

AN ABSTRACT OF THE DISSERTATION OF

Steven A. Highland for the degree of Doctor of Philosophy in Geography presented on April 26, 2011.

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Abstract approved:

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Montane meadows in the western Cascades of Oregon occupy approximately 5% of the landscape, but contribute greatly to the region's biodiversity. Western Cascades meadows are dynamic parts of the landscape and have contracted by over 50% in the past two hundred years in the HJ Andrews Experimental Forest (hereafter Andrews Forest). Many studies have linked the loss of meadows with local extirpation of species and loss of regional biodiversity, but these processes depend upon the factors that create and maintain meadows, and how species respond to meadow configuration. The prehistory of these meadows is poorly understood, as is the contemporary ecology. This study combined previously collected archeological and moth datasets, aerial photographs, and new plant, tree core, and moth data to investigate interactions between landforms, disturbance, vegetation, and moth abundance and diversity in montane meadows of the western Cascades of Oregon.

Burning by prehistoric people may have created and maintained montane meadows, but relatively little evidence remains of the activities of prehistoric peoples in the western Cascades. This study assessed the extent to which prehistoric people preferentially used different landforms and vegetation types by inferring use from landscape distributions of archaeological sites. Descriptions of 359 previously recorded and four newly discovered archeological sites in the McKenzie River watershed of western Oregon were examined using GIS and chi-square analysis to determine how sites were distributed relative to classified vegetation and landforms of the 3700-km² McKenzie River watershed. The high ridges of the HJ Andrews Experimental Forest were analyzed using air photo change detection and archaeological field surveys to identify how archeological sites were distributed relative to landforms and vegetation communities, including meadows. The field surveys documented physical evidence (archeological sites) confirming Native American use of the meadows and

surrounding open forests. The locations of these sites indicate that Native Americans utilized the edges between large open meadows and open forests, as well as gently sloping open meadows. The prior extent of meadows (before air photos) was estimated by dendrochronology of 220 trees along present-day and inferred past meadow edges. Forest age structure and the open-grown forms of Douglas fir suggests a much more open habitat, potentially due to fire, was present more than 200 years ago.

Moths are major consumers of vegetation when in caterpillar stage and are food sources for many birds and mammals, and contribute greatly to the insect diversity in a region. Moth species richness and abundance may be associated with the distribution of vegetation communities and seasonal timing, and the conservation of rare moths may depend on the conservation of rare vegetation habitats. A dataset of moths sampled 10 times/year at 20 locations in the 64-km² Andrews Forest over the period 2004-2008 was analyzed using generalized linear mixed models (GLMM), non-metric multidimensional scaling (NMS), multi-response permutation procedure (MRPP), analysis of variance (ANOVA), and two tailed t-test to identify the overall patterns of rare and common moth distribution as well as moth community relationships to structurally and taxonomically derived vegetation classes and seasonality. Five hundred fourteen species and 69,168 macromoth individuals were identified. Moth species abundance and diversity were significantly higher in low elevation coniferous forests than in other vegetation types, according to the GLMM. Sixty-six rare moth species were significantly associated with high elevation open habitats. Species associated with meadows also were significantly more likely to be hardwood or herb-feeders than conifer-feeders as caterpillars, based on ANOVAs. The 26 most common moth species were significantly associated with low elevation coniferous forests and were more likely to be conifer-feeders as caterpillars, based on ANOVAs. Common moth species were significantly more likely to emerge earlier in warmer years than in cooler years, based on a two-tailed t-test. Managing the western Cascades landscape for moth biodiversity and for moth abundance requires maintenance and potentially expansion of rare upland habitats as well as lowland coniferous forests.

