tables 2.1 and 2.2). As for the habitat results, these results displayed consistent trends tracking the continuum of disturbance (e.g., thinned forest>0.1 leave islands>0.2 leave islands>0.4 leave islands>unthinned forest and vice versa). The species composition and types of ground cover differed greatly among forest types (Table 2.1). Species richness, number of early-successional species, percent exotic species ground cover, and total exotic species ground cover in thinned forest exceeded that of all other forest types (Table 2.1). Also in thinned forest, Shannon diversity, number of herb species, percent early-successional species ground cover, total early-successional species ground cover, percent early-successional species, number of exotic species, percent exotic species, and *Poaceae* ground cover were greater than that of unthinned forest and 0.2 ha and 0.4 ha leave islands but not different from 0.1 ha leave islands. The percentage of late-successional species, number of late-successional species, and percentage of native species were lower in thinned forest than in both 0.4 ha leave islands and in unthinned forest.

As for habitat analyses, results of the integrated analyses of plants paralleled the thinned-unthinned comparisons; for example, analyses of 15 parameters resulted in concurrence of significant differences between thinned and unthinned forest. However, six analyses detected differences in the thinned and unthinned forest comparison that were not also found by the integrated analyses. Specifically, the number of early-successional species and five measures of ground cover were significantly greater in thinned forest than unthinned forest (Table 2.1). One plant species, *Hypochaerus radicata* (hairy catsear), that did not meet normality assumptions within the integrated analysis was found more commonly in the thinned units during the thinned-unthinned comparison.

Treatment effects were evident for two of 77 (2.6%) arthropod analyses (Table 2.1), including densities of immature Staphylinidae and *Geophilomorpha* (Tables 2.1 and 2.2). In particular, 0.4 ha leave islands averaged higher immature Staphylinidae densities (n/m^2) than thinned forest, 0.1 ha leave islands, and 0.2 ha leave islands. Similarly, 0.4 ha leave islands averaged higher *Geophilomorpha* densities (n/m^2) than thinned forest and 0.1 ha leave islands while 0.2 ha leave islands averaged higher *Geophilomorpha* densities (n/m^2) than 0.1 ha leave islands.

Twenty additional arthropod analyses were conducted with the thinned-unthinned comparison than in the integrated analyses, thus allowing examination of additional species that did not meet the normality assumptions within the integrated analysis approach. Seven of these analyses detected differences between thinned and unthinned forest. Treatment means were greater in thinned forest for three of these analyses and greater in unthinned forest for four of these analyses (Tables 2.1 and 2.2). One arthropod species, *A. occidentalis*, did not meet normality assumptions in the integrated analysis but was found to be less abundant in thinned units than unthinned units in the thinned-unthinned analysis approach.

Six amphibian analyses examined two diversity measures and four density measures (Table 2.1). Treatment effects were shown for four of these analyses (66.7%), including amphibian species richness and overall amphibian density, plethodontid salamander density, and *E. eschscholtzii* density (Tables 2.1 and 2.2). Interestingly, the paucity of captures in 0.4 ha leave islands and unthinned forest appeared to disrupt sequential patterns in amphibian densities among forest types (Table 2.2). Specifically, pairwise comparisons indicated that 0.1 ha and 0.2 ha leave islands averaged more amphibian species than 0.4 ha leave islands but the largest leave islands averaged more amphibian species than unthinned forest. For total amphibian density, 0.1 ha leave islands averaged more amphibians/m^2 than thinned forest and 0.4 ha leave islands while 0.2 ha leave islands averaged more amphibians/m^2 than thinned forest and 0.4 ha leave islands. Small leave islands averaged more plethodontids/m^2 than thinned forest and 0.4 ha leave islands while 0.2 ha leave islands averaged more plethodontids/m^2 than thinned forest. Finally, for *E. eschscholtzii* density, 0.1 ha leave islands averaged more *E. eschscholtzii* /m^2 than thinned forest. These results supplemented previous findings comparing thinned and unthinned forest types.

Ten mollusk analyses examined two diversity measures and eight density measures (Table 2.1). No treatment effects were shown (Table 2.1). In contrast, treatment effects on *H. vancouverense* density were shown in the previous thinned-unthinned analysis.

Treatment effects of leave island sizes-

Treatment effects were detected for 12 of 38 (31.6%) habitat measures analyzed (Table 2.1). All six relative humidity analyses and six of 11 ambient temperature analyses were significant (Table 2.1). Specifically, these included spring and summer relative humidity and ambient temperature measures. Direction of effects followed expected sequences with relative humidity increasing with increasing leave island size and ambient temperature increasing with decreasing leave island size. Similarly, average daily ranges of conditions tended to be greatest in 0.1 ha leave islands and progressively smaller in 0.2 ha and 0.4 ha leave islands. Treatment effects were not evident for any measures of soil temperature, soil moisture, downed wood, or forest structure.

Nine fewer habitat measures were examined using the leave island approach than the integrated approach. Similar patterns emerged yet there was not complete concurrence between the analyses for any parameter. Three measures not meeting normality assumptions within the leave island approach were found to have treatment effects within the integrated analyses (summer average daily minimum relative humidity, summer average daily maximum ambient temperatures, and canopy closure).

Overall, leave island size showed an effect for 15 of 44 (34.1%) vascular plant analyses (Table 2.1). Treatment effects were shown for one diversity measure, five successional status measures, three measures of plant origin, and six species. Measures of diversity, exotic species, and early-successional species were consistently greater in 0.1 ha leave islands and progressively less in 0.2 ha and 0.4 ha leave islands. Results differed considerably between this analysis approach and the integrated approach with no complete concurrence in results. This analysis approach detected numerous differences among leave island sizes while the differences detected by the integrated approach were primarily between thinned forest and other forest types.

Overall, 16 of 60 (26.7%) arthropod analyses showed effects of leave island size (Table 2.1). Treatment effects were shown for overall arthropod density, two diversity measures, two forest association measures, five mobility class measures, and six species. These measures tended to be lowest in 0.1 ha leave islands and highest in 0.4 ha leave islands. In contrast, leave island size mattered for only two arthropod parameters in the integrated analyses. Concurrence with the integrated results occurred for these two results, which compared the densities of two individual species.

Five amphibian analyses examined one diversity measure and four density measures (Table 2.1). Treatment effects were shown for amphibian species richness and *Batrachoseps wrighti* (Oregon slender salamander) density (Table 2.1). Contrary to expectations, responses for both measures were higher in 0.1 ha and 0.2 ha leave islands than 0.4 ha leave islands. This is the only analysis approach where treatment effects were shown for *B. wrighti* (Table 2.1). Concurrence with the integrated approach was found only for species richness.

Nine mollusk analyses examined two diversity measures and seven density measures (Table 2.1). Treatment effects were shown for five of these analyses (55.6%), including densities of all mollusks, snails, and three species (Table 2.1). Densities were lowest in 0.1 ha leave islands for all measures. Further, densities of two species were also lower in 0.1 ha leave islands than 0.2 ha leave islands. Results from this analysis approach contrasted sharply with the integrated analysis approach in which no treatment effects were found.

Indicator Species Analyses-

<u>Vascular Plants</u>

ISA identified six indicator species for thinned forest and one indicator species for 0.2 ha leave islands when forest type was used as a grouping variable. Species indicative of thinned forest included *H. radicata* (IV=80.4, randomized groups IV mean=39.5 and s.d.=12.31, p=0.005), *Chamerion angustifolium* (fireweed; IV=75.0, randomized groups IV mean=25.7 and s.d.=13.57, p=0.024), *Epilobium ciliatum* (fringed willowherb; IV=70.4, randomized groups IV mean=27.7 and s.d.=14.07, p=0.027), *Cirsium vulgare* (bull thistle; IV=68.0, randomized groups IV mean=33.1 and s.d.=15.99, p=0.046), Asteraceae species (aster species; IV=65.7, randomized groups IV mean=26.7 and s.d.=14.48, p=0.056), and *Luzula* species (woodrush species; IV=61.0, randomized groups IV mean=34.2 and s.d.=13.39, p=0.060). All six of these species were herbaceous and five of six (83.3%) were associated with early-successional forest. The sole indicator of 0.2 ha leave islands was the native, late-successional shrub, *Acer circinatum* (vine maple; IV=70.3, randomized groups IV mean=48.5 and s.d.=14.50, p=0.078).

In addition, ISA identified vascular plant indicator species for study sites and for mountain ranges. Specifically, ISA of study sites identified indicator species for Bottomline (n=26), Delph Creek (n=8), Green Peak (n=8), and Keel Mountain (n=3; Appendix C). Finally, ISA of mountain ranges identified eight vascular plant indicator species for the Cascade Range and 41 indicator species for the Coast Range (Appendix D).

Arthropods

When forest type was used as a grouping variable, ISA identified mid-mobility, late-successional forest associate trap-door spider, *Hexura,* as an indicator species for 0.2 ha leave islands (IV=30.3; randomized groups IV mean=25.6 and s.d.=2.29, p=0.026) while high-mobility coleopteran Staphylinidae species were identified as indicators of 0.4 ha leave islands (IV=28.6; randomized groups IV mean=25.0 and s.d.=2.11, p=0.057). These results were consistent with the integrated analysis results which indicated that Staphylinidae species density in large leave islands exceeded that of small and medium leave islands as well as thinned forest (Table 2.2). Finally, the mid-mobility coleopteran, *S. carinatus,* was the sole indicator of thinned forest (IV=28.9; randomized groups IV mean=25.7 and s.d.=2.34, p=0.080).

In addition, ISA identified arthropod indicator species for study sites and for mountain ranges. Specifically, ISA of study sites identified indicator species for Bottomline (n=20), Delph Creek (n=17), Green Peak (n=11), and Keel Mountain (n=14; Appendix C). Finally, ISA of mountain ranges identified 23 arthropod indicator species for the Cascade Range and 21 indicator species for the Coast Range (Appendix D).

Amphibians

Indicator species analysis did not identify any amphibian indicator species for any treatment when forest type was used as a grouping variable. However, ISA identified amphibian indicator species for three study sites and for both mountain ranges. Specifically, ISA of study sites identified indicator species for Delph Creek (n=1), Green Peak (n=1), and Keel Mountain (n=1; Appendix C). No indicator species were identified for Bottomline. Finally, ISA of mountain ranges identified two amphibian indicator species for the Cascade Range and one indicator species for the Coast Range (Appendix D).

Mollusks

Indicator species analysis did not identify any indicator species for any treatment when forest type was used as a grouping variable. However, as with amphibian data, ISA identified mollusk indicator species for study sites and for mountain ranges (Appendix D). Specifically, ISA of study sites identified indicator species for Bottomline (n=4), Delph Creek (n=1), Green Peak (n=1), and Keel

Mountain (n=1; Appendix C). Finally, ISA of mountain ranges identified two mollusk indicator species for the Cascade Range and three indicator species for the Coast Range (Appendix D).

Blocked Multi-Response Permutation Procedure Analyses-

Vascular Plants

MRBP revealed no differences in vascular plant communities among the five groups (forest types) of interest. This comparison of unthinned forest, thinned forest, 0.1 ha, 0.2 ha, and 0.4 ha leave islands resulted in a chance-corrected group agreement (A) of 0.0186 and p=0.752, indicating more heterogeneity within groups than expected by chance alone.

Arthropods

MRBP revealed no significant differences in arthropod communities among the five groups of interest. Specifically, this analysis resulted in a chance-corrected within-group agreement (A) of 0.00126 and p=0.477. This indicates that arthropod communities appear to be relatively homogeneous among the five groups examined in this study and more heterogeneous than expected by chance alone.

Amphibians

MRBP did not reveal significant differences in amphibian communities among the five groups of interest. Specifically, this analysis resulted in a chance-corrected group agreement (A) of 0.0206 and p=0.289, indicating more heterogeneity in groups than expected by chance.

Occurrence by Forest Type	Plants	Arthropods	Amphibians	Mollusks	Total Taxa
Thinned only	8	17	0	1	**26**
Thinned and any leave island, only	25	20	0	1	**46**
Unthinned only	1	21	2	0	**24**
Unthinned and any leave island, only	4	39	1	0	**44**
Leave islands only	17	52	0	2	**71**
All forest types (ubiquitous)	49	104	3	8	**164**
Other	16	36	1	0	**53**
Total Taxa	**120**	**289**	**7**	**12**	**428**

Table 2.3. Qualitative comparison of key occupancy patterns per taxon.

<u>Mollusks</u>

MRBP did not reveal significant differences in mollusk communities among the five groups of interest. Specifically, this analysis resulted in a chance-corrected group agreement (A) of 0.0255 and p=0.253, indicating more heterogeneity in groups than expected by chance.

Occupancy Patterns-

Thinning and leave island effects on vascular plant species composition were apparent in qualitative comparisons of occupancy patterns. Vascular plant occupancy patterns represented all possible forest type combinations (Table 2.3; Appendix A). Of the 120 vascular plant species identified, there were 49 (40.8%) ubiquitous species found in all five forest types (Appendix A). Eight species were found only in thinned forest. Seven (87.5%) of these were early-successional herb species, including *Senecio sylvaticus* (woodland ragwort), *Anaphalis margaritacea* (western pearly everlasting), *C. angustifolium*, *Ligusticum apiifolium* (celeryleaf licorice-root), *Pedicularis racemosa* (sickletop lousewort), *Urtica dioica* (stinging nettle), and cudweed species (*Gnaphalium* species). Twenty-five species were not found in unthinned forest but were found only in thinned forest and leave islands. Seventeen of these species (68.0%) were associated with early-successional habitat while six (24.0%) were exotic species. One species, the native, late-successional forest associated species, *Pityopus californica* (California pinefoot), was found only in unthinned forest. Four species found only in unthinned forest and leave islands but not thinned forest were all late-successional, native species, including *Boschniakia hookeri* (Vancouver ground cone), *Listera caurina* (Northwestern twayblade), *Maianthemum dilatatum* (false lily of the valley), and an unidentified *Lilium* species (unidentified lily species). Seventeen species (14.2%) were found only in leave islands. Twelve (70.6%) of these 17 species were associated with late-successional forest habitat while 15 (88.2%) were native species. Due to their rarity, none of these 17 species were incorporated into previous analyses (ANOVA) of treatment effects. These species included three saprophytes (*Monotropa hypopithys* [pinesap], *Corallorrhiza mertensiana* [Pacific coralroot], and the rare *Cephalanthera austiniae* [phantom orchid]), subshrubs (*Menziesia ferruginea* [rusty menziesia] and *Pyrola picta* [whiteveined wintergreen]), and lily species (*Lilium columbianum* [Columbian lily] and *Maianthemum racemosum* [feathery false lily of the valley]). If plant occupancy patterns of species in single forest types (unthinned, thinned, leave islands) were randomly distributed, one might expect numbers of species to reflect sampling effort (i.e., area sampled). Three times as much leave island area was sampled, so leave island species richness would be three times higher. Observed richness was not different from this expectation for plants (χ^2=4, d.f.=2, p>0.10).

Arthropod occupancy patterns were a mix among forest types, similar to those of vascular plants. Of the 289 arthropod species identified, 104 species (36.0%) were found in all five forest types (Appendix B). Seventeen species (5.9%) were found only in thinned forest, 14 (82.4%) of which were high-mobility species, two (11.8%) were low-mobility species, and one (5.9%) was mid-mobility (Table 2.3). Twenty species (6.9%) were found only in thinned forest and leave islands but not unthinned forest. Conversely, 21 species (7.3%) were found only in unthinned forest, 12 (57.1%) of which were high-mobility species, seven (33.3%) were mid-mobility, and two (9.5%) were low-mobility. Thirty-nine species (13.5%) were not found in thinned forest but were found only in unthinned forest and leave islands. Fifty-two species (18.0%) were found only in leave islands, 34 (65.4%) of which were high-mobility species, ten (19.2%) were low-mobility species, and eight (15.4%) were mid-mobility. Eleven of these 52 species had known habitat associations. Six (54.6%) were associated with late-successional or old-growth forest habitat while five (45.4%) were associated with disturbed forest habitat. As in vascular plants, due to their rarity, none of these 52 species were incorporated into previous analyses (ANOVA) of treatment effects. As for plants, observed species richness in leave islands was not different from expected given random assortment of species among the five forest types (χ^2=0.6, d.f.=2, p>0.05).

The three most common amphibian species, *B. wrighti*, *E. eschscholtzii*, and *Plethodon vehiculum* (western redback salamander), were ubiquitous and occurred in all five forest types (Table 2.3; Appendix B). The remaining four species occurred only incidentally. Specifically, we captured *Ambystoma gracile* (northwestern salamander; n=4) only in thinned forest and unthinned forest, *Ascaphus truei* (tailed frog; n=1) and *Rhyacotriton variegatus* (southern torrent salamander; n=1) only in unthinned forest, and *Taricha granulosa* (rough-skinned newt; n=2) only in 0.2 ha leave islands and unthinned forest.

Seven mollusk species and the *Prophysaon* (tail-dropper) species group were ubiquitous across all forest types (Table 2.3; Appendix B). Interestingly, the rare *Hemphillia malonei* (Malone's jumping slug) occurred across all types of forest and most commonly in thinned forest.

Community Analyses-

<u>Vascular Plants</u>

Using NMS, we found a 2-dimensional solution that explained 92.5% of the variation in the original data of vascular plants (Figure 2.4a). This ordination was then rotated to align the strongest variable from the environmental matrix (average annual precipitation) with axis 1. After rotation, this axis explained 79.2% of the variation in vascular plant communities. This axis was strongly related to mountain range with Coast Range and Cascade Range sites being clearly separated on opposite ends of axis 1. This axis represented geographic gradients in annual precipitation, Spring ambient temperature, and soil moisture. Specifically, axis 1 was strongly positively correlated ($r > 0.500$) with average annual precipitation, Spring relative humidity, Spring and Summer soil moisture, trees per hectare, downed wood density, basal area, canopy closure, and heatload (Table 2.4). This axis was strongly negatively correlated ($r < - 0.500$) with Spring ambient temperature and Spring soil temperature. Axis 2 explained 13.3% of the variation in the original data and

Figure 2.4. NMS ordination diagrams for a) vascular plants, b) arthropods, c) amphibians, and d) mollusks. Site names are abbreviated as follows: BL=Bottomline, DC=Delph Creek, GP=Green Peak, and KM=Keel Mountain. Solid ellipses indicate Coast Range sites. Dashed ellipses indicate Cascade Range sites. Sampling units are plotted in species space. a) 2-dimensional NMS ordination solution for vascular plant species data. Together, these two axes represented 92.5% of the variation in the original data (79.2% and 13.3% for axis 1 and axis 2, respectively). b) Axis 2 and axis 1 of 3-dimensional NMS ordination solution for arthropod species data, representing 94.3% of the variation in the original data. Together, these two axes represented 73.1% of the variation in the original data (42.9% and 30.2% for axis 2 and axis 1, respectively). Axis 3 accounted for the remaining 21.2% of the variation in the original data. c) 2-dimensional NMS ordination solution for amphibian species data. Together, these two axes represented 91.3% of the variation in the original data (54.0% and 37.3% for axis 1 and axis 2, respectively). d) Axis 1 and axis 3 of 3-dimensional NMS ordination solution for mollusk species data, representing 96.2% of the variation in the original data. Together, these two axes represented 81.2% of the variation in the original data (61.0% and 20.2% for axis 1 and axis 3, respectively). Axis 2 accounted for the remaining 15.0% of the variation in the original data.