Montane meadows in the Andrews Forest are contracting in size, but it is not known how these changes have affected moth and plant biodiversity. The rate and pattern of meadow contraction from 1949 to 2005 along the high ridges of the Andrews Forest were analyzed using air photo change detection. Overall meadows contracted by nearly 50% from 1949 to 2005, but rates of meadow loss were much higher for the largest meadow complexes. Plant community diversity in seventeen meadows and the diversity, abundance, and community structure of moths at 98 locations sampled in

the summers of 2008, 2009, and 2010 were related to measures of meadow size, isolation, and other variables using cluster analysis (CLA), MRPP, NMS, and generalized additive models (GAMs). Plant diversity in meadows was significantly positively related to meadow area in 1949 and the distance of the meadow from the road, based on GAM analysis. Plant community structure was most closely correlated with meadow area in 1949 and slope, based on CLA, MRPP, and NMS analysis. Calendar day explained the most variation in moth species richness, abundance, and community structure, but the next most important explanatory variables differed according to feeding guild, based on GAMs. Richness, abundance, and community structure of herb-feeding moths was related to meadow area in 1949 and elevation. For angiosperm-feeding moths, area-perimeter ratio in 2005 explained the most variation in richness, abundance, and community structure after calendar day. For gymnosperm-feeding moths, meadow area change from 1949-2005, a variable measuring the amount of increase in coniferous tree cover, explained the most variation in richness, abundance, and community structure after calendar day. The abundance and diversity of herb-feeding moths and meadow plants exhibited a lagged response to habitat loss, which may indicate an extinction debt. In contrast, angiosperm- and gymnosperm-feeding moths responded quickly (within 50 years) to increases in their habitat. Managing for the conservation of biodiversity in the upper elevations of the Andrews Forest will require targeted management strategies for different groups of organisms. Herb-feeding moths and meadow plants will benefit from expansion of open meadow habitat, while angiosperm and gymnosperm-feeders will require the maintenance of edge environments and coniferous forests.

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APPROVED:

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Chair of the Department of Geosciences

Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Steven A. Highland, Author

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CONTRIBUTION OF AUTHORS

Many archeologists for the past three to four decades assisted with the data collection for Chapter 2. Tuan Pham developed the diversity map visualization tool described and utilized in Chapter 3, and he wrote the section of the methods detailing its construction. Dr. Jeffrey Miller was responsible for the collection of the data that was analyzed in Chapter 3. Dr. Julia Jones and Dr. Ronald Metoyer were responsible for the initial development of the project described in Ch 3, contributed to the conceptual development of the paper, and wrote portions of the discussion section.

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CHAPTER 1: INTRODUCTION

BACKGROUND

Land use changes, climate change, and encroachment by invasive/exotic species are recognized as the most important variables affecting the present-day distribution and abundance of species, and in the future (Parmesan and Yohe 2003). Land use changes often refer to recent (within 100 years) alterations of the landscape, but can also include much longer time frames. Within the past 200-300 years displaced indigenous people may have managed the landscape through different means and for different ends than the contemporary occupants and managers. Landscape changes that have occurred due to the cessation of indigenous management practices may account for major ecological changes that are taking place. The effects of these changes may not be immediately apparent and may experience different lag times. At the same time, not all parts of the landscape were likely managed as intensively or in the same manner. Understanding indigenous populations and their patterns of landscape utilization and management in addition to understanding the contemporary ecological patterns and processes that explain the configurations of different parts of a landscape will assist managers and ecologists in identifying locations in need of immediate or little active management.

Prehistoric Occupation and Use of the western Cascades, Oregon

In the Willamette Valley of Oregon, it is widely recognized that prehistoric peoples managed the vegetation, especially through the use of fire. The extent of influence of prehistoric peoples on the vegetation of the mountains of the Pacific Northwest, though, is debated (Norton et al. 1999, Whitlock and Knox 2002). Archeological and ethnographic data indicate active management of the western Washington Cascades through fire (Norton et al. 1999). Pollen/charcoal evidence from forest sites in the margins of the Willamette Valley is much more closely coupled with climate variations than those in the central Willamette Valley, suggesting that prehistoric burning by native peoples had comparatively little effect on fire regimes in forested sites (Walsh et al 2010a,b). Recent analyses of paleo charcoal records from the Willamette Valley indicate that such records are quite site-specific (Walsh et al 2010b). Detailed analyses of fire history of the western Cascades indicate that mixed-severity fire influenced very large areas of forest, and was not restricted to particular landforms (Tepley 2010).