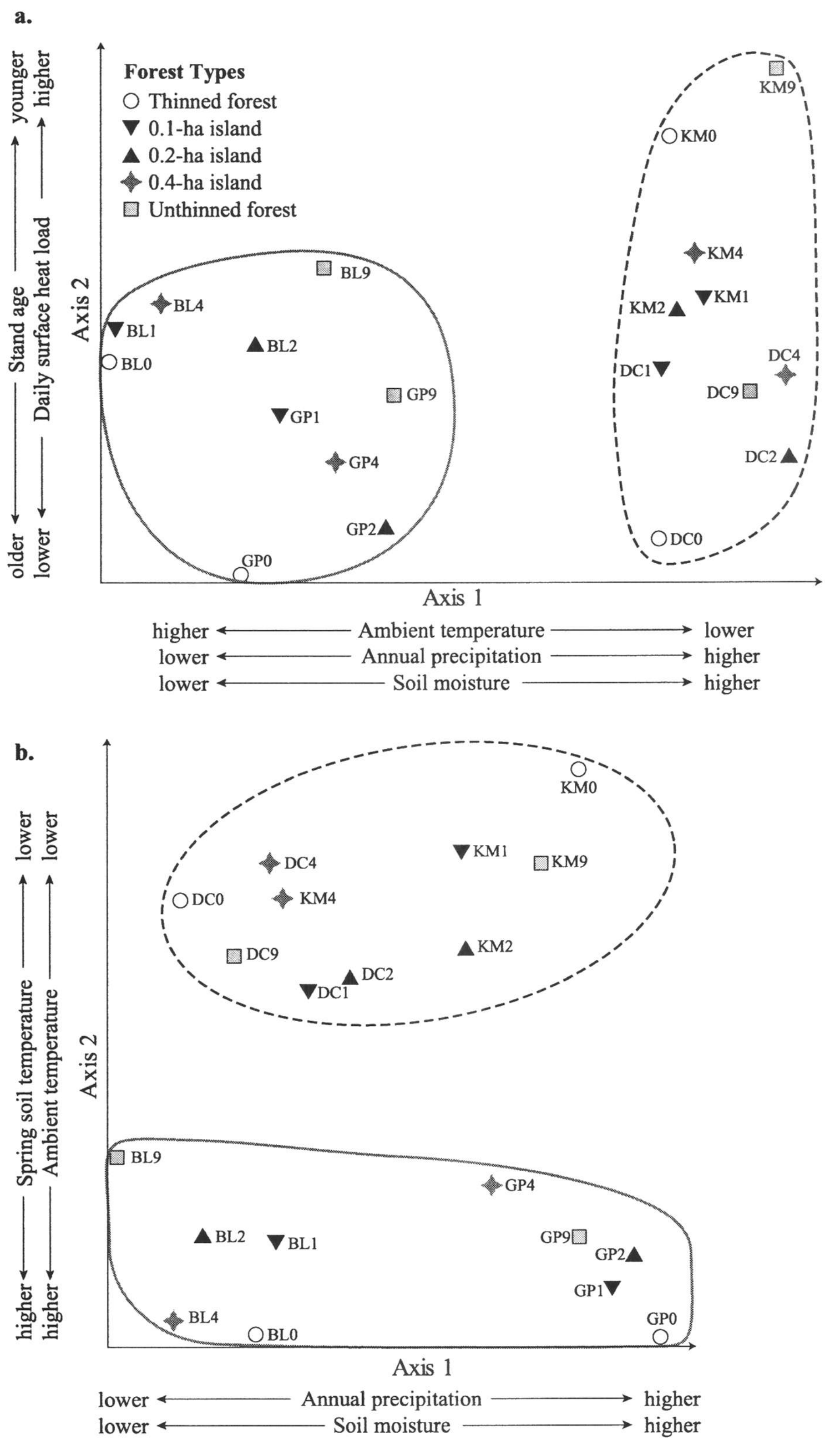
a.
Forest Types
Thinned forest
0.1-ha island
0.2-ha island
0.4-ha island
Unthinned forest
Axis 2
older ← Stand age → younger
lower ← Daily surface heat load → higher
Axis 1
higher ← Ambient temperature → lower
lower ← Annual precipitation → higher
lower ← Soil moisture → higher
KM9
KM0
KM4
KM2
KM1
DC1
DC4
DC9
DC2
DC0
BL9
BL4
BL1
BL0
BL2
GP9
GP1
GP4
GP2
GP0
b.
Axis 2
higher ← Spring soil temperature → lower
higher ← Ambient temperature → lower
Axis 1
lower ← Annual precipitation → higher
lower ← Soil moisture → higher
KM0
KM1
KM9
DC4
KM4
DC0
KM2
DC9
DC2
DC1
BL9
GP4
BL2
BL1
GP9
GP2
GP1
BL4
BL0
GP0

Figure 2.4.

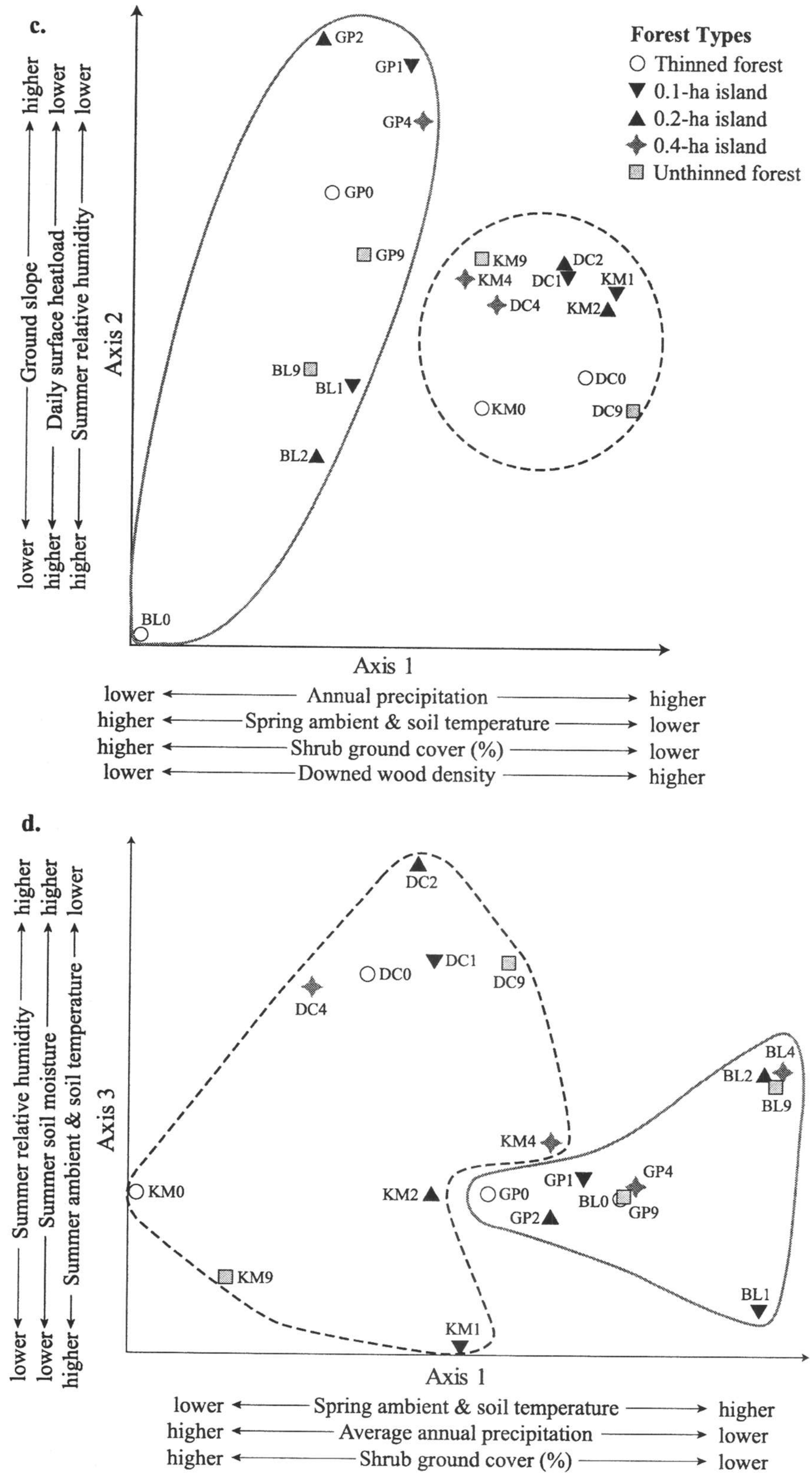

Figure 2.4. (Continued)

Table 2.4. Vascular plant environmental data correlation coefficients with axes 1 and 2 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for both axes displayed. Parameters listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Spring average ambient temperature (°C)	-0.941	0.885	-0.726	-0.378	0.143	-0.284
Average annual precipitation (cm)	0.940	0.884	0.723	0.060	0.004	-0.107
Spring average daily minimum soil temperature (°C)	-0.881	0.775	-0.653	-0.459	0.211	-0.295
Spring average daily minimum RH (%)	0.840	0.705	0.568	0.567	0.321	0.421
Spring soil moisture (%)	0.784	0.615	0.516	0.200	0.040	0.095
Summer soil moisture (%)	0.711	0.505	0.474	0.225	0.051	0.179
Trees per hectare	0.688	0.474	0.547	0.311	0.097	0.189
Downed wood debris density (m^3/m^2)	0.672	0.451	0.432	0.200	0.040	0.095
Basal area (m^2/ha)	0.661	0.436	0.484	0.250	0.062	0.147
Canopy closure (%)	0.600	0.360	0.594	0.360	0.130	0.256
Heatload	0.503	0.253	0.316	0.785	0.617	0.653
Stand age	-0.458	0.210	-0.166	-0.773	0.597	-0.782
Months after timber harvest	-0.307	0.094	-0.426	0.683	0.466	0.403
Summer average ambient temperature (°C)	-0.006	0.000	-0.074	0.515	0.266	0.263

represented gradients in stand age and daily surface heatload. Specifically, this axis was positively correlated with heatload, months after timber harvest, Spring relative humidity, and Summer ambient temperature and negatively correlated with stand age. Study sites within each mountain range displayed clear separation along axis 2.

Vascular plant species positively correlated with axis 1 included *T.heterophylla*, *Oxalis oregana* (redwood-sorrel), *Chimaphila menziesii* (little prince's pine), *Thuja plicata* (western red cedar), and *Blechnum spicant* (deer fern; Table 2.5). Species negatively correlated with this axis included *Campanula scouleri*

Table 2.5. Vascular plant species data correlation coefficients with axes 1 and 2 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for both axes displayed. Species listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Campanula scouleri	-0.929	0.862	-0.674	-0.384	0.148	-0.229
Tsuga heterophylla	0.922	0.850	0.634	0.426	0.182	0.230
Anemone deltoidea	-0.873	0.762	-0.645	-0.233	0.054	-0.089
Osmorhiza berteroi	-0.873	0.762	-0.760	-0.207	0.043	-0.140
Symphoricarpos albus	-0.869	0.756	-0.777	-0.001	0.000	-0.066
Rosa species	-0.855	0.730	-0.768	-0.043	0.002	-0.111
Galium triflorum	-0.838	0.702	-0.783	-0.500	0.250	-0.212
Symphoricarpos mollis	-0.826	0.681	-0.777	-0.003	0.000	-0.114
Poa species	-0.821	0.674	-0.713	-0.168	0.028	-0.128
Holodiscus discolor	-0.820	0.672	-0.669	-0.287	0.082	-0.199
Pteridium aquilinum	-0.813	0.661	-0.674	-0.123	0.015	-0.058
Adenocaulon bicolor	-0.811	0.657	-0.729	-0.103	0.011	-0.186
Achlys triphylla	-0.798	0.636	-0.662	-0.203	0.041	-0.106
Vancouveria hexandra	-0.784	0.615	-0.697	-0.121	0.015	-0.122
Trientalis borealis	-0.783	0.613	-0.494	-0.341	0.117	-0.216
Viola species	-0.768	0.590	-0.554	-0.493	0.243	-0.311
Corylus cornuta	-0.766	0.587	-0.702	0.119	0.014	0.025
Maianthemum stellatum	-0.738	0.545	-0.596	-0.003	0.000	0.017
Moehringia macrophylla	-0.730	0.533	-0.629	0.097	0.009	0.092
Nemophila parviflora	-0.722	0.521	-0.673	-0.041	0.002	-0.170
Oxalis oregana	0.713	0.508	0.571	-0.157	0.025	-0.078
Chimaphila menziesii	0.704	0.495	0.593	0.543	0.295	0.347
Whipplea modesta	-0.673	0.453	-0.574	0.126	0.016	0.244
Claytonia sibirica	-0.655	0.429	-0.560	-0.450	0.203	-0.269
Vicia sativa	-0.635	0.403	-0.660	-0.097	0.009	-0.117
Thuja plicata	0.618	0.382	0.548	0.005	0.000	0.006
Stachys mexicana	-0.617	0.381	-0.693	-0.332	0.110	-0.218
Oxalis suksdorfii	-0.608	0.370	-0.386	0.010	0.000	-0.036
Blechnum spicant	0.604	0.365	0.542	-0.247	0.061	0.024
Fragaria virginiana	-0.597	0.356	-0.538	0.103	0.011	0.208
Galium trifidum	-0.594	0.353	-0.311	0.091	0.008	0.108
Clinopodium douglasii	-0.589	0.346	-0.520	0.130	0.017	0.225

Parameter	Axis 1 r	Axis 1 r^2	Axis 1 tau	Axis 2 r	Axis 2 r^2	Axis 2 tau
Thermopsis gracilis	-0.588	0.345	-0.520	0.102	0.010	0.225
Lonicera hispidula	-0.587	0.344	-0.475	-0.124	0.015	-0.062
Rumex acetosella	-0.516	0.266	-0.488	-0.278	0.077	-0.149
Asarum caudatum	-0.512	0.262	-0.379	-0.515	0.265	-0.448
Pseudotsuga menziesii	-0.446	0.199	-0.315	-0.536	0.287	-0.432
Cardamine species	-0.422	0.178	-0.322	-0.565	0.319	-0.484
Cardamine angulata	-0.418	0.175	-0.293	-0.562	0.315	-0.484
Listera cordata	-0.358	0.128	-0.182	-0.501	0.251	-0.532
Collomia heterophylla	-0.341	0.116	-0.288	-0.530	0.281	-0.428
Trillium ovatum	0.319	0.102	0.289	-0.624	0.389	-0.428
Boykinia occidentalis	0.285	0.081	0.227	0.637	0.406	0.417
Dicentra formosa	-0.231	0.053	-0.203	-0.583	0.340	-0.464
Sonchus species	-0.222	0.049	-0.323	-0.509	0.259	-0.393
Luzula species	0.127	0.016	-0.012	-0.587	0.344	-0.435
Senecio sylvaticus	-0.094	0.009	-0.155	-0.540	0.291	-0.441

(pale bellflower), *Anemone deltoidea* (Columbian windflower), *Osmorhiza berteroi* (sweet cicely), *Symphoricarpos albus* (common snowberry), and *Rosa* species (rose species). Species positively correlated with axis 2 included *Boykinia occidentalis* (coastal brookfoam), *C. menziesii*, *Veronica officinalis* (common gypsyweed), and *T. heterophylla*. Species negatively correlated with this axis included *Trillium ovatum* (Pacific trillium), *Luzula* species (woodrush species), and *Dicentra formosa* (Pacific bleeding heart).

Arthropods

NMS selected a 3-dimensional solution that provided a substantial reduction in stress compared to randomized data and represented 94.3% of the variation in the original data (Figure 2.4b). After rotating to align the strongest variable from the environmental matrix (average annual precipitation) with axis 1, 42.9% of the variation in the original data was represented by axis 2, 30.2% by axis 1, and the remaining 21.2% by axis 3. Axis 2 was strongly related to mountain range with Coast Range and Cascade Range sites being clearly separated on opposite ends of the axis. This axis was strongly positively ($r > 0.500$) correlated with Summer ambient and soil temperatures and strongly negatively correlated ($r < -0.500$) with Spring soil temperature, Summer relative humidity, and total vascular plant ground cover (Table 2.6). Axis 1 was positively correlated with average annual precipitation, Summer soil moisture, percent rock ground cover, and density of all downed wood and negatively correlated with Spring ambient temperature, Spring soil temperature, percent shrub ground cover, and percent vascular plant ground cover. Study sites within each mountain range displayed clear separation along this axis. Finally, axis 3 was positively correlated with Summer soil temperature, stand age, and Summer ambient temperature. This axis was negatively correlated with Summer relative humidity, months after timber harvest, and Spring relative humidity.

Arthropod species positively correlated with axis 2 included *Julid* species, *Notiophilus sylvaticus*, *Listemus formosus*, *Tenebrionid*, and *Micryphantid* species (Table 2.7). Species negatively correlated with this axis included *Chordeumid*, *Agulla*, *Nemocestes puncticollis*, *Pristoceuthophilus*, and *Scytonotus*. Arthropod species positively correlated with axis 1 included *Cicadellid* species, *Bracon* X, *Anatis*, parasitic wasp species, and *Geodercodes latipennis*. Species negatively

Table 2.6. Arthropod environmental data correlation coefficients with axes 1, 2, and 3 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for all axes displayed. Parameters listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Average annual precipitation (cm)	0.908	0.824	0.758	-0.004	0.000	0.107	-0.004	0.000	0.012
Spring average daily minimum ambient temperature (°C)	-0.778	0.605	-0.432	-0.356	0.127	-0.358	0.075	0.006	0.095
Spring average ambient temperature (°C)	-0.770	0.593	-0.411	-0.363	0.132	-0.379	0.053	0.003	0.032
Summer soil moisture (%)	0.718	0.515	0.495	-0.458	0.210	-0.253	-0.257	0.066	-0.137
Spring average daily minimum soil temperature (°C)	-0.698	0.487	-0.463	-0.491	0.241	-0.368	-0.010	0.000	0.021
% rock ground cover (%)	0.677	0.459	0.500	0.386	0.149	0.272	0.135	0.018	0.087
Downed wood debris density (m^3/m^2)	0.668	0.447	0.495	-0.109	0.012	0.021	-0.116	0.013	-0.179
% shrub ground cover (%)	-0.666	0.443	-0.522	-0.430	0.185	-0.332	-0.237	0.056	0.026
Spring average daily minimum RH (%)	0.613	0.376	0.253	0.096	0.009	0.137	-0.304	0.092	-0.211
Spring average daily maximum RH (%)	0.612	0.375	0.434	-0.353	0.124	-0.212	-0.387	0.150	-0.265
Spring average RH (%)	0.601	0.361	0.284	-0.127	0.016	0.042	-0.471	0.222	-0.284
Total % vascular plant ground cover (%)	-0.600	0.360	-0.421	-0.545	0.296	-0.432	-0.025	0.001	0.021
Spring soil moisture (%)	0.564	0.318	0.347	0.147	0.022	0.105	-0.015	0.000	-0.011
Spring average daily maximum soil temperature (°C)	-0.426	0.182	-0.253	-0.768	0.590	-0.579	-0.108	0.012	-0.084
Months after timber harvest	-0.393	0.154	-0.509	0.026	0.001	0.118	-0.502	0.252	-0.308
Summer average daily maximum ambient temperature (°C)	-0.341	0.116	-0.137	0.571	0.326	0.337	0.019	0.000	-0.032
Summer average daily maximum soil temperature (°C)	-0.271	0.073	-0.021	0.773	0.597	0.474	0.267	0.071	0.211
Stand age	-0.242	0.058	-0.083	-0.501	0.251	-0.118	0.304	0.093	0.450

Table 2.6. (Continued)

Parameter	Axis 1			Axis 2			Axis 3		
	r	r^2	tau	r	r^2	tau	r	r^2	tau
Summer average daily minimum soil temperature (°C)	-0.174	0.030	-0.021	0.820	0.673	0.474	0.308	0.095	0.211
Summer average RH (%)	0.159	0.025	0.053	-0.695	0.483	-0.316	-0.587	0.344	-0.432
Summer average daily maximum RH (%)	0.158	0.025	-0.105	-0.630	0.397	-0.368	-0.612	0.375	-0.505
% moss ground cover (%)	0.106	0.011	0.058	-0.514	0.264	-0.343	0.071	0.005	0.100
Aspect	0.070	0.005	0.027	0.506	0.256	0.456	-0.209	0.044	-0.188
Summer average daily minimum ambient temperature (°C)	0.060	0.004	0.053	0.897	0.805	0.589	0.164	0.027	0.137