If native peoples used selected portions of the mountain landscape, then the patterns of fire history and other effects on vegetation, as well as the evidence of their occupation, should be restricted to certain landforms. Archeological site records provide an objective indicator of patterns of

landscape use by prehistoric native peoples. Evidence of prehistoric occupation may be used to focus studies on particular landforms and vegetation types, and seek evidence for possible signatures of prehistoric vegetation management that may still be apparent in contemporary vegetation.

Montane meadow ecosystems of the western Cascades of Oregon may have been, in part, shaped by prehistoric vegetation management and occupation. To investigate the influence of prehistoric peoples on montane meadow vegetation, this study examined the distribution of prehistoric use of montane meadows in the McKenzie River valley, and related detailed studies of plant distribution to prehistoric sites in the montane meadows of the Andrews Forest (hereafter referred to as Andrews Forest), Oregon.

Moth Ecology and Distribution in the western Cascades, Oregon

Moth species are ecologically important due to the diversity of their ecological roles and overall biomass in many ecosystems, including temperate forests (Schowalter et al. 1986, Miller 1993). Ecological roles include herbivory, pollination, and their function as food for birds and bats. Lepidoptera, and moths in particular, are also potential indicators of ecosystem health and change, including ecosystem functioning, landuse changes, and climate change (Erhardt and Thomas 1991, Parmesan et al. 1999, Summerville and Crist 2004, Kitching et al. 2007).

Many insects and Lepidoptera, in particular, should be good indicators of contemporary ecosystem properties, environmental change, and sensitive indicators of landscape dynamics due to their limited mobility and specific phytophagy (Holloway 1985; Luff and Woiwood 1995; Smith and Remington 1996; Niemela 1997; Hammond and Miller 1998; Kitching et al. 2000; Ricketts et al. 2001). Lepidoptera, including macromoths, are highly specialized, often utilizing a single species or genus as a host-plant (Hammond and Miller 1998, Miller and Hammond 2003). Moth species abundance is coupled to that of their host-plants so their abundance and distribution may reflect both the distribution of vegetation types and the phenology of those plants in the local area (Novotny et al. 2005, Illan et al. 2010a). Many studies have related moth species distribution and communities to vegetation factors, including amount of rare habitat (Miller et al. 2003), vegetation disturbance (Kitching et al. 2000; Beck et al. 2002; Summerville and Crist 2004; Kuussaari et al. 2007), land use and habitat changes (Erhardt and Thomas 1991, Baur et al. 2006), and habitat size and distribution (Usher and Keiller 1998; Summerville and Crist 2004; Ober and Hayes 2010).

Lepidoptera are also sensitive to climatic changes. Alterations in pre-winter and spring conditions affect their survival rates (Han and Bauce 1998). Overall climatic warming can increase the survival rates of some species of Lepidoptera and drive range expansions (Parmesan et al. 1999). Populations of Lepidoptera have also been shown to be synchronous in their responses to weather

conditions, so any changes in the climate will likely lead to population-wide distribution and abundance changes (Raimondo et al. 2004). Additionally, butterflies have been shown to be sensitive to local climatic conditions in mountainous regions and models suggests that climatic changes to be influential in alterations of species distributions (Illan et al. 2010b).

Spatial and temporal partitioning of habitat can produce high diversity and abundance of moths. Spatial partitioning occurs as a result of host-plant preferences of moth larvae. Moth species can be grouped into multiple feeding-guilds, including moths whose larvae feed on conifers (“gymnosperm-feeders”), hardwood trees and shrubs (“hardwood-feeders”), and herbs and grasses (“herb-feeders”) (Hammond and Miller 1998). Temporal partitioning is a consequence of the coupling of larval feeding (caterpillar stage) to particular phenological stages of plants, and short adult life spans. Temporal turnover of moth species exceeded spatial turnover in eastern deciduous woodlands of North America (Summerville and Crist 2004) and in the forests of northern Japan (Hirao et al. 2007).

Moth and Plant Ecology of Contracting Montane Meadows

In many temperate parts of the world, including the western United States, montane meadows located within otherwise forested mountain ranges have experienced severe contraction and biological alteration (Miller and Halpern 1998; Debinski et al. 2000; Lepofsky et al. 2003; Norman and Taylor 2005; Baur et al. 2006; Zier and Baker 2006; Takaoka and Swanson 2008; Zald 2009;). Although the contraction of montane meadows is well documented, the effects of such contraction on plant and invertebrate distributions are less documented (but see Baur et al. 2006). Nevertheless, studies in lowland grassland and semi-grassland habitats indicate that contraction has a negative effect on plants and invertebrates (Erhardt and Thomas 1991; Schwartz et al. 1997; Helm et al. 2006; Lindborg 2007). This is consistent with island biogeography theory, which predicts that reduction of habitat size and increases in distance between habitat patches will lower the diversity of the organisms that rely on those habitats (Wilson and MacArthur 1967). Overall habitat loss appears to be the dominant driver of biodiversity loss (Fahrig 2003), but fragmentation and patch connectivity or separation is also important (Helm et al. 2006; Lindborg 2007; Pardini et al. 2010).

As habitat patches contract and become more isolated, species distributions and communities are predicted to become disrupted and some species may be extirpated or go extinct (Andren 1994, 1996; Pardini et al. 2010). The rate at which species will disappear from the landscape is dependent upon the type and degree of landscape change as well as characteristics of the species themselves, such as longevity and dispersal ability (Helm et al. 2006; Lindborg 2007; Pardini et al. 2010). Small patches of grassland can maintain higher levels of plant diversity than anticipated (Schwartz et al. 1997). The concept of “extinction debt” has been developed to explain such patterns,

postulating a time lag in response of species richness to change in area that results in metapopulation disequilibrium (Tilman et al. 1994; Hanski and Ovaskainen 2000, 2002).

It is debated whether plant and insect species and communities respond similarly to changes in landscape configuration, habitat size, or other drivers, such as climate change. At the community level, this debate concerns whether population sizes are driven primarily by changes in the abundances of co-occurring competitors (i.e., compensatory dynamics), or whether most species have a common response to environmental factors. An analysis of species abundance data from many natural communities showed that the primary driver of community dynamics is abiotic environmental forcing, not competition (Houlihan et al 2007). On the other hand, the abundance and diversity of species specialized to rare habitats would be expected to decline, and those specialized to common habitats would be expected to increase, as a result of a relative loss of rare habitat.

In addition, it has been suggested that species may persist for some time in habitat networks where they are expected to go extinct even without further landscape change. This concept, called “extinction debt” (Tilman et al. 1994) has been examined for butterflies using metapopulation models (Bulman et al 2007). Few field studies have examined insect species and plant communities in terms of extinction debt. Cumulative declines in the area of montane meadows provide an opportunity to test the relationships between present-day abundance and diversity and past meadow size and configuration.

OVERVIEW

I combined data from fieldwork, aerial photographs, and previous studies to better understand the historical and contemporary population dynamics and plant-insect interactions of montane meadows in western Oregon. The fieldwork was conducted in the HJ Andrews Forest on the high bounding eastern ridge containing multiple complexes of meadows and a mosaic of forest types. Fieldwork consisted of archeological surveys, meadow plant sampling, forest stand sampling, and moth sampling. The aerial photograph study involved the identification of meadows in the HJ Andrews Forest using 1949 and 2005 aerial photos. The previous acquired data analyzed here were of archeological sites in the McKenzie River watershed, acquired from the Oregon State Historic Preservation Office and a five-year moth sampling dataset from the HJ Andrews Forest.