Table 2.7. Arthropod species data correlation coefficients with axes 1, 2, and 3 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for all axes displayed. Species listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Geophilomorpha species	-0.856	0.733	-0.660	0.103	0.011	0.047	-0.082	0.007	0.005
Staphylinidae species	-0.783	0.613	-0.570	0.253	0.064	0.194	-0.209	0.044	-0.022
Carabid species	-0.760	0.578	-0.538	0.477	0.227	0.312	0.045	0.002	0.086
Striaria species	-0.760	0.577	-0.669	-0.419	0.176	-0.200	-0.299	0.089	0.017
Lithobid species	-0.760	0.577	-0.533	0.181	0.033	0.090	-0.189	0.036	-0.111
Scolopocryptops	-0.745	0.555	-0.595	-0.174	0.030	-0.080	-0.339	0.115	-0.220
Tachinus species	-0.733	0.537	-0.651	0.091	0.008	0.006	-0.329	0.108	-0.088
Hesperonemastoma	-0.706	0.499	-0.573	-0.169	0.029	-0.152	-0.307	0.094	-0.129
Caseya	-0.693	0.480	-0.544	-0.419	0.175	-0.227	-0.325	0.106	-0.058
Bdellozoniun	-0.689	0.475	-0.560	-0.235	0.055	-0.110	-0.609	0.371	-0.110
Cicadellid species	0.686	0.471	0.665	-0.303	0.092	-0.078	-0.071	0.005	-0.169
Bracon X	0.681	0.464	0.552	-0.205	0.042	-0.169	0.191	0.036	0.155
Batrissodes species	-0.622	0.387	-0.454	0.403	0.163	0.238	-0.027	0.001	-0.054
Lucifotychus species	-0.601	0.361	-0.447	0.503	0.253	0.277	0.098	0.010	0.032
Arctorthezia occidentalis	-0.598	0.358	-0.448	0.483	0.233	0.328	0.384	0.147	0.197
Antrodiaetus species	-0.590	0.349	-0.439	0.615	0.379	0.428	-0.144	0.021	-0.005
Myrmica	-0.580	0.336	-0.459	-0.345	0.119	-0.216	-0.489	0.239	-0.237
Colon	-0.539	0.291	-0.498	-0.350	0.123	-0.234	-0.497	0.247	-0.376

Table 2.7. (Continued)

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Atrechus	-0.532	0.283	-0.358	-0.589	0.347	-0.336	-0.437	0.191	-0.325
Taracus	-0.531	0.281	-0.446	-0.315	0.099	-0.234	-0.412	0.170	-0.304
Ptiliid species	-0.525	0.276	-0.312	-0.055	0.003	-0.043	-0.514	0.264	-0.519
Pterostichus species	-0.524	0.275	-0.313	-0.431	0.186	-0.292	0.002	0.000	0.037
Anatis	0.517	0.268	0.381	0.023	0.001	0.073	0.133	0.018	0.073
Braconid species	0.517	0.267	0.379	-0.004	0.000	-0.048	-0.334	0.111	-0.197
Geodercodes latipennis	0.496	0.246	0.327	0.036	0.001	0.172	-0.601	0.362	-0.449
Brachyrhinus rugostriatus	0.491	0.241	0.280	0.581	0.337	0.430	0.344	0.119	0.140
Microcreagis	-0.489	0.239	-0.324	-0.059	0.003	0.005	-0.641	0.411	-0.355
Fenderia capizii	-0.482	0.232	-0.351	-0.210	0.044	0.011	-0.879	0.772	-0.612
Lasius	-0.467	0.218	-0.242	-0.344	0.118	-0.277	-0.526	0.277	-0.313
Lophioderus	-0.455	0.207	-0.308	-0.115	0.013	-0.099	-0.810	0.657	-0.539
Acrotrichus species	-0.437	0.191	-0.229	-0.213	0.045	-0.229	-0.835	0.697	-0.486
Julid species	-0.425	0.181	-0.281	0.865	0.748	0.606	0.100	0.010	0.076
Tipulid	-0.409	0.167	-0.303	0.634	0.402	0.476	0.169	0.029	0.227
Agulla	0.399	0.159	0.220	-0.730	0.534	-0.610	-0.179	0.032	-0.170
Machilid	0.399	0.159	0.339	-0.576	0.331	-0.364	-0.327	0.107	-0.236
Lucanid (immature)	-0.383	0.147	-0.298	-0.132	0.018	-0.107	-0.608	0.370	-0.394
Noctuid	-0.383	0.146	-0.278	-0.270	0.073	-0.213	-0.605	0.366	-0.409

Table 2.7. (Continued)

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Microcybaeus	-0.382	0.146	-0.277	-0.203	0.041	-0.121	-0.716	0.513	-0.555
Liposcelis	-0.380	0.145	-0.274	-0.045	0.002	0.107	-0.625	0.391	-0.417
Usofila	-0.378	0.143	-0.291	0.426	0.182	0.260	0.500	0.250	0.449
Ceratolasma	-0.372	0.138	-0.301	-0.486	0.236	-0.380	-0.503	0.253	-0.396
Pselaphid (immature)	-0.369	0.136	-0.253	0.253	0.064	0.189	-0.553	0.306	-0.351
Nearctodesmus	-0.367	0.135	-0.182	-0.084	0.007	0.084	-0.606	0.367	-0.251
Nemocestes puncticollis	0.359	0.129	0.210	-0.712	0.507	-0.581	-0.262	0.069	-0.259
Megaselia	0.352	0.124	0.292	0.525	0.276	0.541	-0.087	0.008	-0.115
Pristoceuthophilus	0.351	0.123	0.228	-0.650	0.423	-0.425	-0.393	0.154	-0.265
Smittia	-0.351	0.123	-0.227	0.532	0.283	0.406	0.170	0.029	0.351
Bollmannella	-0.350	0.123	-0.148	0.512	0.262	0.371	0.538	0.289	0.432
Ceraphron species	0.348	0.121	0.199	0.090	0.008	0.133	-0.528	0.279	-0.354
Catopocerus species	-0.328	0.108	-0.198	0.023	0.001	0.134	-0.669	0.448	-0.424
Aranaeus saevus	-0.326	0.106	-0.107	-0.113	0.013	-0.060	-0.560	0.313	-0.203
Enicmus	-0.324	0.105	-0.110	0.033	0.001	0.269	-0.643	0.413	-0.448
Siro acaroides	-0.300	0.090	-0.170	0.722	0.521	0.565	0.115	0.013	0.115
Micropeplus	-0.297	0.088	-0.253	0.054	0.003	-0.063	-0.580	0.336	-0.586
Polyxenes	0.283	0.080	0.328	-0.329	0.108	-0.236	-0.571	0.327	-0.342
Harpalus species	-0.277	0.076	-0.070	-0.228	0.052	-0.269	-0.589	0.347	-0.329
Proctotrupid species	-0.274	0.075	-0.169	-0.139	0.019	-0.104	-0.636	0.404	-0.430

Table 2.7. (Continued)

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Actium	-0.260	0.067	-0.142	-0.053	0.003	-0.026	-0.559	0.312	-0.530
Tenebrionid (immature)	-0.246	0.060	-0.186	0.763	0.582	0.483	0.343	0.117	0.239
Micromoth	-0.245	0.060	0.026	-0.057	0.003	0.166	-0.680	0.462	-0.480
Malachius	-0.229	0.052	-0.141	0.070	0.005	0.141	-0.663	0.440	-0.423
Piestus	-0.222	0.049	-0.135	-0.262	0.069	-0.151	-0.628	0.394	-0.326
Scaphinotus species	0.190	0.036	0.172	-0.595	0.353	-0.474	-0.339	0.115	-0.287
Scutigerella	0.161	0.026	0.175	0.525	0.275	0.328	-0.368	0.135	-0.295
Byrrhid (immature)	-0.150	0.023	-0.016	0.642	0.412	0.443	0.234	0.055	0.165
Scytonotus	-0.150	0.023	-0.061	-0.628	0.395	-0.419	-0.739	0.546	-0.530
Bradysia	-0.149	0.022	-0.171	0.545	0.297	0.471	-0.524	0.275	-0.342
Diapriid species	-0.150	0.022	-0.061	-0.146	0.021	-0.122	-0.661	0.437	-0.511
Listemus formosus	0.143	0.020	0.089	0.814	0.662	0.691	0.268	0.072	0.195
Trombidiid	-0.136	0.018	-0.098	0.682	0.465	0.522	-0.235	0.055	-0.174
Elater species	0.118	0.014	0.069	0.525	0.276	0.451	-0.477	0.228	-0.324
Chordeumid	-0.115	0.013	-0.070	-0.746	0.556	-0.456	-0.376	0.141	-0.274
Micryphantid species	-0.100	0.010	-0.193	0.729	0.531	0.588	-0.104	0.011	-0.032
Notiophilus sylvaticus	-0.082	0.007	-0.042	0.862	0.744	0.601	0.404	0.163	0.346
Megarofonus species	-0.084	0.007	0.029	0.151	0.023	0.179	-0.538	0.290	-0.295
Apochthonius	0.076	0.006	-0.021	0.586	0.344	0.434	-0.341	0.116	-0.254
Cytilus alternatus	0.072	0.005	0.048	0.602	0.363	0.400	0.265	0.070	0.133

Table 2.7. (Continued)

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Geometrid (immature)	-0.057	0.003	0.014	0.066	0.004	0.027	-0.576	0.332	-0.544
Ichneumonid (adult)	0.028	0.001	0.133	-0.130	0.017	0.000	-0.522	0.272	-0.266

correlated with this axis included *Geophilomorpha* species, Staphylinidae species, *Lysiopetalid*, *Lithobid*, and *Carabid* species. Finally, arthropod species positively correlated with axis 3 included *Bollmannella*, *Usofila*, *N. sylvaticus*, *Mycetophilid*, and *Chionea*. Species negatively correlated with this axis included *Fenderia capizii*, *Acrotrichus* species, *Lophioderus*, *Scytonotus*, and *Microcybaeus*.

Amphibians

NMS selected a 2-dimensional solution that represented 91.3% of the variation in the original data (Figure 2.4c). This ordination was then rotated to alignthe strongest variable from the environmental matrix (average annual precipitation) with axis 1. After rotation, this axis explained 54.0% of the variation in amphibian communities. This axis was strongly related to mountain range with all Coast Range and Cascade Range sites being segregated on opposite ends of axis 1. This axis was positively correlated with average annual precipitation, density of all downed wood, percent litter ground cover, Spring relative humidity, and Spring soil moisture and negatively correlated with Spring ambient temperature, Spring soil temperature, and percent shrub ground cover (Table 2.8). The second axis represented 37.3% of the variation in the original data. This axis was positively correlated with slope, trees per hectare, Summer soil temperature, and Summer ambient temperature. This axis was negatively correlated with Summer relative humidity, heat load, total and vascular plant ground cover. Amphibian assemblages at Coast Range study sites were distinctly separated along this axis while Cascade Range study sites displayed a less clear separation along this axis.

Table 2.8. Amphibian environmental data correlation coefficients with axes 1 and 2 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for both axes displayed. Parameters listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Average annual precipitation (cm)	0.875	0.765	0.757	0.004	0.000	-0.020
Spring average ambient temperature (°C)	-0.820	0.673	-0.567	-0.053	0.003	-0.088
Spring average daily maximum ambient temperature (°C)	-0.793	0.628	-0.579	-0.083	0.007	-0.076
% shrub ground cover (%)	-0.765	0.585	-0.563	-0.445	0.198	0.000
Spring average daily minimum soil temperature (°C)	-0.727	0.529	-0.497	-0.106	0.011	-0.041
Downed wood debris density (m^3/m^2)	0.690	0.476	0.532	-0.126	0.016	-0.205
% litter ground cover (%)	0.666	0.444	0.394	0.240	0.058	-0.037
Spring average daily minimum RH (%)	0.654	0.428	0.404	-0.229	0.053	-0.123
Total % vascular plant ground cover (%)	-0.649	0.422	-0.380	-0.479	0.229	-0.205
Spring soil moisture (%)	0.641	0.411	0.520	-0.140	0.020	-0.123
Spring average RH (%)	0.626	0.392	0.298	-0.397	0.158	-0.135
Summer soil moisture (%)	0.622	0.387	0.404	-0.399	0.159	-0.193
Average tree diameter at breast height (cm)	-0.584	0.340	-0.404	-0.308	0.095	-0.158
% rock ground cover (%)	0.552	0.305	0.433	0.175	0.031	0.120
Trees per hectare	0.553	0.305	0.380	0.413	0.171	0.251
Basal area (m^2/ha)	0.544	0.296	0.333	0.314	0.099	0.298
Spring average daily maximum soil temperature (°C)	-0.514	0.264	-0.357	-0.289	0.084	-0.205
Heatload	0.366	0.134	0.216	-0.515	0.265	-0.263
Months after timber harvest	-0.337	0.113	-0.428	-0.565	0.319	-0.309
Summer average daily maximum RH (%)	0.199	0.040	-0.029	-0.724	0.524	-0.556

Amphibian species positively correlated with axis 1 included *B. wrighti* and *E. eschscholtzii* while *T. granulosa* and *P. vehiculum* were negatively correlated with this axis (Table 2.9). *P. vehiculum* and *E. eschscholtzii* were positively correlated with axis 2 while *B. wrighti* was negatively correlated with this axis.

Table 2.9. Amphibian species data correlation coefficients with axes 1 and 2 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for both axes displayed. Species listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Batrachoseps wrighti	0.888	0.789	0.862	-0.172	0.029	-0.265
Ensatina eschscholtzii	0.595	0.354	0.397	0.701	0.491	0.519
Plethodon vehiculum	-0.269	0.072	-0.301	0.753	0.567	0.680

Mollusks

NMS found a 3-dimensional solution that explained 96.2% of the variation in the original data (Figure 2.4d). This ordination was then rotated to align the strongest variable from the environmental data matrix (average daily minimum Spring soil temperature) with axis 1. After rotation, this axis represented 61.0% of the variation in mollusk communities. This axis was related to mountain range with Cascade Range and Coast Range sites being largely segregated along axis 1. This axis was positively correlated with Spring soil temperature, Spring ambient temperature, and percent shrub ground cover and negatively correlated with average annual precipitation, percent rock ground cover, Spring soil moisture, average daily minimum Spring relative humidity, and density of all downed wood (Table 2.10).

Table 2.10. Mollusk environmental data correlation coefficients with axes 1, 2, and 3 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for all axes displayed. Parameters listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Spring average daily minimum soil temperature (°C)	0.816	0.666	0.621	-0.002	0.000	0.032	0.045	0.002	0.032
Spring average daily minimum ambient temperature (°C)	0.809	0.654	0.547	0.125	0.016	0.147	-0.090	0.008	0.021
Average annual precipitation (cm)	-0.772	0.596	-0.687	-0.190	0.036	-0.142	0.488	0.239	0.284
% shrub ground cover (%)	0.771	0.594	0.649	-0.113	0.013	0.005	-0.155	0.024	-0.090
Spring average daily maximum ambient temperature (°C)	0.750	0.562	0.484	0.179	0.032	0.147	-0.120	0.015	-0.021
% rock ground cover (%)	-0.745	0.556	-0.489	0.199	0.039	-0.054	0.110	0.012	0.065
Total % vascular plant ground cover (%)	0.722	0.521	0.558	-0.150	0.022	-0.032	-0.067	0.004	0.032
Spring average daily maximum soil temperature (°C)	0.685	0.469	0.432	-0.139	0.019	-0.116	0.374	0.140	0.221
Spring soil moisture (%)	-0.603	0.363	-0.421	-0.228	0.052	-0.147	0.200	0.040	0.084
Spring average daily minimum RH (%)	-0.588	0.345	-0.347	-0.356	0.127	-0.347	0.167	0.028	0.074
Downed wood debris density (m^3/m^2)	-0.504	0.254	-0.421	-0.286	0.082	-0.232	0.432	0.187	0.295
% litter ground cover (%)	-0.479	0.230	-0.414	-0.177	0.031	-0.303	0.451	0.203	0.370
Spring average RH (%)	-0.477	0.228	-0.358	-0.436	0.190	-0.379	0.303	0.092	0.126
Summer soil moisture (%)	-0.467	0.218	-0.316	-0.399	0.159	-0.400	0.676	0.457	0.421
% herbaceous ground cover (%)	0.465	0.216	0.242	-0.134	0.018	-0.137	0.033	0.001	0.095
Stand age	0.436	0.190	0.154	0.102	0.010	0.320	0.423	0.179	0.225
Summer average daily minimum ambient temperature (°C)	-0.432	0.186	-0.189	0.256	0.065	0.211	-0.666	0.443	-0.442

Table 2.10. (Continued)

Parameter	Axis 1			Axis 2			Axis 3		
	r	r^2	tau	r	r^2	tau	r	r^2	tau
Trees per hectare	-0.418	0.174	-0.347	-0.247	0.061	-0.179	0.043	0.002	0.053
Spring average daily maximum RH (%)	-0.376	0.141	-0.339	-0.407	0.166	-0.423	0.504	0.254	0.296
Average tree diameter at breast height (cm)	0.342	0.117	0.284	0.209	0.044	0.116	0.010	0.000	-0.032
Basal area (m^2/ha)	-0.339	0.115	-0.242	-0.308	0.095	-0.263	0.145	0.021	0.074
Heatload	-0.317	0.100	-0.179	-0.281	0.079	-0.284	-0.069	0.005	-0.116
Months after timber harvest	0.316	0.100	0.415	-0.166	0.027	-0.036	-0.458	0.210	-0.391
Hardwood basal area (m^2/ha)	0.266	0.071	0.270	-0.431	0.185	-0.284	-0.098	0.010	-0.036
Summer average daily minimum soil temperature (°C)	-0.236	0.056	-0.116	0.566	0.320	0.347	-0.707	0.499	-0.432
Summer average ambient temperature (°C)	-0.236	0.055	-0.211	0.281	0.079	0.189	-0.785	0.617	-0.526
% moss ground cover (%)	0.208	0.043	0.121	-0.183	0.034	-0.016	0.133	0.018	0.005
Summer average soil temperature (°C)	-0.200	0.040	-0.105	0.571	0.326	0.358	-0.720	0.518	-0.442
Canopy closure (%)	-0.200	0.040	-0.354	-0.354	0.125	-0.213	0.052	0.003	-0.005
Slope (%)	0.185	0.034	0.150	0.483	0.233	0.353	-0.288	0.083	-0.128
Aspect	-0.171	0.029	-0.091	-0.062	0.004	-0.123	-0.441	0.195	-0.274
% exposed soil ground cover (%)	0.134	0.018	0.043	-0.394	0.155	-0.333	0.296	0.088	0.312
Summer average RH (%)	0.110	0.012	0.042	-0.603	0.364	-0.400	0.614	0.377	0.421
Summer average daily maximum RH (%)	0.090	0.008	0.158	-0.573	0.328	-0.284	0.400	0.160	0.179
Summer average daily minimum RH (%)	-0.033	0.001	-0.063	-0.568	0.322	-0.442	0.659	0.434	0.400
Summer average daily maximum ambient temperature (°C)	-0.030	0.001	-0.021	0.379	0.143	0.211	-0.747	0.559	-0.484

Axis 3 represented 20.2% of the variation in the data. This axis was positively correlated with Summer soil moisture, Summer relative humidity, Spring relative humidity, and average annual precipitation. This axis was negatively correlated with Summer ambient temperature and Summer soil temperature. Delph Creek study site sampling units were distinctly clustered at the top of this axis while sampling units from other sites were only moderately separated. Finally, axis 2 explained 15.0% of the variation in the data. This axis was positively correlated with Summer soil temperature, slope, and Summer ambient temperature and negatively correlated with Summer relative humidity, basal area of hardwood trees, and percent exposed soil ground cover.

Mollusk species positively correlated with axis 1 included *Ancotrema sportella* (beaded lancetooth snail), *Vespericola columbianus* (northwest hesperian snail), and *H. vancouverense* (Table 2.11). Species negatively correlated with this axis included *Prophysaon* species (tail-dropper species) and *H. malonei*. Species positively correlated with axis 3 included *H. malonei* and *A. sportella/H. vancouverense* juveniles (beaded lancetooth/robust lancetooth juvenile snails) while species negatively correlated with this axis included *Ariolimax columbianus* (Pacific banana slugs) and *A. sportella*. Finally, *A. columbianus* was the only species positively correlated with axis 2 while *H. vancouverense*, *V. columbianus*, and *Prophysaon* species were negatively correlated with the axis.