The primary objective of chapter 2 is to identify the overall patterns of occupation and utilization exhibited by the prehistoric occupants of the western Cascades. Previously and newly recorded archeological sites were used to identify what localities, landforms, and vegetation types associated with prehistoric occupants. Once the overall patterns were identified, the specific patterns

of landform and vegetation usage on the eastern ridge of the HJ Andrews Forest were examined. The goal was to identify where prehistoric peoples lived and what parts of the landscape they were or were not associated with in order to specify potential areas of active indigenous land management and contemporary associated habitat changes.

In chapter 3, the objective is to gain an overall understanding of the contemporary distribution of moth species richness, abundance, and community structure in the western Cascades. Overall moth distributional patterns are examined in relation to vegetation types and other environmental variables to understand the drivers of the patterns of moth ecology in the western Cascades. This analysis was conducted on a previously acquired five-year moth dataset from the HJ Andrews Forest and newly acquired vegetation data. Additionally, we developed a unique tool for visualizing the distribution of moths on the HJ Andrews landscape to further our understanding of the relationship of moth distribution to different landscape factors and their interactions.

The objective of chapter 4 is to identify the changes that have occurred to montane meadows in the HJ Andrews and their relationship to contemporary plant and moth biogeographic patterns. Aerial photograph change analysis was conducted to identify the changing configuration of the meadows from 1949 to 2005. Plant and moth sampling in meadows and surrounding forests was used to identify the contemporary distribution of moths and plants. The moth and plant distributions were then analyzed in relation to the changes that have occurred to identify the presence or absence of an extinction debt among groups of plants or moths in the HJ Andrews.

Appendices are provided detailing the results of plant and moth sampling for chapters 3 and 4.

CHAPTER 2: PREHISTORIC OCCUPATION OF THE MCKENZIE RIVER WATERSHED AND SPECIALIZED UTILIZATION OF MONTANE MEADOWS IN THE WESTERN OREGON CASCADES

ABSTRACT

The relationship between prehistoric Native Americans and montane meadows is unclear but potentially important. Burning by Native Americans is one possible factor responsible for the existence of montane meadows. Descriptions of 359 previously recorded and four newly discovered archeological sites in the McKenzie River watershed of western Oregon were examined to determine their relationships with the vegetation and landforms of the region. The high ridges of the Andrews Forest were more closely investigated for the finer scale relationships of archeological sites to specific vegetation communities and landforms, including meadows. Physical evidence of Native American use of the meadows and surrounding open forests was identified. Native Americans utilized the edges between large open meadows and open forests, as well as gently sloped open meadows. Tree stand structure suggests a much more open habitat, potentially due to fire, was present more than 200 years ago.

INTRODUCTION

Although it is widely recognized that prehistoric peoples managed the vegetation of the Willamette Valley extensively, especially through the use of fire, the extent of influence of prehistoric peoples on the vegetation of the mountains of the Pacific Northwest is debated (Whitlock and Knox, 2002). Some argue that forest structure, particularly the mixed-age forest stands of the Cascade Range of Oregon, may be attributable to prehistoric burning (Zybach 2004). On the other hand, pollen/charcoal evidence from forest sites in the margins of the Willamette Valley is much more closely coupled with climate variations than those in the central Willamette Valley, suggesting that prehistoric burning by native peoples had comparatively little effect on fire regimes in forested sites (Walsh 2008, Walsh et al 2010a,b). Recent analyses of paleo charcoal records from the Willamette Valley indicate that such records are quite site-specific (Walsh et al 2010b). Detailed analyses of fire history of the western Cascades indicate that mixed-severity fire influenced very large areas of forest, and was not restricted to particular landforms (Tepley 2010).

If native peoples utilized selected portions of the mountain landscape, then the patterns of fire history and other effects on vegetation, as well as the evidence of their occupation, should be restricted to certain landforms. Archeological site records provide an objective indicator of patterns of landscape use by prehistoric native peoples. Evidence of prehistoric occupation may be used to focus

studies on particular landforms and vegetation types, and seek evidence for possible signatures of prehistoric vegetation management that may still be apparent in contemporary vegetation.

Montane meadow ecosystems of the western Cascades of Oregon may have been, in part, shaped by prehistoric vegetation management and occupation. To test the influence of prehistoric peoples on montane meadow vegetation, this study examined the distribution of prehistoric use of montane meadows in the McKenzie River valley, and related detailed studies of plant distribution to prehistoric sites in the montane meadows of the Andrews Forest (hereafter referred to as Andrews Forest), Oregon.

The earliest evidence of human occupation of eastern Oregon dates to approximately 14,000 years ago (Gilbert et al. 2008). Humans have occupied western Oregon for at least 11,000 years and have utilized the western Cascade mountain range for at least 8,000 years (Ames and Maschner 1999, Whitlock and Knox 2002). During this time, humans followed a foraging lifestyle centered on the gathering of multiple plant foods and the hunting of various animals.

The foraging behavior of prehistoric hunter-gatherers in the western Cascades is poorly understood. Some subsistence resources are known, but no diet-breadth outline has ever been constructed for foragers of the western Cascades. Major subsistence resources known to exist in the western Cascades include elk, deer, bracken fern, various bulbs and roots, and huckleberries. All of these known foods are most likely to occur in open forest (riparian and upland), edge, and meadow (wet, mesic, and xeric) environments in the western Cascades (Ames and Maschner 1999, Boyd 1999, French 1999, Norton et al. 1999). This suggests that prehistoric foragers most likely concentrated their foraging attention in the open meadow and open forest environments of the western Cascades for both hunting and gathering activities. Some of these resources are also known to be major trade items associated with large gatherings that took place at Celillo Falls or Willamette Falls located on the Columbia and Willamette Rivers, respectively (Juntunen et al. 2005). Other, non-food items of importance for trade and daily life are also located in the western Cascades, including major obsidian sources (Obsidian Cliff), and were likely influential in the movement of people on the landscape.

Hunter-Gatherer Theory

Optimal Foraging Theory (OFT), as part of human behavioral ecology (HBE), has been successful in predicting and explaining prehistoric foraging strategies as well as ethnographic foraging behavior (Kelly 1995). In general, OFT states that people attempt to capture the highest caloric return for the amount of energy expended, although variations from such optimizations are possible (Kelly 1995). This suggests that people concentrate on a predictable, high return foraging strategy involving

a small number of high-calorie food sources when available, but expand their diet and exploit a larger range of low-calorie foods when high calorie food sources are not predictably available.

Hunter-gatherers engage in very different food collection strategies depending upon where they live. A theoretical continuum has been proposed to describe these variations, ranging from a foraging strategy at one extreme to a collector strategy at the other. In this continuum, foragers theoretically live in a homogenous environment in which food is readily available during all times of the year. As a result, foragers have no need to collect and store food, and they utilize the landscape in a spatially homogeneous manner. Collectors, on the other hand, live in highly heterogeneous environments in which foods are distributed unevenly both spatially and temporally. As a result, collectors utilize the landscape in a patchy manner, and they collect and store food for later use.

Actual hunter-gatherers typically fall somewhere between the two are theoretical extremes, depending upon the patchiness of resources and degree of seasonality in their environments (Bettinger 1991, Binford 1980, Kelly 1995). These two theoretical poles would be represented archeologically by a homogeneous distribution of archeological sites (forager in a homogeneous landscape) and by a highly heterogeneous and patchy distribution of archeological sites of varying complexity and size (collector in a heterogeneous landscape).