Table 2.11. Mollusk species data correlation coefficients with axes 1, 2, and 3 of NMS ordination solution. Pearson (r), proportion of variance (r^2), and Kendall rank correlation (tau) coefficients for all axes displayed. Species listed only if proportion of variance (r^2) explained by at least one axis was greater than or equal to 0.250.

	Axis 1			Axis 2			Axis 3		
Parameter	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**	**r**	**r^2**	**tau**
Ancotrema sportella	0.872	0.760	0.732	-0.066	0.004	-0.005	-0.378	0.143	-0.222
Vespericola columbianus	0.823	0.678	0.642	-0.700	0.490	-0.379	-0.020	0.000	0.011
Haplotrema vancouverense	0.762	0.581	0.501	-0.784	0.615	-0.512	0.370	0.137	0.301
Monadenia fidelis	0.686	0.471	0.728	-0.218	0.047	-0.146	-0.072	0.005	-0.040
Prophysaon species	-0.540	0.292	-0.412	-0.462	0.214	-0.345	-0.032	0.001	0.033
Hemphillia malonei	-0.412	0.170	-0.427	-0.181	0.033	-0.222	0.778	0.605	0.602
Ancotrema sportella-Haplotrema vancouverense juveniles	0.257	0.066	0.219	-0.462	0.214	-0.432	0.647	0.419	0.517
Ariolimax columbianus	-0.175	0.031	-0.122	0.402	0.162	0.387	-0.554	0.307	-0.498

DISCUSSION

Forest management activities can dramatically alter forest structure and habitat conditions for resident biota. Sustaining species adversely affected by silvicultural activities may require the implementation of innovative mitigation strategies such as aggregated and dispersed green tree retention. Our retrospective study showed treatment effects on habitat and some biota resulting from thinning, and leave islands represented a potentially effective strategy to mitigate some treatment effects (Table 2.12). The larger leave islands (0.2 ha and 0.4 ha) appeared effective in maintaining a semblance of interior forest conditions and several taxa within thinned forests. The smallest leave islands (0.1 ha) appeared analogous to thinned forests as shown by several measures of microclimate and the presence of taxa associated with thinned forests. Leave islands may provide incidental benefits to a host of forest taxa. Thinning most consistently affected microclimate, forest stand structure, and the composition and abundance of vascular plants. About half (45 of 88) of these measures showed an effect of thinning. Microclimate differences followed intuitive predictions, with measures of ambient temperature and soil temperature consistently higher in thinned forest than unthinned forest and measures of relative humidity consistently higher in unthinned forest than thinned forest. Similarly, differences in forest stand structure followed logical patterns with measures of canopy closure, trees per hectare, and basal area consistently higher in unthinned forest than thinned forest.

Thinning effects on resident biota were most pronounced for vascular plant species composition, with species assemblages in thinned forest including more early-

Table 2.12. Summary of key findings. Bold indicates concurrence of findings among different analyses. +/- indicates direction of treatment effect (i.e., + indicates parameter increased with forest thinning/with larger leave island size). Treatment names for indicator species analysis results are abbreviated as follows: T=thinned forest, S=small (0.1 ha) leave islands, M=medium (0.2 ha) leave islands, L=large (0.4 ha) leave islands, and U=unthinned forest.

	Taxon			
Analysis	**Plants**	**Arthropods**	**Amphibians**	**Mollusks**
ANOVA—Thinning effect	**% late-successional species ground cover (-)**	% low-mobility captures (-)	Species richness (-)	1 species (-)
	% late-successional species (-)	1 species (-)		
	% native species (-)	**4 species groups (-)**		
	Species richness (+)	2 species (+)		
	Shannon diversity (+)	1 species group (+)		
	Total ground cover (+)			
	Herb and tree ground cover (+)			
	No. herb species (+)			
	% early-successional species ground cover* (+)			
	Early-successional species ground cover (+)			
	No. early-successional species (+)			
	% early-successional species* (+)			
	% exotic species ground cover* (+)			
	Exotic species ground cover (+)			
	No. exotic species (+)			
	% exotic species* (+)			
	No. native species (+)			
	2 species ground cover (+)			
	1 species group ground cover (+)			

Table 2.12. (Continued)

	Taxon			
Analysis	**Plants**	**Arthropods**	**Amphibians**	**Mollusks**
ANOVA—Leave island effect	**% late-successional species ground cover** (+)	Species richness (+)	**Species richness (-)**	Mollusk density (+)
	% late-successional species (+)	Arthropods density (+)	1 species (-)	Snail density (+)
	% native species (+)	No. functional groups (+)	1 species (+)	2 species (+)
	1 species ground cover (+)	No. low-mobility species (+)		1 species group (+)
	Species richness (-)	Low-mobility captures (+)		
	Shannon diversity (-)	No. high-mobility species (+)		
	No. herb species (-)	High-mobility species density (+)		
	% early-successional species ground cover* (-)	LSOG-associated captures/m^2 (+)		
	Early-successional species ground cover (-)	**6 species groups (+)**		
	% early-successional species* (-)			
	No. early-successional species (-)			
	% exotic species ground cover* (-)			
	Exotic species ground cover (-)			
	No. exotic species (-)			
	% exotic species* (-)			
	No. native species (-)			
	4 species ground cover (-)			
	1 species group ground cover (-)			

Table 2.12. (Continued)

	Taxon			
Analysis	**Plants**	**Arthropods**	**Amphibians**	**Mollusks**
Indicator species	*Hypochaeris radicata* (T)	*Steremnius carinatus* (T)		
	Chamerion angustifolium (T)	*Hexura* (M)		
	Epilobium ciliatum (T)	*Staphylinid* species (L)		
	Cirsium vulgare (T)			
	Asteraceae species (T)			
	Luzula species (T)			
	Acer circinatum (M)			

successional and exotic plant species while unthinned forest assemblages were comprised of late-successional and native species. Differences in plant species composition resulting from forest thinning may have cascading effects on other biota associated with or dependent upon particular vascular plant species. For example, the federally endangered *Icaricia icarioides fenderi* (Fender's blue butterfly) has a strong habitat association with the federally threatened *Lupinus sulphureus* ssp. *kincaidii* (Kincaid's lupine; Kaye 1999), although these species were not examined here.

Thinning resulted in a less distinct pattern of effects on arthropods, amphibians, and mollusks. Only six of the 112 (5.4%) measures analyzed for these taxa decreased with thinning (amphibian species richness, percentage of low-mobility arthropod species captures, density of the arthropods *A. occidentalis, Myrmica*, and *Pristoceuthophilus*, and density of the mollusk *Haplotrema vancouverense*) while three of 112 (2.7%) measures increased with thinning (density of the plant-feeding arthropods *C. alternatus*, *S. carinatus*, and Lygaeidae; Table 2.1; Appendix B). While these effects should not be discounted, with a significance level (α) of 0.10 one might expect to see this number of significant results by chance alone.

Several explanations might be offered for this difference in thinning effects between plants and animals. Habitat conditions resulting from the moderate intensity of the 200 tph thinning treatment may have remained relatively hospitable for most animal taxa. That is, although habitat analyses revealed multiple treatment effects of thinning on microclimate and forest structure, they may not have been biologically relevant for animals; the resulting range of ecological conditions may have allowed the persistence of most of the resident animal taxa. Organisms may respond more dramatically to fine-scale structural habitat changes rather than to coarse-scale changes associated with this thinning treatment. Also, the scale of sampling might not be appropriate for detecting treatment effects on these low-mobility organisms associated with or dependent upon discrete microhabitat features. Further, the limited area of each study site (approximately 2.59 km^2 or 259 ha) resulted in a rather tightly packed mosaic of forest types. The moderate thinning treatment wholeplot abutted the unthinned forest wholeplot at three of our four study sites, and unthinned riparian reserves occurred within the moderate thinning treatment. The close proximity of the two forest types may have aided dispersal of organisms, even those with general low mobility, thereby obscuring treatment effects.

The integrated and leave island analyses also showed more effects on habitats and plants (64 of 175 [36.6%]) than fauna (29 of 167 [17.4%]). Interestingly, more fauna could be analyzed by these approaches (167 vs. 112 in thinned vs. unthinned analyses) and the number of faunal treatment effects doubled (17% vs. 8%) once leave islands were incorporated into analyses.

In the integrated analyses comparing the five forest types, microclimate within leave islands was often intermediate to thinned and unthinned forest and differed sharply from thinned forest. Relative humidity, ambient temperature, soil temperature, and attributes of forest structure differed among our five forest types, resulting in a heterogeneous mosaic of conditions within sites. Measures of soil moisture and downed wood density (m^3/m^2) did not differ among forest types. An apparent threshold in microclimate conditions was evident at the 0.2 ha leave island size: microclimate conditions in 0.4 ha leave islands were most similar to the unthinned forest while conditions in 0.1 ha leave islands were similar to the thinned forest.

In Pacific Northwest Douglas-fir forests, Chen et al. (1995) found that microclimatic edge effects from a clearcut boundary typically extend from 30 to more than 240 m into the interior of adjacent old-growth forest patches, depending upon the measure. Although we do not directly address edge effects in this study, the restricted size of these leave islands (radii of approximately 18m, 25m, and 36m for 0.1, 0.2, and 0.4 ha leave islands, respectively) suggests that the interior of these leave islands likely show strong edge effects along the boundary between thinned forest and the embedded leave islands. However, the circular configuration of these leave islands maximizes the interior-to-edge ratio (Forman and Godron 1986) and thereby minimizes the proportion of the leave island interior influenced by the surrounding thinned forest. In this study, within stand variability in measures of microclimate appeared to be ameliorated between 18 and 36 m (radii of 0.1 ha and 0.4 ha leave islands, respectively) from a stand edge for some measures of relative humidity, ambient temperature, and soil temperature (Tables 2.1 and 2.2). This size threshold is consistent with past research suggesting that leave islands smaller than 0.12 ha in size are functionally ineffective for timber production due to edge effects causing poor growth form and slow regeneration growth (Oliver and Larson 1996). Also, minimum size recommendations greater than 0.12 ha have been made for forest "clumps" based on the poor growth form and slow regeneration growth resulting from edge effects permeating forest islands below this size threshold (Oliver and Larson 1996).

Plant species diversity and species composition were vastly different among the five forest types. While plant diversity was greatest in the thinned forest and lowest in the unthinned forest, the calculation of diversity was influenced by early-successional and exotic species. We found over two times more early-successional species (52 and 25 species in thinned and unthinned forest, respectively) and over three times more exotic species in thinned forest than unthinned forest (10 and 3 species in thinned and unthinned forest, respectively). Conversely, late-successional species (n=62 species) and native species (n=104) dominated the species composition of larger leave islands and unthinned forest. We found a distinct gradient in species diversity and composition from thinned forest, small through large leave islands, and unthinned forest. Specifically, the percentage of exotic and the percentage of early-successional species was greatest in thinned forest, incrementally less in 0.1 ha, 0.2 ha, and 0.4 ha leave islands, and smallest in unthinned forest. Further, four native species associated with late-successional forest habitat that occurred in leave islands and unthinned forest were absent in thinned forest.

Arthropods dominated the biodiversity in our study with more than 30,000 individual captures within 23 orders. However, only 77 and 60 measures were incorporated into the integrated and leave island analyses, respectively. Of these 137, 18 showed treatment effects at the 0.10 significance level. This number is likely to be expected by chance alone (Ramsey and Schafer 2002). However, interesting patterns are apparent. The percentage of low-mobility captures and the density of *A. occidentalis*, *Myrmica*, and *Pristoceuthophilus* decreased with thinning while the density of *C. alternatus*, Lygaeidae, and *S. carinatus* increased. This bi-directional pattern was anticipated, given that some arthropods likely track plant responses. Both early and late successional associates are expected in the group. Results from the integrated analyses across all five forest types indicated that leave islands might provide some refugia from forest thinning for two arthropod taxa, *Geophilomorpha* (the largest of the predaceous arthropods; Moldenke, pers. comm.) and immature Staphylinidae (the most common and most diverse of the predaceous arthropods; Moldenke, pers. comm.). Further, the focused leave island size analyses revealed a tendency for increasing densities of these species with increasing leave island size. Forest management strategies incorporating leave islands might help maintain the persistence of these and potentially other arthropod species in managed forests. Fifteen arthropod species occurred in all forest types except for thinned forest (Appendix B).

Across all ANOVA analyses, seven of 16 (43.8%) amphibian analyses were significant. Species richness and densities of individual species were consistently greater in unthinned forest than thinned forest. Similarly, these responses were consistently greater in small and medium leave islands than thinned forest. However, contrary to our predictions, these responses were consistently higher in small and medium leave islands than large leave islands. Several explanations for this apparent anomaly can be offered. First, treatment effects may have been obscured because of the optimal ecological conditions during springtime amphibian sampling. Surface activities of terrestrial amphibians are confined to relatively narrow environmental conditions due to thermal and moisture requirements (Sinsch 1990; Frisbie and Wyman 1991; Blaustein et al. 1995). Above ground activity is generally restricted to cool, moist microhabitats and conditions of high relative humidity (Petranka 1998). Habitat conditions in thinned forests at the time of sampling (wet spring conditions) were designed to be within the ecological range required for amphibian surface activity. Thus, overland dispersal among the various forest types may have been occurring. Treatment effects also may have been obscured due to the restricted nature of our sampling. Terrestrial amphibians occupy three-dimensional microhabitats but our surveys of the forest floor sampled only a limited two-dimensional area. Also, amphibians are well-known to have patchy occurrences, often corresponding to unique habitat components such as decadent downed wood or moist, rocky substrate. Treatment effects for such organisms can be obscured by these patchy occurrences. In some cases, amphibians may be responding to fine-scale habitat conditions rather than to habitat at a larger, leave island scale. That is, microsite components such as sufficient soil moisture and abundant, decayed downed wood might be functioning as the key drivers of amphibian abundance. However, these did not vary among forest types in our study. Similarly, arthropods and mollusks may be tied to such microhabitats (Schumacher 1999). However, information on the ecology of arthropods and terrestrial mollusks in the Pacific Northwest is sparse (Dunk 2004) and habitat associations are poorly understood. Our results did not indicate that any mollusk species were locally extirpated by the moderate thinning treatment.

While our study was designed to provide insights into the role of leave islands for maintaining potentially sensitive forest-dependent species, rare species in particular, our analyses were constrained by species abundances. Abundances varied across forest types and study sites, restricting analyses to the more common taxa. The role of leave islands as potential species lifeboats for the very rare taxa could not be addressed statistically; 311 of the 428 species (72.7%) we censused were extremely rare and could not be addressed statistically while some vascular plants and many arthropods could not be identified to species (Figure 2.3; Appendices A and B). However, our multi-pronged analysis approach was designed to address this issue of species rarity. Specifically, analyses of selected genera, families, or functional groups (i.e., for arthropods and vascular plants) were designed to incorporate rare species into analyses while ISA and MRBP analyses and occupancy pattern assessments included all taxa (Tables 2.3 and 2.12).

Leave islands placed over forest legacy elements or biodiversity hotspots may provide habitat for rare species with patchy occurrences or strong habitat associations. This may account for some occurrences in leave islands while not elsewhere, supporting their role as a lifeboat for some species (Table 2.3). Seventy-one species occupied only leave islands. These occurrences may reflect random distributions in the area rather than leave island associations. However, intact forest patches may offer refugia for incidental species occurrences. The refugia role of intact forest also would apply to the large number of species found only in unthinned forest and leave islands (n=139, 32.5%; Table 2.3). Species occurring in any unthinned study unit comprised 349 (81.5%) taxa while leave islands harbored 325 (75.9%) taxa overall. The importance of intact forest for one of these species was reinforced by concurrent results with the integrated and ISA analysis approaches. Specifically, the integrated analysis approach revealed that Staphylinidae species density was highest in 0.4 ha leave islands while ISA identified Staphylinidae species as indicators of 0.4 ha leave islands (Tables 2.1 and 2.3).

Habitat-based management approaches have been proposed to maintain species diversity in managed forest systems (Noss et al. 1997). Concerns about biodiversity due to forest fragmentation may be mitigated by intentionally introducing spatial complexity and heterogeneity at the forest stand scale. Incorporating leave islands at the time of timber harvest can enhance the complexity of an otherwise relatively homogenous thinned forest matrix. In this study, leave islands effectively enhanced stand heterogeneity by providing microclimatic conditions and forest structures intermediate between thinned forest and unthinned forest. Further, leave islands appeared to help maintain vascular plant assemblages characteristic of interior forest by harboring late-successional and native species within a thinned forest matrix with more early-successional and exotic species. Medium and large (0.2 ha and 0.4 ha) leave islands harbored consistently different vascular plant assemblages from thinned forest while plant assemblages in small (0.1 ha) leave islands were often similar to thinned forest (Table 2.1). Additionally, two arthropod and one amphibian species exhibited higher densities in leave islands than thinned forests. Thus, leave islands appeared to be an effective habitat-based management strategy for maintaining multiple species within managed forests.

In addition to habitat management approaches, forest managers also can use silvicultural techniques designed to moderate the contrast between the managed forest matrix and patches of the formerly contiguous forest. Prescribing moderate thinning densities (Hunter 1990) and retaining legacy structures such as downed wood and large trees can "soften" the matrix (Franklin 1993) to ameliorate contrasts of habitat conditions. In our study, thinning to 200 tph appeared a relatively benign disturbance to our faunal groups. Negative effects of thinning were shown for only three arthropod species, one arthropod functional group, overall amphibian species richness, and one mollusk of 167 total measures analyzed. Some legacy elements (such as wolf trees, hardwood trees, and biodiversity hotspots for lichens, fungi, and bryophytes) were preserved within leave islands at each of our study sites during study implementation and may explain occurrences of some rare old-forest associated species within them. For example, ISA identified the minority hardwood species, *A. circinatum* as an indicator of 0.2 ha leave islands (Table 2.12). Species occurrence and persistence may have been particularly enhanced in leave islands located over identified forest legacy elements such as hardwood or wolf trees (Neitlich and McCune 1997). That is, leave islands that were created to preserve a forest legacy element might provide a uniquely valuable habitat patch for resident species with strong habitat associations (e.g., some amphibian, mollusk, lichen, and vascular plant species). The patchy occurrence of some species might be coincident with these legacy elements. This "matrix management" (Lindenmayer and Franklin 2002) may maintain a relatively permeable matrix for forest interior-associated species. The value of multiple-entry thinning to maintain moderate changes at each entry warrants further evaluation relative to forest dependent species. Multiple, low-intensity thinning entries resulting in incremental changes to stand density might allow the persistence of such species more effectively than fewer, higher-intensity timber harvest entries creating sudden, dramatic changes in stand density.

In contrast, past research examining heavier thinning treatments and clearcuts has shown treatment effects on the resident forest biota. Specifically, these studies revealed decreased abundances of some arthropods (Spence et al. 1997) and amphibians (Dupuis 1997). Conversely, vascular plant species richness often increases following timber harvest, with this increased species richness often driven by the influx of early-successional and exotic species. Biotic response to timber harvest seems to vary along a gradient according to the intensity of harvest and seems to be taxa-specific.

Biotic response to thinning is also likely influenced by temporal dynamics. That is, treatment effects on forest biota likely emerge during the lag time following timber harvest as forest succession proceeds. Resident wildlife may respond not to stand density but to the ecological characteristics of the harvested stand (Hayes et al. 1997). The biota may require several years to differentiate among forest types. The duration of this lag time and the nature of the biotic response is likely taxa-specific. Thus, the timing of biotic sampling seems crucial for detecting treatment effects on biota with differential temporal responses to thinning. Sampling too soon or too late after forest thinning might not fully capture responses of resident species. Thinning and leave island treatments were administered at our four study sites between October 1997 and March 2000. Vascular plant, arthropod, and amphibian and mollusk sampling was conducted 17 to 45 months, 28 to 56 months, and 26 to 54 months after timber harvest, respectively. Our results suggest that vascular plant assemblages responded relatively quickly and dramatically to the thinning and the leave island treatments. Results for other taxa were less pronounced. However, intriguing results emerged from an initial ordination analysis comparing arthropod assemblages in thinned and unthinned forest at our Bottomline and Delph Creek study sites (oldest and newest harvest dates, respectively). After 56 months, arthropod assemblages in thinned forest and unthinned forest at Bottomline displayed a clear separation into two data clouds. In contrast, arthropod assemblages in thinned and unthinned forest at Delph Creek had not differentiated 28 months after thinning and were relatively homogeneous. This exploratory analysis supports our hypothesis regarding the taxa-specific, temporal dimension of resident biota response to forest thinning.

Our community and ISA analysis results also highlighted the importance of addressing multiple spatial scales in forest management prescriptions. Specifically, NMS ordinations clearly illustrated the distinct vascular plant, arthropod, amphibian, and mollusk species assemblages occurring at both the site scale and the mountain range scale (Figure 2.4a-d). Further, ISA identified indicator species for forest types (vascular plant and arthropod species), study sites (all taxa) and mountain ranges (all taxa; Appendices C and D). While some of these indicator species might truly be indicative of unique habitat conditions, some of the identified indicator species might also be artifacts of the leave island placement strategy. Leave islands were often placed over special habitat features such as legacy forest elements (e.g., wolf trees or minority species, such as *A. circinatum*) or over known locations of species diversity (i.e., lichen species). Maintaining the biodiversity of these unique biotic communities at the nested microsite, forest stand, and landscape scales will likely require both fine-scale and coarse-scale management strategies instead of generic or standardized approaches. Results from this study can guide forest managers in developing tiered or nested silvicultural prescriptions addressing the complexity of species distributions and assemblages. Forest biodiversity might be sustained at multiple spatial scales by incorporating alternative strategies such as leave islands and moderate thinning treatments in silvicultural prescriptions.

In our study, the close proximity of leave islands and riparian reserves within the moderate 200 tph thinning context may have minimized the scale of forest fragmentation. This particular combination of silvicultural treatments may have ameliorated disturbances to habitat conditions, making the thinned forest "functionally contiguous" for many of the resident species (Andrén and Delin 1994). As noted earlier, surface cover and soil conditions were similar among treatments and are the likely haunts of ground-dwelling species examined here. Treatment effects would likely have been muted if conducive habitat conditions did not preclude dispersal of organisms among the five types of forest. Silvicultural strategies that effectively maintain connectivity within these study sites seems especially important in the intensively managed forest landscape of western Oregon.

Although not addressed in our study, the landscape surrounding our study sites was a heterogenous mosaic of forest conditions resulting from multiple ownerships and diverse management objectives. Adjacent stands were comprised of a range of forest conditions and successional stages, including recent regeneration harvests, young managed stands, and riparian reserves but no late-successional stands. Effects on species by management at larger spatial scales is not known for most taxa, however, emerging results from stream and riparian studies in PNW western forests suggests some amphibians are strongly affected by landscape management patterns (Bisson et al. 2002; Stoddard and Hayes 2005).

In our study, we found somewhat of a gradient of response to treatment among taxa. Multiple treatment effects were evident for vascular plants, fewer for amphibians and arthropods, and fewer still for mollusks. Thus, the taxa examined in the current study displayed different responses to the scale of forest treatment. The taxa examined in this study are thought to be sensitive to habitat changes created by silvicultural activities at the forest stand scale (Wiens 1989). However, the forest stand scale might not be the appropriate scale at which these patterns become evident for faunal taxa. Species are thought to respond to ecological processes and disturbance at different domains of scale (Wiens 1989). Vascular plants seemed to be more responsive than other taxa to forest treatments at the treatment scale; while vascular plants may have small domain of scale, arthropods, amphibians, and mollusks may display different domains of scale. At this study's spatial scale, fragmentation might be too limited to be detectable; the forest matrix might not be inhospitable enough to be associated with differences in mollusks, less so in arthropods and amphibians. Ecological processes shaping forest biodiversity operate over wide ranges of spatial and temporal scales (Christensen et al. 1996; Davies et al. 2001). Patterns detected in research are inextricably tied to the chosen scale of investigation. The effects of managing for complexity at the stand scale might not have detectable cascading effects at larger (or smaller) spatial scales. The relative influence of stand-scale habitat features might be less important than that of landscape-scale or finer-scale habitat.

In summary, our results indicate that treatment effects of thinning and leave islands included substantial differences in microclimate, forest stand structure, and vascular plant assemblages (Table 2.12). Less dramatic and consistent treatment effects were evident for arthropods, amphibians, and mollusks, but some examples were apparent in each group, nonetheless. While the taxa in this study responded to the moderate thinning treatment to varying degrees, they still occurred in these managed forests. If a primary management goal for these forests is to maintain species persistence at the stand scale, this silvicultural approach of combined dispersed and aggregated green tree retention involving a moderate thinning treatment and embedded leave islands holds promise. This design may have provided for species persistence across these study sites by creating a functionally contiguous matrix for many species.

CHAPTER 3:

RESEARCH SYNTHESIS

The principles of forest ecosystem management and sustainability can be applied at multiple spatial scales, from the forest stand or project unit scale, through the watershed or intermediate scale, to the landscape or ecosystem scale (Whittaker 1962; Oliver and Larson 1990). The landscape perspective is crucial to practicing ecosystem management (Crow and Gustafson 1997; Swanson et al. 1997). This paradigm reinforces the idea that landscapes are properly viewed as ecological wholes rather than as disconnected parcels of land, and that the fate of a single parcel of land is closely linked to its larger spatial context. The interconnected nature of spatial scales has significant implications for devising sustainability objectives. The challenge for land managers lies in merging the design of forest stand scale objectives with the objectives for intermediate and landscape scales to create desirable future landscape conditions and levels of productivity (Swanson and Franklin 1992).

At larger spatial scales, concerns about achieving ecosystem stability with timber harvesting often center on forest fragmentation. Fragmentation occurs when a formerly contiguous expanse of forest is changed into a complex mosaic of patches within a matrix of harvested forest (Lehmkuhl and Ruggiero 1991). The resulting forest fragments within the surrounding matrix may display functional dynamics resembling oceanic islands, including the island biogeographic principles of size and area effects on species (MacArthur and Wilson 1967; Simberloff 1976; Haila 1999). These forest fragmentation impacts may compromise the stability and ecological integrity of the forest landscape or ecosystem (Burgess and Sharpe 1981). The effects of isolation suggest that such systems tend to become less diverse and less ecologically stable relative to their original state (MacArthur and Wilson 1967; Diamond 1975; Burgess and Sharpe 1981).

Forest landscape fragmentation may simply reflect underlying habitat patchiness resulting from stand-scale management objectives. Fine-scale strategies designed to accomplish specific, stand-scale management objectives (i.e., timber harvest goals) can result in extensive fragmentation at coarser scales. Planning for sustainability at the project unit scale may entail simple objectives aimed at few species and habitat components while planning at the ecosystem scale generally involves increasingly complex objectives encompassing numerous species and habitat components. Thus, the complexity of sustainability objectives follows a continuum when moving from smaller to larger spatial scales. Sustainability objectives at these smaller scales are nested within the objectives of increasingly larger spatial scales.

Edge effects are an additional consequence of forest fragmentation (Harris 1984; Franklin and Forman 1987; Chen 1992; Murcia 1995; Chen et al. 1999). An edge is defined as the interface between two types of habitat (Forman and Godron 1986) while the modified environmental conditions found at this habitat boundary are described as edge effects (USDA 1993). Edge effects can be especially pronounced in stands with high levels of contrast between adjacent management units (Laurance and Yensen 1991). For example, Chen et al. (1992) reported that microclimate conditions at the interface between a clearcut and adjacent intact forest were more variable than conditions in the intact forest interior. Specifically, microclimate conditions at the forest edge were characterized by greater fluctuations in temperature and moisture levels and higher wind and light intensity than the forest interior.

Forest fragmentation in a managed landscape can be either accentuated or ameliorated by silvicultural techniques applied at stand scales (Harris 1984; Hunter 1997). Clearcutting and partial cutting can create dramatic contrasts (edges) between adjacent managed and unmanaged forest tracts. There is an array of silvicultural techniques to choose from which can minimize this contrast between forest stands. Among these strategies are managing for old forest components, selective thinning in old forest stands, and managing for mixed-aged stands. Careful selection of suitable techniques can allow managers to achieve sustainability objectives at the project scale and contribute to the maintenance of across-scale sustainability of patterns and processes.

To achieve these objectives, modern forest managers and researchers have shifted their attention to retaining old-growth conditions as well as accelerating development of old forest conditions within managed stands. Retaining structural forest legacies such as snags, large woody debris, and large green residual trees are techniques aimed at creating old forest conditions in second-growth stands (Halpern et al. 1999). These old forest remnants are often the only remaining complex structural elements within a young managed forest matrix and may provide critical habitat for old forest-associated biota (Dunster and Dunster 1996; MacKinnon 1998). Manipulation of forest stand heterogeneity and retention of old forest habitat components can serve as effective tools in sustaining forest biodiversity.

Retaining undisturbed standing timber at the time of timber harvest has become an important alternative silvicultural method designed to maintain habitat for plant and animal diversity within managed forest stands. Unharvested trees can be either dispersed or retained in clusters or patches (leave islands). Leave islands in upslope areas typically range in size from less than 1 hectare to over 50 hectares. Retaining patches of green trees conceptually promotes species diversity by providing refugia or centers of dispersal for multiple taxonomic groups (USDA and USDI 1994; Spies and Turner 1999; Olson et al. 2000). Our study examined the utility of retaining leave islands within a dispersed green tree matrix for sustaining biodiversity objectives in forests. Our study is the first to address the stand-scale efficacy of combined aggregated and dispersed green tree retention for maintenance of habitat elements including microclimate and biodiversity including >400 species of vascular plants, arthropods, amphibians, and mollusks.

Key Findings of Our Study

Conceptually, variable retention harvest systems represent a promising silvicultural strategy for sustaining biodiversity in managed forest landscapes. Results from our study indicate that combined aggregated and dispersed green tree retention may provide for the persistence of multiple species in young managed forests of western Oregon. Our findings validate the conceptual utility of green tree retention (both aggregated and dispersed) at the time of timber harvest (Tables 2.1, 2.3, and 2.12). Specifically, our results indicate that:

- Leave islands provided microclimate conditions intermediate to thinned and unthinned forest conditions in this moderate thinning context. Microclimate conditions in large leave islands (0.4 ha) closely mirrored that of unthinned forest while conditions in small leave islands resembled that of thinned forest. Analysis results displayed consistent trends tracking the continuum of disturbance (e.g., thinned forest>0.1 ha leave islands>0.2 ha leave islands>0.4 ha leave islands>unthinned forest and vice versa).

- Leave islands performed a refugia or lifeboat function for multiple species in this managed forest context. Leave islands effectively harbored native and late-successional vascular plant species and multiple arthropod, amphibian, and mollusk species groups within this managed forest matrix.
- Vascular plant indicator species for thinned forest were comprised largely of early-successional species.
- Occupancy pattern assessments validated the conceptual utility of managing for habitat heterogeneity in managed forest mosaics. Leave islands seemed to function as species lifeboats by harboring 71 species not found in any other forest type. Unthinned forest similarly harbored unique species not found in other forest types. These results indicate that intentionally managing for forest complexity and heterogeneity may be an effective strategy for sustaining forest biodiversity.
- Community analysis results reinforced the importance of incorporating multiple spatial scales in management plans. Results of nonmetric multidimensional scaling analyses revealed strong gradients shaping biotic communities across study sites and across mountain ranges. Microclimate conditions seemed to be especially important in shaping species assemblages. Findings support the idea of managing for biodiversity across multiple, nested spatial scales.

Matrix Management for Biodiversity

Biotic diversity and species richness may be maintained in young managed forests by creating leave islands, or unharvested live tree retention clusters, at the time of timber harvest. The "forest matrix management" concept has been proposed as a potentially effective approach to balancing multiple forest resource objectives while simultaneously sustaining biodiversity (Lindenmayer and Franklin 2002). Forest matrix management represents a potentially important approach to sustaining biodiversity in landscapes comprised largely of managed forest matrix (e.g., Pacific Northwest). Conceptually, leave islands can perform multiple roles in thinned forests, including mitigating negative effects of logging by "softening the matrix" (Franklin et al. 1993), providing habitat connectivity, serving as refugia, and creating structural enrichment (Franklin et al. 1997). The utility of dispersed and aggregated green tree retention ranks as one of the most important research questions in the modern forest ecosystem management era (Franklin et al. 1997). However, data supporting the value of leave islands in intensively managed second-growth forests are few, while concerns have been raised relative to the direct and indirect effects of forest fragmentation (e.g., patch sizes, edge effects). Important questions remain regarding the appropriate size, configuration, placement, and juxtaposition of variable retention silvicultural prescriptions.

This leave island study and the Demonstration of Ecosystem Management Options Study (USDA 1996) are among the first research projects to examine the efficacy of combined dispersed and aggregated green tree retention methods for biodiversity management. Results from both studies validate the conceptual utility of an integrated green tree retention approach to sustaining biodiversity in intensively-managed, second-growth Douglas-fir forests. Results from our leave island study indicate that leave islands represent an effective silvicultural strategy for maintaining heterogenous habitat conditions and for sustaining biodiversity in intensively managed forests. Early results from the Demonstration of Ecosystem Management Options Study report similar findings of multiple habitat and biotic responses to varying levels and spatial patterns of green tree retention (Aubry et al. 2004). Results from our leave island study support the utility of combined aggregated and dispersed green tree retention as part of comprehensive management strategies for sustaining biodiversity in managed forests.

Historical forest management was characterized by managing for simplicity and wood production at the stand level (Kohm and Franklin 1997). In contrast, the ontogeny of modern forest management has led to managing for complexity at multiple scales while simultaneously balancing multiple forest resource objectives. Forest managers have developed a myriad of alternative silvicultural approaches to address the sustainability objectives of the new forest ecosystem management paradigm. Our study indicates that combined leave island and moderate thinning treatments comprise a potentially effective matrix management strategy for maintaining biodiversity in intensively managed forests.

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APPENDICES

Appendix A: Flora species list. Site names are abbreviated as follows: BL=Bottomline, DC=Delph Creek, GP=Green Peak, and KM=Keel Mountain. Forest types are abbreviated as follows: T=thinned forest, S=small (0.1 ha) leave islands, M=medium (0.2 ha) leave islands, L=large (0.4 ha) leave islands, and U=unthinned forest.

						Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Stratum**	**Origin**	**Seral Class**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Abies grandis	101	Pinaceae	Tree	Native	Late-successional			X		X	X			
Abies procera	113	Pinaceae	Tree	Native	Late-successional		X					X		
Acer circinatum	13	Aceraceae	Shrub	Native	Late-successional	X	X	X	X	X	X	X	X	X
Acer macrophyllum	67	Aceraceae	Tree	Native	Late-successional	X		X		X	X	X	X	
Achlys triphylla	68	Berberidaceae	Herb	Native	Late-successional	X		X		X	X	X	X	X
Actaea rubra	75	Ranunculaceae	Herb	Native	Late-successional	X	X	X		X	X	X		
Adenocaulon bicolor	22	Asteraceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Alnus rubra	81	Betulaceae	Tree	Native	Early-successional			X	X			X	X	
Anaphalis margaritacea	114	Asteraceae	Herb	Native	Early-successional	X				X				
Anemone deltoidea	30	Ranunculaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Anemone lyallii	84	Ranunculaceae	Herb	Native	Late-successional			X			X	X		
Anemone oregana	85	Ranunculaceae	Herb	Native	Early-successional	X			X	X	X	X	X	
Asarum caudatum	35	Aristolochiaceae	Herb	Native	Late-successional	X		X		X	X	X	X	X
Asteraceae species	60	Asteraceae	Herb	Unknown	Unknown	X		X	X	X	X			
Blechnum spicant	32	Blechnaceae	Herb	Native	Late-successional		X		X	X	X	X	X	X
Boschniakia hookeri	102	Orobanchaceae	Herb	Native	Late-successional			X					X	X
Boykinia occidentalis	96	Saxifragaceae	Herb	Native	Late-successional				X	X				X

Appendix A. (Continued)

						Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Stratum**	**Origin**	**Seral Class**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Calocedrus decurrens	107	Cupressaceae	Tree	Native	Late-successional	X				X				
Campanula scouleri	14	Campanulaceae	Herb	Native	Early-successional	X		X	X	X	X	X	X	X
Cardamine angulata	42	Brassicaceae	Herb	Native	Early-successional	X		X		X	X	X	X	X
Cardamine species	61	Brassicaceae	Herb	Native	Early-successional	X		X		X	X	X	X	X
Cephalanthera austiniae	97	Orchidaceae	Herb	Native	Late-successional			X				X	X	
Chamerion angustifolium	79	Onagraceae	Herb	Native	Early-successional		X	X	X	X				
Chimaphila menziesii	24	Pyrolaceae	Subshrub	Native	Late-successional	X	X	X	X	X	X	X	X	X
Chrysolepis chrysophylla	72	Fagaceae	Shrub	Native	Late-successional	X		X	X	X	X	X	X	X
Cirsium vulgare	58	Asteraceae	Herb	Exotic	Early-successional	X	X	X		X	X			
Claytonia sibirica	15	Portulacaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Clinopodium douglasii	29	Lamiaceae	Herb	Native	Early-successional	X				X	X		X	X
Clintonia uniflora	115	Liliaceae	Herb	Native	Late-successional			X			X			
Collomia heterophylla	74	Polemoniaceae	Herb	Native	Early-successional	X		X		X		X	X	
Corallorrhiza mertensiana	103	Orchidaceae	Herb	Native	Late-successional			X			X			
Corallorrhiza striata	89	Orchidaceae	Herb	Native	Late-successional	X		X	X	X	X	X		X
Cornus nuttallii	104	Cornaceae	Tree	Native	Late-successional	X	X			X			X	
Corylus cornuta	20	Betulaceae	Shrub	Native	Late-successional	X		X		X	X	X	X	X
Crataegus monogyna	116	Rosaceae	Shrub	Exotic	Early-successional	X					X			
Dicentra formosa	52	Fumariaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X

Appendix A. (Continued)

Scientific Name	Rank	Family	Stratum	Origin	Seral Class	Sites				Forest Types				
						BL	DC	GP	KM	T	S	M	L	U
Digitalis purpurea	76	Scrophulariaceae	Herb	Exotic	Early-successional		X	X		X	X	X		
Disporum hookeri	23	Liliaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Dryopteris expansa	71	Dryopteridaceae	Herb	Native	Late-successional		X			X		X		X
Epilobium ciliatum	46	Onagraceae	Herb	Native	Early-successional	X	X	X		X	X	X		
Equisetum fluviatile	105	Equisetaceae	Herb	Native	Early-successional				X				X	
Fragaria virginiana	50	Rosaceae	Herb	Native	Early-successional	X				X	X		X	X
Frangula purshiana	37	Rhamnaceae	Shrub	Native	Late-successional	X	X	X	X	X	X	X	X	X
Galium trifidum	38	Rubiaceae	Herb	Native	Late-successional	X	X			X	X	X	X	X
Galium triflorum	7	Rubiaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Gaultheria shallon	2	Ericaceae	Shrub	Native	Late-successional	X	X	X	X	X	X	X	X	X
Gnaphalium species	106	Asteraceae	Herb	Native	Early-successional		X			X				
Goodyera oblongifolia	57	Orchidaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Hieracium albiflorum	54	Asteraceae	Herb	Native	Early-successional	X	X	X		X	X	X	X	
Holodiscus discolor	27	Rosaceae	Shrub	Native	Early-successional	X		X		X	X	X	X	X
Hypericum perforatum	51	Clusiaceae	Herb	Exotic	Early-successional	X		X		X	X	X	X	
Hypochaeris radicata	19	Asteraceae	Herb	Exotic	Early-successional	X	X	X	X	X	X	X	X	X
Ilex aquifolium	118	Aquifoliaceae	Shrub	Exotic	Early-successional		X						X	
Ligusticum apiifolium	94	Apiaceae	Herb	Native	Early-successional	X				X				
Lilium columbianum	90	Liliaceae	Herb	Native	Late-successional			X				X		

Appendix A. (Continued)