Different foraging strategies along the continuum from forager to collector result in differing patterns of landscape usage and, subsequently, diverse distributions of artifacts across the landscape (Binford 1980, Camilli and Ebert 1992, Ebert 1992, Stafford and Hajic 1992). The forager strategy consists of hunter-gatherers continually moving across the landscape using available resources, which are homogeneously distributed in time and space, and never storing excess food for later use. The collector strategy consists of hunter-gatherers logistically collecting and storing excess food to eat at a later date. The collector strategy would most likely occur in a seasonal environment in which fresh food is not available year round. The forager strategy would occur in an environment lacking substantial seasonal fluctuations in the availability of fresh food and in an environment in which food resources are homogeneously and predictably distributed across the landscape (Bettinger 1991, Binford 1980, Kelly 1995).

A forager strategy would produce a low-density, even distribution of artifacts across the landscape, whereas a collector strategy would result in uneven distributions of artifacts, some in clusters and highly dispersed across the landscape (Ebert 1992).

With a collector strategy, specialized collecting events take place in specific localities, areas of usage overlap, and use of those areas changes from one event to another (Ebert 1992). For example, a locality that was a base camp could become a specialized small camp at a later point in time. This

would result in the deposition of different artifact concentrations at the same place, as different events would most likely require the usage of different artifacts (Ebert 1992). All other things being equal, the events that occur at a specific location are related to the resources available there (Ebert 1992). Hunter-gatherer theory generally states that hunter-gatherer behavioral patterns largely reflect their subsistence habits (Bettinger 1991, Kelly 1995). Because hunter-gatherers at mid-latitude settings typically derive the majority of total calories from vegetation, the locations of archeological sites in relation to vegetation patterns are generally reflective of their diets. The distribution of specific artifact types, then, should have a relationship to the surrounding resources.

Prehistorically Important Flora and Fauna of the W. Cascades

Many plants and animals in the western Cascades are known to have been utilized by indigenous inhabitants of the Pacific Northwest for food or other purposes. Prominent plants (Table 2.1) and animals (Table 2.2) utilized by prehistoric people of the western Cascades include common camas (*Camassia quamash*), huckleberries (*Vaccinium* spp.), white-tailed deer (*Odocoileus virginianus*), and Roosevelt elk (*Cervus canadensis roosevelti*).

Study objective and research questions

The objective of this study was to examine the relationships among archeological sites, landform positions, and past and present plant communities in the McKenzie River valley. We asked:

- 1) What landforms and vegetation types did prehistoric occupants of the McKenzie River watershed utilize? How are patterns of utilization related to known or probable foods?
- 2) How do utilization patterns compare in the western Cascades versus the High Cascades portions of the McKenzie River watershed?
- 3) How do utilization patterns compare in the foothill region of the western Cascades portion of the McKenzie River watershed versus the high elevation portions of the western Cascades?
- 4) What is the current distribution and diversity of plants in montane meadows of the high-elevation western Cascades? How do plant distribution, tree age, and meadow configuration differ in sites with versus without evidence of prehistoric occupation?

METHODS

Study Site Description

The study was conducted in the McKenzie River watershed of western Oregon (Figure 2.1). The McKenzie River watershed encompasses approximately 3700 km² in the western Cascade Range. The McKenzie River drains the west slope of the North, Middle, and South Sisters mountains, as well as multiple drainage basins of the western Cascades, including the Mohawk and Blue Rivers. Elevation

ranges from approximately 100 m at the junction of the McKenzie River and the Willamette River to approximately 3150 m at the peak of the South Sister.

The topography of the younger (<7 m y) High Cascades differs markedly from that of the older (25-35 m y) western Cascades (Sherrod and Smith 2000). The High Cascades platform is a constructional landscape formed of eruptions as recent as a few hundred years ago; scattered subalpine lakes are present but the drainage density is very low due to the youthfulness of the landforms. The western Cascades have been subjected to weathering and erosion, are deeply dissected, with steep slopes and many narrow valleys and sharp ridges.