Scientific Name	Rank	Family	Stratum	Origin	Seral Class	Sites				Forest Types				
						BL	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Lily species	63	Liliaceae	Herb	Native	Late-successional	X	X	X	X		X	X	X	X
Linnaea borealis	44	Caprifoliaceae	Subshrub	Native	Late-successional	X	X		X	X	X	X		X
Listera caurina	80	Orchidaceae	Herb	Native	Late-successional	X		X				X	X	X
Listera cordata	55	Orchidaceae	Herb	Native	Late-successional		X	X		X	X	X	X	X
Lonicera hispidula	69	Caprifoliaceae	Subshrub	Native	Early-successional	X		X		X	X	X	X	X
Lupinus polyphyllus	98	Fabaceae	Herb	Native	Early-successional	X				X			X	
Luzula species	34	Juncaceae	Herb	Native	Early-successional	X	X	X	X	X	X	X	X	X
Mahonia nervosa	4	Berberidaceae	Subshrub	Native	Late-successional	X	X	X	X	X	X	X	X	X
Maianthemum dilatatum	82	Liliaceae	Herb	Native	Late-successional		X		X			X	X	X
Maianthemum racemosum	93	Liliaceae	Herb	Native	Late-successional	X		X			X	X		
Maianthemum stellatum	39	Liliaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Menziesia ferruginea	119	Ericaceae	Shrub	Native	Late-successional		X					X		
Moehringia macrophylla	36	Caryophyllaceae	Herb	Native	Early-successional	X		X	X	X	X	X	X	X
Monotropa hypopithys	117	Monotropaceae	Herb	Native	Late-successional		X						X	
Mycelis muralis	33	Asteraceae	Herb	Exotic	Early-successional	X	X	X	X	X	X	X	X	X
Nemophila parviflora	48	Hydrophyllaceae	Herb	Native	Early-successional	X		X		X	X	X	X	X
Osmorhiza berteroi	31	Apiaceae	Herb	Native	Early-successional	X		X	X	X	X	X	X	X
Oxalis oregana	3	Oxalidaceae	Herb	Native	Late-successional		X	X	X	X	X	X	X	X
Oxalis suksdorfii	53	Oxalidaceae	Herb	Native	Early-successional	X	X			X	X	X	X	

Appendix A. (Continued)

						Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Stratum**	**Origin**	**Seral Class**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Pedicularis racemosa	45	Scrophulariaceae	Herb	Native	Early-successional				X	X				
Penstemon species	108	Scrophulariaceae	Herb	Native	Early-successional				X	X	X			
Phacelia nemoralis	66	Hydrophyllaceae	Herb	Native	Late-successional			X		X	X	X	X	
Pityopus californica	120	Monotropaceae	Herb	Native	Late-successional				X					X
Poa species	12	Poaceae	Herb	Unknown	Early-successional	X	X	X	X	X	X	X	X	X
Polypodium glycyrrhiza	109	Polypodiaceae	Herb	Native	Late-successional	X					X	X		
Polystichum munitum	1	Dryopteridaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Pseudotsuga menziesii	18	Pinaceae	Tree	Native	Late-successional	X	X	X	X	X	X	X	X	X
Pteridium aquilinum	8	Dennstaedtiaceae	Herb	Native	Early-successional	X	X	X	X	X	X	X	X	X
Pyrola picta	91	Pyrolaceae	Subshrub	Native	Late-successional			X	X		X	X	X	
Ranunculus uncinatus	110	Ranunculaceae	Herb	Native	Late-successional			X		X	X			
Rhododendron macrophyllum	95	Ericaceae	Shrub	Native	Late-successional		X					X		X
Ribes species	92	Grossulariaceae	Shrub	Native	Late-successional	X			X		X	X	X	
Rosa species	21	Rosaceae	Shrub	Native	Early-successional	X	X	X		X	X	X	X	X
Rubus laciniatus	83	Rosaceae	Shrub	Exotic	Early-successional	X	X		X	X		X		X
Rubus nivalis	64	Rosaceae	Subshrub	Native	Late-successional		X		X		X	X		X
Rubus parviflorus	56	Rosaceae	Shrub	Native	Early-successional	X	X	X		X	X	X	X	
Rubus spectabilis	78	Rosaceae	Shrub	Native	Early-successional		X		X	X	X		X	
Rubus ursinus	6	Rosaceae	Shrub	Native	Early-successional	X	X	X	X	X	X	X	X	X

Appendix A. (Continued)

Scientific Name	Rank	Family	Stratum	Origin	Seral Class	Sites				Forest Types				
						BL	DC	GP	KM	T	S	M	L	U
Rumex acetosella	88	Polygonaceae	Herb	Exotic	Early-successional	X		X		X	X			
Sanicula crassicaulis	99	Apiaceae	Herb	Native	Early-successional	X							X	
Senecio sylvaticus	62	Asteraceae	Herb	Exotic	Early-successional		X	X		X				
Sonchus species	73	Asteraceae	Herb	Exotic	Early-successional	X	X	X		X	X			
Stachys mexicana	49	Lamiaceae	Herb	Native	Early-successional	X		X		X	X	X	X	X
Symphoricarpos albus	5	Caprifoliaceae	Shrub	Native	Early-successional	X		X		X	X	X	X	X
Symphoricarpos mollis	10	Caprifoliaceae	Subshrub	Native	Early-successional	X		X		X	X	X	X	X
Synthyris reniformis	47	Scrophulariaceae	Herb	Native	Early-successional	X	X	X	X	X	X	X	X	
Tellima grandiflora	70	Saxifragaceae	Herb	Native	Early-successional			X		X	X	X		
Thermopsis gracilis	87	Fabaceae	Herb	Native	Early-successional	X				X	X		X	X
Thuja plicata	41	Cupressaceae	Tree	Native	Late-successional		X	X	X	X	X	X	X	X
Tiarella trifoliata	65	Saxifragaceae	Herb	Native	Late-successional		X		X	X	X	X	X	
Toxicodendron diversilobum	111	Anacardiaceae	Shrub	Native	Early-successional	X		X		X				X
Trientalis borealis	28	Primulaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Trifolium species	77	Fabaceae	Herb	Unknown	Early-successional			X		X	X	X		
Trillium ovatum	26	Liliaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Tsuga heterophylla	16	Pinaceae	Tree	Native	Late-successional	X	X	X	X	X	X	X	X	X
Urtica dioica	100	Urticaceae	Herb	Unknown	Early-successional		X			X				
Vaccinium ovalifolium	25	Ericaceae	Shrub	Native	Late-successional		X		X	X	X	X	X	

Appendix A. (Continued)

						Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Stratum**	**Origin**	**Seral Class**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Vaccinium parvifolium	9	Ericaceae	Shrub	Native	Late-successional	X	X	X	X	X	X	X	X	X
Vancouveria hexandra	17	Berberidaceae	Herb	Native	Late-successional	X	X	X	X	X	X	X	X	X
Veronica officinalis	59	Scrophulariaceae	Herb	Native	Early-successional				X	X	X	X		
Vicia americana	86	Fabaceae	Herb	Native	Early-successional	X		X		X	X			
Vicia sativa	43	Fabaceae	Herb	Exotic	Early-successional	X		X		X	X	X	X	
Viola species	11	Violaceae	Herb	Native	Early-successional	X	X	X	X	X	X	X	X	X
Whipplea modesta	40	Hydrangaceae	Subshrub	Native	Early-successional	X				X	X	X	X	X
Xerophyllum tenax	112	Liliaceae	Herb	Native	Late-successional			X	X	X				X

Appendix B: Fauna species list. Site names are abbreviated as follows: BL=Bottomline, DC=Delph Creek, GP=Green Peak, and KM=Keel Mountain. Forest types are abbreviated as follows: T=thinned forest, S=small (0.1 ha) leave islands, M=medium (0.2 ha) leave islands, L=large (0.4 ha) leave islands, and U=unthinned forest. Forest association assignments are as follows: LSOG=late-successional/old-growth, DIST=disturbed forest, BIPH=bi-phasic, associated with both LSOG and disturbed forest during different life stages.

ARTHROPODS				**Functional Groups**			**Sites**				**Forest Types**				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Acalypta	92	Tingidae	Hemiptera	Plant sucker	Mid	BIPH	X		X		X	X		X	X
Acrotrichus sp	15	Ptiliidae	Coleoptera	Fungivore	Mid		X	X	X	X	X	X	X	X	X
Actium	77	Pselaphidae	Coleoptera	Micropredator	Mid	LSOG	X	X	X	X	X	X	X	X	X
Agathidium sp A	154	Leiodidae	Coleoptera	Slime-mold feeder	High	LSOG		X	X					X	X
Agathidium sp B	174	Leiodidae	Coleoptera	Slime-mold feeder	High	LSOG	X		X	X	X			X	
Agathidium sp C	161	Leiodidae	Coleoptera	Slime-mold feeder	High	LSOG	X		X				X	X	
Agathidium sp D	227	Leiodidae	Coleoptera	Slime-mold feeder	High	LSOG	X						X		
Agathidium sp E	227	Leiodidae	Coleoptera	Slime-mold feeder	High	LSOG		X			X				
Agathidium sp F	203	Leiodidae	Coleoptera	Slime-mold feeder	High	LSOG	X			X	X			X	
Agulla	73	Raphidiidae	Neuroptera	Micropredator	High		X		X		X	X	X	X	X
Aleocharine black	55	Staphylinidae	Coleoptera	Parasitoid	Mid		X	X	X	X	X	X	X	X	X
Aleocharine red sp AR	64	Staphylinidae	Coleoptera	Parasitoid	Mid		X	X	X	X	X	X	X	X	X
Aleocharine red sp BR	118	Staphylinidae	Coleoptera	Parasitoid	Mid		X	X	X	X		X	X	X	X
Anaspis	227	Melandryiidae	Coleoptera	Plant chewer	High	DIST	X				X				

Appendix B. (Continued)

ARTHROPODS				**Functional Groups**			**Sites**					**Forest Types**			
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Anatis	174	Coccinellidae	Coleoptera	Micropredator	High				X	X	X	X			X
Anobiid	227	Anobiidae	Coleoptera	Xylivore	High		X					X			
Anthocorid	203	Anthocoridae	Hemiptera	Micropredator	High					X	X				
Antrodiaetus	40	Antrodiaetidae	Araneae	Macropredator	High		X	X	X	X	X	X	X	X	X
Antrodiaetus giant	116	Antrodiaetidae	Araneae	Macropredator	High		X	X		X		X	X		X
Aphodius	174	Scarabaeidae	Coleoptera	Dung feeder	High		X		X	X	X	X			X
Apochthonius	9	Chthoniidae	Pseudoscorpiones	Micropredator	Low		X	X	X	X	X	X	X	X	X
Aranaeus saevus	88	Araneidae	Araneae	Macropredator	High		X		X						X
Arctorthezia occidentalis	49	Ortheziidae	Homoptera	Plant sucker	Low		X	X	X	X	X	X	X	X	X
Argilophilus	227	Megascolecidae	Oligochaeta	Fungivore	Low		X								X
Asilid	227	Asilidae	Diptera	Micropredator	High	DIST		X						X	
Atrechus	27	Staphylinidae	Coleoptera	Micropredator	High		X	X	X	X	X	X	X	X	X
Batrissodes sp	54	Pselaphidae	Coleoptera	Micropredator	High	LSOG	X	X	X	X	X	X	X	X	X
Bdellozonium	53	Polyzoniidae	Diplopoda	Unknown	Low	LSOG	X	X	X	X	X	X	X	X	X
Beetle X	227	Beetle s.n.	Coleoptera	Unknown	Low				X			X			
Beetle Y	227	Beetle s.n.	Coleoptera	Unknown	Low					X	X				
Beetle Z	203	Beetle s.n.	Coleoptera	Unknown	Low					X	X				
Bembidion sp	227	Carabidae	Coleoptera	Micropredator	High	DIST				X	X				

Appendix B. (Continued)

ARTHROPODS				**Functional Groups**			**Sites**				**Forest Types**				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Bibio (adult)	203	Bibionidae	Diptera	Plant chewer	High	DIST	X			X	X		X		
Bibionid (immature)	187	Bibionidae	Diptera	Plant chewer	High	DIST		X						X	X
Black thrips	227	Thripidae	Thysanoptera	Herbivore	Mid				X					X	
Bollmannella	73	Conotylidae	Diplopoda	Shredder	Low			X	X	X	X	X	X	X	X
Brachyrhinus rugostriatus	35	Curculionidae	Coleoptera	Plant chewer	Mid		X	X	X	X	X	X	X	X	X
Braconid sp FB	104	Braconidae	Hymenoptera	Parasitoid	Mid				X	X	X	X	X	X	X
Braconid sp RE	227	Braconidae	Hymenoptera	Parasitoid	Mid					X				X	
Braconid sp W	45	Braconidae	Hymenoptera	Parasitoid	Mid		X	X	X	X	X	X	X	X	X
Bracon X	141	Braconidae	Hymenoptera	Parasitoid	High			X	X	X	X	X	X		X
Bradysia	2	Sciaridae	Diptera	Shredder	High		X	X	X	X	X	X	X	X	X
Buprestid	161	Buprestidae	Coleoptera	Xylivore	High	DIST	X			X	X				X
Byrrhid (immature)	26	Byrrhidae	Coleoptera	Plant chewer	High	LSOG	X	X	X	X	X	X	X	X	X
Campodea	11	Campodeidae	Diplura	Fungivore	Low		X	X	X	X	X	X	X	X	X
Camponotus modoc	203	Formicidae	Hymenoptera	Macropredator	High				X	X	X				
Cantharid (immature)	32	Cantharidae	Coleoptera	Micropredator	High		X	X	X	X	X	X	X	X	X
Cantharis (adult)	227	Cantharidae	Coleoptera	Micropredator	High					X			X		
Carabid (immature)	24	Carabidae	Coleoptera	Macropredator	High		X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites					Forest Types			
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Carabid sp A	227	Carabidae	Coleoptera	Macropredator	High				X						X
Carabid sp B	227	Carabidae	Coleoptera	Macropredator	High			X				X			
Carabid sp D	227	Carabidae	Coleoptera	Macropredator	High					X				X	
Caseya	10	Caseyidae	Diplopoda	Shredder	Mid		X	X	X	X	X	X	X	X	X
Catopocerus sp A	43	Leiodidae	Coleoptera	Fungivore	Low	LSOG	X	X	X	X	X	X	X	X	X
Catopocerus sp T	81	Leiodidae	Coleoptera	Fungivore	Low	LSOG	X	X	X	X	X	X	X	X	X
Cecidomyid	108	Cecidomyiidae	Diptera	Fungivore	High		X		X	X		X	X	X	X
Cecidomyid wingless	154	Cecidomyiidae	Diptera	Fungivore	Low	LSOG		X	X	X	X			X	X
Ceraphron sp A	108	Ceraphonidae	Hymenoptera	Parasitoid	Low		X		X	X		X	X	X	X
Ceraphron sp B	87	Ceraphonidae	Hymenoptera	Parasitoid	Low		X	X	X	X	X	X	X	X	X
Ceraphron sp C	227	Ceraphonidae	Hymenoptera	Parasitoid	Low		X					X			
Ceraphron sp D	174	Ceraphonidae	Hymenoptera	Parasitoid	Low				X	X	X				X
Ceraphron sp E	187	Ceraphonidae	Hymenoptera	Parasitoid	Low				X					X	
Ceraphron sp F	203	Ceraphonidae	Hymenoptera	Parasitoid	Low				X					X	
Ceraphron sp G	203	Ceraphonidae	Hymenoptera	Parasitoid	Low		X		X			X		X	
Ceraphron sp H	147	Ceraphonidae	Hymenoptera	Parasitoid	Low			X		X	X		X	X	X
Ceraphron sp I	174	Ceraphonidae	Hymenoptera	Parasitoid	Low					X	X	X	X	X	
Ceraphron sp J	227	Ceraphonidae	Hymenoptera	Parasitoid	Low					X			X		

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Ceraphron sp R	161	Ceraphonidae	Hymenoptera	Parasitoid	Low		X	X	X	X	X		X	X	X
Ceratolasma	123	Nemastomatidae	Opilionida	Macropredator	Mid	LSOG	X		X		X	X	X	X	X
Ceratopogonid	79	Ceratopogonidae	Diptera	Unknown	High		X	X		X		X	X	X	X
Cercopid	203	Cercopidae	Homoptera	Plant sucker	High			X	X		X			X	
Chionea	161	Tipulidae	Diptera	Unknown	Low	LSOG		X			X			X	X
Chironomid	41	Chironomidae	Diptera	Unknown	High		X	X	X	X	X	X	X	X	X
Chordeumid	22	Chordeumid s.n.	Diplopoda	Shredder	Mid		X	X	X	X	X	X	X	X	X
Chrysopa	174	Chrysopidae	Neuroptera	Micropredator	High				X	X			X	X	X
Cicadellid	94	Cicadellidae	Homoptera	Plant sucker	High	DIST			X	X	X	X	X	X	X
Cicadellid PW	227	Cicadellidae	Homoptera	Plant sucker	High	DIST			X					X	
Coccinella	187	Coccinellidae	Coleoptera	Micropredator	High	DIST		X			X			X	
Colon	187	Leiodidae	Coleoptera	Cadaver feeder	High		X						X	X	X
Cupila	118	Pselaphidae	Coleoptera	Micropredator	High	LSOG	X			X	X				X
Curculionid (immature)	77	Curculionidae	Coleoptera	Plant chewer	Mid			X	X	X	X	X	X	X	X
Curculionid sp AA	227	Curculionidae	Coleoptera	Plant chewer	Mid			X					X		
Curculionid sp BB	227	Curculionidae	Coleoptera	Plant chewer	Mid			X							X
Curculionid sp CC	203	Curculionidae	Coleoptera	Plant chewer	Mid		X					X		X	
Curculionid sp DD	161	Curculionidae	Coleoptera	Plant chewer	Mid				X	X		X	X	X	X

Appendix B. (Continued)

ARTHROPODS				**Functional Groups**			**Sites**				**Forest Types**				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Curculionid sp XX	174	Curculionidae	Coleoptera	Plant chewer	Mid				X		X	X		X	
Curculionid sp YY	118	Curculionidae	Coleoptera	Plant chewer	Mid		X	X	X	X		X	X	X	X
Curculionid sp ZZ	135	Curculionidae	Coleoptera	Plant chewer	Mid				X	X	X	X	X	X	X
Cybaeus	27	Agelenidae	Araneae	Macropredator	High		X	X	X	X	X	X	X	X	X
Cybaeus blacklegs	135	Agelenidae	Araneae	Macropredator	High		X		X		X	X	X	X	X
Cybaeus giant	129	Agelenidae	Araneae	Macropredator	High			X		X	X	X	X	X	
Cybaeus leg-striped	102	Agelenidae	Araneae	Macropredator	High		X	X	X	X	X	X	X	X	X
Cynipid X	113	Cynipidae	Hymenoptera	Parasitoid	Mid		X	X	X	X	X	X	X	X	X
Cytilus alternatus	47	Byrrhidae	Coleoptera	Plant chewer	High	LSOG	X	X	X	X	X	X	X	X	X
Dendrolasma	100	Nemastomatidae	Opilionida	Micropredator	Mid		X		X	X	X	X	X	X	X
Diapriid sp A	112	Diapriidae	Hymenoptera	Parasitoid	Low		X		X	X		X	X	X	X
Diapriid sp B	187	Diapriidae	Hymenoptera	Parasitoid	Low		X		X	X	X	X		X	
Diapriid sp C	227	Diapriidae	Hymenoptera	Parasitoid	Low		X					X			
Diapriid sp D	227	Diapriidae	Hymenoptera	Parasitoid	Low				X				X		
Diapriid sp T	187	Diapriidae	Hymenoptera	Parasitoid	Low				X	X			X	X	
Dyslobus productus	118	Curculionidae	Coleoptera	Plant chewer	Low		X	X	X	X	X	X	X	X	X
Elater 2HK	65	Elateridae	Coleoptera	Plant chewer	High		X	X	X	X	X	X	X	X	X
Elater sp 1	69	Elateridae	Coleoptera	Plant chewer	High		X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				**Functional Groups**			**Sites**				**Forest Types**				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Elater sp 2	227	Elateridae	Coleoptera	Plant chewer	High					X		X			
Elater sp 3	141	Elateridae	Coleoptera	Plant chewer	High		X				X				X
Elater sp 4	174	Elateridae	Coleoptera	Plant chewer	High				X		X		X		
Elater sp 5	227	Elateridae	Coleoptera	Plant chewer	High				X		X				
Elater sp 6	203	Elateridae	Coleoptera	Plant chewer	High			X	X			X			X
Elater sp 7	154	Elateridae	Coleoptera	Plant chewer	High				X	X	X		X	X	
Elaterid (immature)	29	Elateridae	Coleoptera	Plant chewer	High		X	X	X	X	X	X	X	X	X
Ellychnia hatchi	71	Lampyridae	Coleoptera	Macropredator	High		X	X	X	X	X	X	X	X	X
Enicmus	126	Lathridiidae	Coleoptera	Fungivore	High		X			X	X			X	X
Eurypauropodus	161	Eurypauropodidae	Pauropoda	Fungivore	Low	LSOG	X			X	X	X		X	
Eusphalerium	187	Staphylinidae	Coleoptera	Micropredator	High			X							X
Fenderia capizii	36	Staphylinidae	Coleoptera	Micropredator	Low	LSOG	X	X	X	X	X	X	X	X	X
Forficula	227	Forficulidae	Dermaptera	Macropredator	High	DIST		X			X				
Formica fusca	227	Formicidae	Hymenoptera	Macropredator	High	DIST				X					X
Formica neorufibarbis	227	Formicidae	Hymenoptera	Macropredator	High	DIST		X							X
Formica subnuda	100	Formicidae	Hymenoptera	Macropredator	High	DIST	X		X	X	X		X		X
Garypus	63	Garypidae	Pseudoscorpiones	Micropredator	Low		X		X	X	X	X	X	X	X
Gelis	147	Ichneumonidae	Hymenoptera	Parasitoid	Low		X						X	X	X

Appendix B. (Continued)

ARTHROPODS				**Functional Groups**			**Sites**				**Forest Types**				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Geocoris	227	Lygaeidae	Hemiptera	Plant sucker	High	DIST			X				X		
Geodercodes latipennis	56	Curculionidae	Coleoptera	Plant chewer	Low		X	X	X	X	X	X	X	X	X
Geometrid (immature)	104	Geometridae	Lepidoptera	Plant chewer	High		X		X	X	X	X		X	X
Geophilomorpha	1	Geophilomorph s.n.	Chilopoda	Macropredator	Mid		X	X	X	X	X	X	X	X	X
Giant *Geophilomorpha*	21	Geophilomorph s.n.	Chilopoda	Macropredator	Mid		X	X	X	X	X	X	X	X	X
Haltica	227	Chrysomelidae	Coleoptera	Plant chewer	High	DIST			X		X				
Harpalus sp	147	Carabidae	Coleoptera	Macropredator	Mid		X		X		X	X			X
Harpaphe haydeniana haydeniana (adult)	31	Xystodesmidae	Diplopoda	Shredder	High		X	X	X	X	X	X	X	X	X
Harpaphe h. haydeniana (immature)	6	Xystodesmidae	Diplopoda	Shredder	Mid		X	X	X	X	X	X	X	X	X
Harpaphe h. haydeniana (very immature)	57	Xystodesmidae	Diplopoda	Shredder	Low		X	X	X	X	X	X	X	X	X
Hesperonemastoma	75	Ischyropsalididae	Opilionida	Micropredator	Low	LSOG	X	X	X	X	X	X	X	X	X
Hexura	20	Mecicobothridae	Araneae	Macropredator	Mid	LSOG	X	X	X	X	X	X	X	X	X
Ichneumonid (adult)	85	Ichneumonidae	Hymenoptera	Parasitoid	High		X	X	X	X	X	X	X	X	X
Japyx	187	Japygidae	Diplura	Micropredator	Low			X		X			X	X	
Julid RT	161	Julidae	Diplopoda	Shredder	Low			X		X	X			X	X
Julid ST	8	Julidae	Diplopoda	Shredder	Low		X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				**Functional Groups**			**Sites**				**Forest Types**				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Kleidocerys	227	Lygaeidae	Hemiptera	Plant sucker	High					X				X	
Lasiocampid	227	Lasiocampidae	Lepidoptera	Plant chewer	High			X				X			
Lasioglossum	96	Halticidae	Hymenoptera	Plant chewer	High	DIST			X	X	X	X	X	X	X
Lasius	30	Formicidae	Hymenoptera	Macropredator	High		X	X	X	X	X	X	X	X	X
Lathridiid	227	Lathridiidae	Coleoptera	Fungivore	High					X	X				
Leiodes	94	Leiodidae	Coleoptera	Fungivore	High	LSOG	X	X	X	X	X	X			X
Leptotyphline	203	Staphylinidae	Coleoptera	Micropredator	Low	LSOG				X					X
Leuronychus	161	Phalangiidae	Opilionida	Micropredator	High		X	X		X	X	X	X		X
Ligidium gracile	39	Ligiidae	Crustacea	Xylivore	Low		X	X	X	X	X	X	X	X	X
Linyphiid	141	Linyphiidae	Araneae	Macropredator	High		X	X	X	X	X		X	X	X
Lioon simplicipes	14	Byrrhidae	Coleoptera	Plant chewer	High	LSOG	X	X	X	X	X	X	X	X	X
Liposcelis	129	Liposcelidae	Psocoptera	Fungivore	Low		X			X				X	X
Listemus formosus	66	Byrrhidae	Coleoptera	Plant chewer	High			X	X	X	X	X	X	X	X
Lithobid	5	Lithobid s.n.	Chilopoda	Macropredator	Mid		X	X	X	X	X	X	X	X	X
Lobosoma horrida	161	Curculionidae	Coleoptera	Plant chewer	Low	LSOG			X	X			X	X	X
Lophioderus	52	Pselaphidae	Coleoptera	Micropredator	Low	LSOG	X	X	X	X	X	X	X	X	X
Lucanid (immature)	135	Lucanidae	Coleoptera	Xylivore	High		X					X			X
Lucifotychus impellus	19	Pselaphidae	Coleoptera	Micropredator	High	LSOG	X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites					Forest Types			
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Lucifotychus sp 2	123	Pselaphidae	Coleoptera	Micropredator	High	LSOG	X		X			X	X	X	X
Lycid (adult)	203	Lycidae	Coleoptera	Micropredator	High	LSOG	X						X		
Lygaeidae	75	Lygaeidae	Hemiptera	Plant sucker	High	BIPH	X	X	X	X	X	X	X	X	X
Lygus	227	Miridae	Hemiptera	Plant sucker	High	DIST			X			X			
Machilid	82	Machilidae	Thysanura	Plant chewer	Mid		X		X	X	X	X	X	X	X
Malachius	113	Cantharidae	Coleoptera	Micropredator	High	DIST	X	X	X	X		X	X	X	X
Mayetia	174	Pselaphidae	Coleoptera	Micropredator	Low	LSOG		X	X	X	X				X
Megarofonus sp	61	Pselaphidae	Coleoptera	Micropredator	Mid	LSOG	X	X	X	X	X	X	X	X	X
Megaselia	129	Phoridae	Diptera	Cadaver feeder	High					X	X	X	X		X
Meioneta	147	Linyphiidae	Araneae	Micropredator	High				X	X	X	X	X		
Metanonychus	25	Triaenonychidae	Opilionida	Micropredator	Low		X	X	X	X	X	X	X	X	X
Microcreagis	3	Neobisiidae	Pseudoscorpiones	Micropredator	Low		X	X	X	X	X	X	X	X	X
Microcybaeus	66	Agelenidae	Araneae	Macropredator	Mid		X		X			X	X	X	X
Microhexura	18	Dipluridae	Araneae	Micropredator	Low		X	X	X	X	X	X	X	X	X
Micropeplus	91	Staphylinidae	Coleoptera	Micropredator	High		X		X	X		X	X	X	X
Micryphantid (immature)	16	Micryphantidae	Araneae	Micropredator	High		X	X	X	X	X	X	X	X	X
Micryphantid sp A	96	Micryphantidae	Araneae	Micropredator	High		X	X		X	X	X	X	X	X
Micryphantid sp B	227	Micryphantidae	Araneae	Micropredator	High					X					X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Micryphantid sp C	69	Micryphantidae	Araneae	Micropredator	High			X	X	X	X	X	X	X	X
Micryphantid sp D	83	Micryphantidae	Araneae	Micropredator	High		X	X	X	X	X	X	X	X	X
Micryphantid sp E	187	Micryphantidae	Araneae	Micropredator	High		X				X		X		
Micryphantid sp F	129	Micryphantidae	Araneae	Micropredator	High		X	X	X	X		X		X	X
Micryphantid sp G	227	Micryphantidae	Araneae	Micropredator	High		X					X			
Micryphantid sp H	227	Micryphantidae	Araneae	Micropredator	High				X		X				
Micryphantid sp I	227	Micryphantidae	Araneae	Micropredator	High				X						X
Micryphantid sp J	154	Micryphantidae	Araneae	Micropredator	High			X			X	X	X	X	
Micryphantid sp K	227	Micryphantidae	Araneae	Micropredator	High			X				X			
Micryphantid sp L	227	Micryphantidae	Araneae	Micropredator	High			X			X				
Micryphantid sp M	227	Micryphantidae	Araneae	Micropredator	High		X								X
Micryphantid sp N	227	Micryphantidae	Araneae	Micropredator	High			X			X				
Mirid	129	Miridae	Hemiptera	Plant sucker	High		X		X	X			X	X	X
Molorchus	227	Cerambycidae	Coleoptera	Micropredator	High				X					X	
Moth s.n.	98	Incurvariidae	Lepidoptera	Plant chewer	High		X		X	X	X		X	X	X
Mycetophilid	187	Mycetophilidae	Diptera	Fungivore	High			X			X			X	X
Mymarid	227	Mymaridae	Hymenoptera	Parasitoid	Mid					X	X				
Myrmica	4	Formicidae	Hymenoptera	Macropredator	High	DIST	X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Nearctodesmus	66	Nearctodesmidae	Diplopoda	Shredder	Mid		X	X	X	X		X	X	X	X
Nemocestes puncticollis	98	Curculionidae	Coleoptera	Plant chewer	Low		X	X	X	X	X	X	X	X	X
Neon	104	Salticidae	Araneae	Micropredator	High		X	X	X		X	X	X	X	X
Nitidulid sp A	227	Nitidulidae	Coleoptera	Fungivore	High					X				X	
Nitidulid sp B	161	Nitidulidae	Coleoptera	Fungivore	High			X		X	X			X	
Noctuid	46	Noctuidae	Lepidoptera	Plant chewer	High		X	X	X	X	X	X	X	X	X
Notiophilus sylvaticus	59	Carabidae	Coleoptera	Micropredator	High			X		X	X	X	X	X	X
Nuctenea patagiata	174	Araneidae	Araneae	Macropredator	High		X	X		X				X	X
Omaline	227	Staphylinidae	Coleoptera	Micropredator	High					X				X	
Omus californicus	227	Carabidae	Coleoptera	Macropredator	Mid		X								X
Ostoma	203	Trogositidae	Coleoptera	Micropredator	High				X			X			
Panorpa	203	Panorpodidae	Neuroptera	Macropredator	High	LSOG			X			X			
Pardosa	227	Lycosidae	Araneae	Macropredator	High	DIST			X				X		
Pentatomid	147	Pentatomidae	Hemiptera	Plant sucker	High	DIST	X		X	X	X		X	X	
Philonthus sp A	129	Staphylinidae	Coleoptera	Macropredator	High				X	X	X	X	X	X	X
Philonthus sp B	203	Staphylinidae	Coleoptera	Macropredator	High			X					X		X
Philonthus sp C	227	Staphylinidae	Coleoptera	Macropredator	High			X			X				
Phora	174	Phoridae	Diptera	Fungivore	High				X	X		X			X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Phrurotimpus	227	Clubionidae	Araneae	Micropredator	Mid					X					X
Piestus	135	Staphylinidae	Coleoptera	Micropredator	High		X	X	X			X		X	X
Pimoa	203	Linyphiidae	Araneae	Macropredator	High				X	X				X	X
Pityohyphantes	227	Linyphiidae	Araneae	Macropredator	High					X					X
Polyxenes	47	Polyxenidae	Diplopoda	Shredder	Low		X		X	X	X	X	X	X	X
Pristoceuthophilus	88	Gryllacrididae	Orthoptera	Unknown	Mid		X		X	X	X	X	X	X	X
Proctotrupid sp A	108	Proctotrupidae	Hymenoptera	Parasitoid	Mid		X	X	X	X	X	X	X	X	X
Proctotrupid sp B	227	Proctotrupidae	Hymenoptera	Parasitoid	Mid					X			X		
Promecognathus laevissimus	161	Carabidae	Coleoptera	Macropredator	Low	LSOG	X	X			X			X	
Protura	51	Protura s.n.	Protura	Fungivore	Low		X	X		X	X	X	X	X	X
Pselaphid (immature)	88	Pselaphidae	Coleoptera	Micropredator	Mid		X		X	X	X	X	X	X	X
Pselaptrichus rothi	44	Pselaphidae	Coleoptera	Micropredator	Mid	LSOG	X	X	X	X	X	X	X	X	X
Pseudotyrranochthonius	116	Chthoniidae	Pseudoscorpiones	Micropredator	Low	LSOG	X	X		X	X		X	X	X
Psychodid	118	Psychodidae	Diptera	Fungivore	High		X		X	X	X	X		X	
Pterostichus herculaneus	187	Carabidae	Coleoptera	Macropredator	High		X	X			X	X			
Pterostichus inopinus	227	Carabidae	Coleoptera	Macropredator	Mid			X							X
Pterostichus lanei	37	Carabidae	Coleoptera	Macropredator	Mid		X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Pterostichus sp X	227	Carabidae	Coleoptera	Macropredator	Mid			X				X			
Pterostichus sp Y	126	Carabidae	Coleoptera	Macropredator	Mid		X				X				X
Ptiliid (adult)	62	Ptiliidae	Coleoptera	Fungivore	Mid		X	X		X	X	X	X	X	X
Ptiliid black	108	Ptiliidae	Coleoptera	Fungivore	Mid		X		X			X	X	X	X
Rhyncolus brunneus	161	Curculionidae	Coleoptera	Plant chewer	Low		X	X		X		X	X	X	X
Sabacon	187	Ischyropsalididae	Opilionida	Micropredator	Low	LSOG	X	X			X	X			X
Scaphinotus (immature)	154	Carabidae	Coleoptera	Macropredator	High		X		X			X	X	X	
Scaphinotus marginatus	174	Carabidae	Coleoptera	Macropredator	High		X		X		X	X			X
Scarabid (immature)	187	Scarabaeidae	Coleoptera	Plant chewer	High		X	X			X				
Sciarid (immature)	227	Sciaridae	Diptera	Shredder	High			X						X	
Sclerobunus	154	Triaenonychidae	Opilionida	Macropredator	Mid	LSOG	X	X		X		X		X	X
Scolopocryptops	23	Scolopocryptopidae	Chilopoda	Macropredator	Mid		X	X	X	X	X	X	X	X	X
Scutigerella	50	Scutigerellidae	Symphyla	Plant chewer	Low		X	X	X	X	X	X	X	X	X
Scydmaenid (immature)	135	Scydmaenidae	Coleoptera	Micropredator	Low		X	X	X			X	X		X
Scydmaenus	80	Scydmaenidae	Coleoptera	Micropredator	Low	LSOG	X	X	X	X	X	X		X	X
Scytonotus	17	Polydesmidae	Diplopoda	Shredder	Mid	DIST	X	X	X	X	X	X	X	X	X
Silis	203	Cantharidae	Coleoptera	Micropredator	High			X						X	X
Siro acaroides	7	Sironidae	Opilionida	Micropredator	Low		X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				**Functional Groups**			**Sites**				**Forest Types**				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Smittia	93	Chironomidae	Diptera	Unknown	High			X		X	X	X	X	X	X
Sonoma	123	Pselaphidae	Coleoptera	Micropredator	High	LSOG	X		X	X	X	X		X	X
Sphaerocerid	203	Sphaeroceridae	Diptera	Fungivore	High			X		X		X	X		
Staphylinidae (immature)	12	Staphylinidae	Coleoptera	Micropredator	High		X	X	X	X	X	X	X	X	X
Staphylinidae sp AR	72	Staphylinidae	Coleoptera	Micropredator	High		X	X	X	X	X	X	X	X	X
Staphylinidae sp AZ	126	Staphylinidae	Coleoptera	Micropredator	High		X	X	X	X	X	X	X	X	X
Staphylinidae sp B	227	Staphylinidae	Coleoptera	Micropredator	High				X			X			
Staphylinidae sp BX	227	Staphylinidae	Coleoptera	Micropredator	High				X						X
Staphylinidae sp EE	227	Staphylinidae	Coleoptera	Micropredator	High			X							X
Staphylinidae sp GEO	227	Staphylinidae	Coleoptera	Micropredator	High			X					X		
Staphylinidae sp PH	174	Staphylinidae	Coleoptera	Micropredator	High		X		X	X	X			X	X
Staphylinidae sp RA	147	Staphylinidae	Coleoptera	Micropredator	High			X	X	X		X		X	X
Staphylinidae sp TB	227	Staphylinidae	Coleoptera	Micropredator	High					X				X	
Staphylinidae sp TY	203	Staphylinidae	Coleoptera	Micropredator	High			X				X			X
Stenus sp B	141	Staphylinidae	Coleoptera	Micropredator	High			X	X	X	X	X			X
Stenus sp R	113	Staphylinidae	Coleoptera	Micropredator	High		X	X		X	X		X	X	X
Steremnius carinatus	58	Curculionidae	Coleoptera	Plant chewer	Mid		X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Striaria	38	Striariidae	Diplopoda	Shredder	Mid		X	X	X	X	X	X	X	X	X
Syrphid	154	Syrphidae	Diptera	Micropredator	High	DIST	X	X	X			X			X
Tachinus sp A	141	Staphylinidae	Coleoptera	Micropredator	High		X			X				X	X
Tachinus sp B	86	Staphylinidae	Coleoptera	Micropredator	High		X	X	X	X	X	X	X	X	X
Tachyporus sp A	60	Staphylinidae	Coleoptera	Micropredator	High		X	X	X	X	X	X	X	X	X
Tachyporus sp B	141	Staphylinidae	Coleoptera	Micropredator	High		X								X
Tachyporus sp C	187	Staphylinidae	Coleoptera	Micropredator	High					X		X	X		
Taracus	102	Ischyropsalididae	Opilionida	Micropredator	Low	LSOG	X	X		X	X	X	X	X	X
Tenebrionid (immature)	13	Tenebrionidae	Coleoptera	Plant chewer	High		X	X	X	X	X	X	X	X	X
Tenthredenid	84	Tenthredinidae	Lepidoptera	Plant chewer	High		X	X	X	X	X	X	X	X	X
Theridion	135	Theridiidae	Araneae	Micropredator	High		X	X	X	X		X	X	X	X
Thrips	203	Phloeothripidae	Thysanoptera	Fungivore	Mid			X							X
Thrips (banded wings)	203	Phloeothripidae	Thysanoptera	Fungivore	Mid				X						X
Throscid	227	Throscidae	Coleoptera	Micropredator	High		X						X		
Timarcha	147	Chrysomelidae	Coleoptera	Plant chewer	Mid		X	X	X	X	X	X			X
Tipulid	32	Tipulidae	Diptera	Plant chewer	High		X	X	X	X	X	X	X	X	X
Tribolium	187	Tenebrionidae	Coleoptera	Fungivore	High		X	X			X		X		X
Trombidiid	41	Trombidiidae	Acari	Micropredator	Low		X	X	X	X	X	X	X	X	X

Appendix B. (Continued)

ARTHROPODS				Functional Groups			Sites				Forest Types				
Scientific Name	**Rank**	**Family**	**Order**	**Feeding Group**	**Mobility**	**Forest Assoc.**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Tylobolus	161	Spirobolidae	Diplopoda	Shredder	Mid		X	X	X		X	X		X	X
Usechomorpha	203	Tenebrionidae	Coleoptera	Fungivore	High	LSOG	X		X					X	
Usofila	104	Telemidae	Araneae	Micropredator	High			X			X	X	X	X	X
Veraphis	203	Scydmaenidae	Coleoptera	Micropredator	Mid	LSOG				X				X	
Wubana	227	Linyphiidae	Araneae	Micropredator	High					X		X			
Xylophagid	227	Xylophagidae	Diptera	Xylivore	High		X					X			
Xysticus	34	Thomisidae	Araneae	Macropredator	High	DIST	X	X	X	X	X	X	X	X	X
Zacotus matthewsi	187	Carabidae	Coleoptera	Macropredator	Mid			X		X		X	X	X	
Zelotes	227	Gnaphosidae	Araneae	Micropredator	Mid					X					X
Zygiella	203	Araneidae	Araneae	Macropredator	High			X				X			

Appendix B. (Continued)

AMPHIBIANS				Sites				Forest Types				
Scientific Name	**Rank**	**Common Name**	**Family**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Ambystoma gracile	4	Northwestern Salamander	Ambystomatidae		X	X		X				X
Ascaphus truei	6	Tailed Frog	Leiopelmatidae			X						X
Batrachoseps wrighti	2	Oregon Slender Salamander	Plethodontidae		X		X	X	X	X	X	X
Ensatina eschscholtzii	1	Ensatina	Plethodontidae	X	X	X	X	X	X	X	X	X
Plethodon vehiculum	3	Western Redback Salamander	Plethodontidae			X		X	X	X	X	X
Rhyacotriton variegatus	7	Southern Torrent Salamander	Rhyacotritonidae			X						X
Taricha granulosa	5	Rough-Skinned Newt	Salamandridae	X		X				X		X
MOLLUSKS												
Ancotrema sportella	3	Beaded Lancetooth	Haplotrematidae	X	X	X	X	X	X	X	X	X
Ancotrema sportella/ Haplotrema vancouverense juveniles	4	Beaded Lancetooth/Robust Lancetooth juvenile	Arionidae	X	X	X	X	X	X	X	X	X
Ariolimax columbianus	6	Pacific Banana Slug	Arionidae	X	X	X	X	X	X	X	X	X
Haplotrema vancouverense	1	Robust Lancetooth	Haplotrematidae	X	X	X	X	X	X	X	X	X
Hemphillia malonei	7	Malone Jumping Slug	Arionidae		X			X	X	X	X	X
Monadenia fidelis	8	Pacific Sideband	Bradybaenidae	X		X	X	X	X	X	X	X
Prophysaon andersoni	5	Reticulate Tail-dropper	Arionidae	X	X	X	X	X	X	X	X	X
Prophysaon coeruleum	5	Blue-gray Tail-dropper	Arionidae			X			X			
Prophysaon dubium	5	Papillose Tail-dropper	Bradybaenidae	X				X				

Appendix B. (Continued)

MOLLUSKS					Sites			Forest Types				
Scientific Name	**Rank**	**Common Name**	**Family**	**BL**	**DC**	**GP**	**KM**	**T**	**S**	**M**	**L**	**U**
Prophysaon species	5	Tail-Dropper species	Bradybaenidae	X	X		X		X	X		
Prophysaon vanattae	5	Scarlet-back Tail-dropper	Bradybaenidae	X	X		X	X	X	X	X	
Vespericola columbianus	2	Northwest Hesperian	Polygyridae	X	X	X	X	X	X	X	X	X

Appendix C: Study site indicator species analysis results. Vascular plant, arthropod, amphibian, and mollusk indicator species listed for all study sites (p<0.10). Site names are abbreviated as follows: BL=Bottomline, DC=Delph Creek, GP=Green Peak, and KM=Keel Mountain.

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups Mean	s.d.	p *
Vascular Plants:					
Corylus cornuta	BL	92.4	30.0	11.46	0.001
Galium trifidum	BL	86.3	29.1	10.60	0.001
Moehringia macrophylla	BL	91.5	33.6	12.88	0.001
Rubus ursinus	BL	53.0	36.0	5.01	0.001
Whipplea modesta	BL	100.0	25.3	12.48	0.001
Rosa species	BL	76.9	32.0	10.82	0.002
Symphoricarpos albus	BL	84.8	34.7	13.14	0.002
Pteridium aquilinum	BL	49.3	34.0	4.26	0.003
Symphoricarpos mollis	BL	87.3	33.4	12.50	0.003
Adenocaulon bicolor	BL	78.5	35.8	11.25	0.005
Oxalis suksdorfii	BL	74.0	27.3	12.52	0.006
Poa species	BL	65.7	41.2	9.10	0.006
Maianthemum stellatum	BL	76.5	36.0	11.62	0.007
Clinopodium douglasii	BL	80.0	26.3	13.34	0.008

Appendix C. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups Mean	s.d.	p *
Fragaria virginiana	BL	80.0	24.6	13.18	0.008
Thermopsis gracilis	BL	80.0	23.4	12.31	0.008
Vancouveria hexandra	BL	78.5	47.9	13.36	0.009
Achlys triphylla	BL	61.5	27.0	10.52	0.015
Osmorhiza berteroi	BL	61.8	32.4	10.83	0.020
Vicia sativa	BL	68.4	28.1	13.21	0.021
Nemophila parviflora	BL	63.8	32.6	12.86	0.029
Rubus parviflorus	BL	56.2	26.9	12.05	0.035
Holodiscus discolor	BL	53.1	30.6	10.52	0.036
Anemone deltoidea	BL	51.7	33.6	8.66	0.041
Lonicera hispidula	BL	46.5	26.3	10.83	0.061
Viola species	BL	37.8	32.4	3.61	0.084
Blechnum spicant	DC	85.8	32.1	11.94	0.001
Trillium ovatum	DC	43.5	32.5	4.37	0.009
Frangula purshiana	DC	54.8	31.2	9.41	0.024
Luzula species	DC	63.6	35.3	12.45	0.040
Dryopteris expansa	DC	60.0	21.7	12.36	0.048
Oxalis oregana	DC	51.5	33.5	9.59	0.051

Appendix C. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups		
			Mean	s.d.	p *
Tiarella trifoliata	DC	45.2	22.1	11.93	0.060
Thuja plicata	DC	48.3	33.0	9.02	0.068
Cardamine angulata	GP	96.4	25.3	11.64	0.002
Cardamine species	GP	94.7	25.4	11.75	0.002
Listera cordata	GP	97.9	25.8	12.19	0.002
Asarum caudatum	GP	79.7	26.1	10.80	0.003
Pseudotsuga menziesii	GP	44.2	32.6	3.67	0.003
Trientalis borealis	GP	56.0	32.7	8.00	0.006
Phacelia nemoralis	GP	80.0	29.5	13.54	0.009
Goodyera oblongifolia	GP	65.1	34.1	10.81	0.022
Campanula scouleri	GP	54.7	30.9	9.57	0.025
Chrysolepis chrysophylla	GP	60.0	28.4	11.93	0.025
Collomia heterophylla	GP	53.7	23.7	12.78	0.039
Claytonia sibirica	GP	67.0	42.6	12.80	0.040
Acer circinatum	GP	75.4	49.7	13.55	0.041
Tellima grandiflora	GP	60.0	24.8	12.23	0.042
Trifolium species	GP	60.0	25.3	11.99	0.042
Dicentra formosa	GP	59.3	33.8	13.62	0.061

Appendix C. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups		
			Mean	s.d.	p *
Tsuga heterophylla	KM	59.9	33.5	7.50	0.001
Chimaphila menziesii	KM	49.4	31.3	7.77	0.028
Veronica officinalis	KM	60.0	23.6	11.71	0.034
Arthropods:					
Atrechus	BL	72.3	34.6	7.96	0.001
Caseya	BL	41.3	30.8	2.78	0.001
Sciaria species	BL	72.1	32.3	8.74	0.001
Scolopocryptops	BL	44.9	31.7	3.12	0.001
Chordeumid	BL	47.2	32.0	5.61	0.003
Fenderia capizii	BL	57.6	32.0	8.37	0.003
Acalypta	BL	74.3	25.1	12.01	0.006
Taracus	BL	75.0	25.6	10.25	0.007
Lygaeidae	BL	56.8	30.4	8.71	0.010
Myrmica	BL	33.8	28.7	1.99	0.010
Lasius	BL	63.8	31.4	10.42	0.011
Ceratolasma	BL	65.7	23.3	10.84	0.012
Bdellozonium	BL	55.1	29.8	10.26	0.027

Appendix C. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups Mean	s.d.	p *
Hesperonemastoma	BL	51.5	30.9	8.84	0.034
Geophilomorpha species	BL	28.6	26.9	1.20	0.037
Colon	BL	60.0	19.4	12.88	0.042
Gelis	BL	60.0	20.0	12.59	0.042
Dendrolasma	BL	48.5	29.1	8.57	0.043
Pterostichus species	BL	36.2	30.9	3.21	0.047
Scytonotus	BL	47.3	31.3	7.94	0.048
Bollmannella	DC	80.5	30.0	10.36	0.001
Arctorthezia occidentalis	DC	55.8	32.9	5.65	0.001
Usofila	DC	100.0	23.1	10.73	0.001
Tenebrionid (immature)	DC	39.3	30.9	2.78	0.003
Smittia	DC	65.3	26.4	10.97	0.005
Chironomid	DC	60.9	32.4	9.16	0.007
Notiophilus sylvaticus	DC	54.3	28.4	9.04	0.010
Carabid species	DC	40.9	31.3	4.22	0.011
Lucifotychus species	DC	36.2	30.3	2.56	0.012
Siro acaroides	DC	51.4	32.7	8.00	0.025
Cybaeus species	DC	30.4	27.7	1.48	0.027

Appendix C. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups Mean	s.d.	p *
Chionea	DC	60.0	19.4	11.81	0.029
Lithobid	DC	29.9	27.5	1.40	0.029
Mycetophilid	DC	60.0	18.9	12.04	0.029
Tachyporus species	DC	50.8	32.5	8.04	0.033
Metanonychus	DC	41.4	32.6	4.53	0.035
Staphylinidae species	DC	33.4	29.8	2.38	0.078
Agulla	GP	67.1	28.1	9.86	0.002
Tenthredenid	GP	64.9	32.2	9.60	0.002
Cicadellid species	GP	73.2	29.5	11.08	0.003
Braconid species	GP	37.0	30.2	2.71	0.004
Polyxenes	GP	70.1	28.3	11.40	0.005
Pristoceuthophilus	GP	62.5	28.8	9.78	0.007
Machilid	GP	66.5	28.1	10.10	0.008
Nemocestes puncticollis	GP	58.4	29.8	8.82	0.013
Bracon X	GP	49.1	25.1	9.88	0.036
Scaphinotus species	GP	47.1	25.6	10.56	0.081
Ceraphron species	GP	35.4	30.9	3.35	0.095
Campodea	KM	41.6	31.1	3.04	0.001

Appendix C. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups Mean	s.d.	p *
Scutigerella	KM	56.1	33.3	6.04	0.001
Listemus formosus	KM	63.8	30.3	9.21	0.002
Megaselia	KM	80.0	23.5	12.80	0.004
Bradysia	KM	47.0	33.3	4.03	0.005
Elater species	KM	32.0	27.8	1.59	0.009
Protura	KM	67.5	30.8	10.99	0.013
Cecidomyid species	KM	58.5	27.1	10.56	0.014
Lasioglossum	KM	53.0	27.4	10.78	0.028
Julid species	KM	40.6	31.4	5.09	0.031
Curculionid species	KM	44.8	32.6	6.14	0.035
Garypus	KM	43.8	31.5	7.13	0.060
Sonoma	KM	46.5	25.0	10.26	0.083
Cytilus alternatus	KM	35.2	31.1	3.08	0.090
Amphibians:					
Plethodon vehiculum	GP	100.0	25.6	12.11	0.001
Batrachoseps wrighti	DC	57.9	30.1	9.42	0.010
Ensatina eschscholtzii	KM	30.5	28.4	1.68	0.098

Appendix C. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups Mean	s.d.	p *
Mollusks:					
Ancotrema sportella	BL	52.5	32.1	6.73	0.001
Monadenia fidelis	BL	77.0	28.4	11.25	0.003
Haplotrema vancouverense	BL	29.9	27.5	1.30	0.013
Vespericola columbianus	BL	33.4	29.5	2.18	0.038
Hemphillia malonei	DC	100.0	22.6	9.90	0.001
Ariolimax columbianus	GP	41.3	32.3	4.96	0.038
Prophysaon species	KM	50.4	33.7	6.60	0.011

Appendix D: Mountain range indicator species analysis results. Vascular plant, arthropod, amphibian, and mollusk indicator species listed for Cascade and Coast mountain ranges (p<0.10).

		Observed	IV from Randomized Groups		
Species	**Max Group**	**Indicator Value (IV)**	**Mean**	**s.d.**	**p ***
Vascular Plants:					
Anemone deltoidea	Coast	94.7	46.1	9.15	0.001
Campanula scouleri	Coast	99.8	39.0	9.43	0.001
Claytonia sibirica	Coast	94.2	49.2	11.48	0.001
Corylus cornuta	Coast	90.0	34.4	10.15	0.001
Galium triflorum	Coast	81.8	58.3	7.00	0.001
Holodiscus discolor	Coast	100.0	36.7	9.88	0.001
Nemophila parviflora	Coast	90.0	35.3	10.74	0.001
Osmorhiza berteroi	Coast	99.3	39.7	9.96	0.001
Pteridium aquilinum	Coast	75.9	56.5	5.21	0.001
Rosa species	Coast	99.2	39.6	10.24	0.001
Symphoricarpos albus	Coast	100.0	38.7	11.01	0.001
Symphoricarpos mollis	Coast	100.0	37.6	11.13	0.001
Trientalis borealis	Coast	84.6	45.6	8.84	0.001
Vancouveria hexandra	Coast	97.2	54.1	11.37	0.001
Viola species	Coast	71.0	55.3	4.39	0.001
Achlys triphylla	Coast	80.0	30.8	9.09	0.002
Adenocaulon bicolor	Coast	93.5	45.3	10.71	0.002
Poa species	Coast	85.8	57.5	9.81	0.003
Stachys mexicana	Coast	80.0	32.3	10.77	0.003
Moehringia macrophylla	Coast	78.6	38.1	11.36	0.004

Appendix D. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups		
			Mean	s.d.	p *
Lonicera hispidula	Coast	70.0	28.4	9.22	0.005
Maianthemum stellatum	Coast	84.2	43.3	11.19	0.005
Asarum caudatum	Coast	70.0	28.6	9.54	0.006
Chrysolepis chrysophylla	Coast	66.5	32.1	9.88	0.008
Vicia sativa	Coast	60.0	26.3	10.04	0.010
Cardamine angulata	Coast	60.0	26.0	9.27	0.016
Cardamine species	Coast	60.0	26.0	9.39	0.016
Pseudotsuga menziesii	Coast	64.9	55.3	4.21	0.017
Gaultheria shallon	Coast	78.7	60.8	7.90	0.022
Acer macrophyllum	Coast	50.0	23.4	8.92	0.027
Hypericum perforatum	Coast	50.0	26.4	9.46	0.033
Whipplea modesta	Coast	50.0	23.1	8.87	0.033
Listera cordata	Coast	48.9	25.9	9.46	0.036
Disporum hookeri	Coast	65.3	52.0	7.81	0.070
Collomia heterophylla	Coast	40.0	20.3	8.02	0.078
Listera caurina	Coast	40.0	21.0	8.30	0.080
Asteraceae species	Coast	39.0	23.6	9.23	0.081
Phacelia nemoralis	Coast	40.0	22.2	8.76	0.088
Clinopodium douglasii	Coast	40.0	20.8	8.75	0.093
Fragaria virginiana	Coast	40.0	20.3	8.50	0.093
Thermopsis gracilis	Coast	40.0	20.2	8.35	0.093
Blechnum spicant	Cascade	100.0	38.0	10.79	0.001
Oxalis oregana	Cascade	94.6	44.2	9.77	0.001

Appendix D. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups		
			Mean	s.d.	p *
Tsuga heterophylla	Cascade	98.1	48.0	8.67	0.001
Thuja plicata	Cascade	88.5	44.4	9.79	0.003
Chimaphila menziesii	Cascade	71.5	42.8	8.47	0.005
Maianthemum dilatatum	Cascade	50.0	23.6	8.77	0.024
Vaccinium ovalifolium	Cascade	50.0	22.8	8.65	0.038
Tiarella trifoliata	Cascade	40.0	20.0	8.22	0.086
Arthropods:					
Agulla	Coast	90.0	33.2	9.16	0.001
Chordeumid	Coast	78.9	48.9	7.29	0.001
Nemocestes puncticollis	Coast	81.0	38.2	8.95	0.001
Pristoceuthophilus	Coast	86.3	36.3	8.97	0.001
Scytonotus	Coast	87.2	43.0	8.75	0.001
Machilid	Coast	76.9	33.8	9.49	0.002
Scaphinotus species	Coast	70.0	28.1	8.81	0.002
Lasius	Coast	74.3	39.0	9.70	0.005
Polyxenes	Coast	64.6	31.6	9.80	0.011
Tenthredenid	Coast	66.9	41.9	9.47	0.017
Ceratolasma	Coast	50.0	22.3	7.77	0.023
Atrechus	Coast	68.0	48.3	8.96	0.031
Acalypta	Coast	50.0	22.9	9.14	0.036
Caseya	Coast	60.6	54.3	3.56	0.044
Neon	Coast	49.4	30.5	9.31	0.049

Appendix D. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups Mean	s.d.	p *
Xysticus	Coast	59.2	54.0	3.36	0.054
Myrmica	Coast	56.4	52.8	2.64	0.060
Dendrolasma	Coast	53.8	38.3	8.78	0.067
Pterostichus species	Coast	60.3	51.6	5.48	0.072
Acrotrichus	Coast	63.5	49.1	9.80	0.085
Microcybaeus	Coast	40.0	20.2	8.21	0.087
Julid species	Cascade	79.1	48.4	6.99	0.001
Listemus formosus	Cascade	97.4	38.4	9.12	0.001
Notiophilus sylvaticus	Cascade	100.0	35.7	8.86	0.001
Tipulid	Cascade	73.4	54.7	5.50	0.001
Siro acaroides	Cascade	85.2	45.4	8.69	0.002
Tenebrionid (immature)	Cascade	69.2	54.6	3.83	0.002
Byrrhid (immature)	Cascade	64.9	53.3	4.28	0.003
Micryphantid species	Cascade	56.6	51.8	2.16	0.003
Cytilus alternatus	Cascade	66.3	53.5	4.66	0.004
Bollmannella	Cascade	74.6	36.7	9.91	0.005
Smittia	Cascade	70.0	28.2	9.60	0.006
Chironomid	Cascade	71.1	43.7	9.08	0.007
Brachyrhinus rugostriatus	Cascade	61.5	53.5	3.19	0.012
Antrodiaetus species	Cascade	64.6	51.8	5.45	0.015
Carabid species	Cascade	66.5	50.4	6.28	0.015
Lucifotychus species	Cascade	62.0	54.2	3.58	0.022
Usofila	Cascade	50.0	23.4	8.72	0.034

Appendix D. (Continued)

Species	Max Group	Observed Indicator Value (IV)	IV from Randomized Groups		
			Mean	s.d.	p *
Apochthonius	Cascade	55.8	52.3	2.38	0.038
Arctorthezia occidentalis	Cascade	67.0	51.2	7.27	0.040
Batrissodes species	Cascade	63.4	52.5	5.88	0.047
Trombidiid	Cascade	64.2	49.2	7.50	0.048
Megaselia	Cascade	40.0	20.3	8.11	0.083
Protura	Cascade	52.7	37.3	10.10	0.088
Amphibians:					
Plethodon vehiculum	Coast	55.6	24.3	9.67	0.016
Batrachoseps wrighti	Cascade	100.0	37.6	9.57	0.001
Ensatina eschscholtzii	Cascade	56.7	52.7	2.56	0.045
Mollusks:					
Ancotrema sportella	Coast	88.6	46.9	7.82	0.001
Monadenia fidelis	Coast	66.3	32.3	9.95	0.009
Vespericola columbianus	Coast	58.2	53.5	3.17	0.071
Prophysaon species	Cascade	84.6	49.4	7.93	0.001
Hemphillia malonei	Cascade	50.0	23.2	8.60	0.038