The McKenzie River watershed includes major vegetation zones in the western Cascades, from lower elevation Douglas-fir (*Pseudotsuga menziesii*) dominated coniferous forests to Alpine zones in the Three Sisters and Mountain. Washington Wilderness areas. The McKenzie River watershed is dominated by conifer forests, but contains some other ecologically and anthropologically important habitats. In the lower elevations of the watershed, mixed oak-Douglas fir forests, prairies, and oak woodlands are present, and these vegetation types were much more extensive prehistorically (pre-1800) than they are today. On the upper ridges of the western Cascades, montane meadows occur within the matrix of coniferous forests dominated by Douglas fir (*Pseudotsuga menziesii*), noble fir (*Abies procera*), or Pacific silver fir (*Abies amabilis*), and these montane meadows also were much more extensive prehistorically. In the high Cascades, subalpine and alpine meadows occur above treeline on North, Middle, and South Sister volcanic peaks, as well as Mt. Washington.

At the time of Euro-American contact (approximately 1850), the Molalla occupied the upper (eastern) McKenzie River watershed; they were culturally distinct from the Kalapuyans, who occupied the middle and lower McKenzie River watershed and Willamette Valley. The vegetation of the upper (eastern) McKenzie River watershed was very different than vegetation in the lower McKenzie River watershed in 1850 when the earliest vegetation surveys were conducted. The lower McKenzie River watershed consisted of a transition from low elevation oak (*Quercus garryana*) forest, savanna, and prairie to higher elevation closed forests dominated by Douglas fir (*Pseudotsuga menziesii*) (Thilenius 1968; Johannessen et al. 1971). The upper McKenzie River watershed consisted of mostly mixed conifer forest of Douglas fir and various true firs (*Abies* spp.) interspersed with mid-montane meadows with alpine meadows and permanent snow fields in the high elevations. Contrasting vegetation/landscape use patterns by the two distinct prehistoric people may be the result, or the cause, of these differences.

Questions and Hypotheses

This study examined the relationships among archeological sites, landform positions, and past and present plant communities in the McKenzie River valley. We asked:

- 1) Did the prehistoric occupants of the McKenzie River watershed have a preference for specific landforms and vegetation types? If so, are these preferences related to known or probable foods?

We expected that the prehistoric inhabitants of the McKenzie River watershed preferred to use wide river valleys and broad mountain ridges because these landforms provided foods such as deer and huckleberries (*Vaccinium* spp.). To answer this question, we examined the relationship between archeological sites and landforms in the McKenzie River valley.

- 2) Did the prehistoric occupants of the McKenzie River watershed utilize the western Cascades and High Cascades differently?

We hypothesize that the archeological sites of the western Cascades and High Cascades exhibit different patterns associated with differences in landforms and vegetation. The High Cascades and western Cascades represent two very dissimilar geographical and geological areas. The High Cascades are younger and much less dissected than the western Cascades. As a result, they have different landscape patterns associated with slope, surface water, and vegetation. Prehistorically, the High Cascades may have been somewhat culturally distinct from the western Cascades, with the Molalla chiefly occupying the High Cascades and mountainous Kalapuyans occupying the western Cascades, but these patterns are ethnographically unclear (General Land Office 1855; Juntunen 2005). We compared the distributions of archeological between for the High Cascades and western Cascades.

- 3) Did the prehistoric occupants of the foothill region of the western Cascades portion of the McKenzie River watershed utilize the landscape differently than occupants of the high elevation portions of the Western Cascades?

We hypothesized that the distribution of archeological sites by landform type was similar in low- and high-elevation portions of the western Cascades. We compared the archeological site distributions in the Mohawk River watershed, located in the lowest reaches of the McKenzie River watershed, to the Blue River watershed, located in the upper portions of the western Cascades.

- 4) What is the current distribution and diversity of plants in montane meadows of the high-elevation western Cascades? How do plant distribution, tree age, and meadow configuration differ in sites with versus without evidence of prehistoric occupation?

We hypothesized that native people used fire to actively manage meadows and surrounding open forests in the high-elevation portions of the Andrews Forest, and that the effects of that management may still be detected in plant community composition today. The use and management of low and

higher elevation meadows and grasslands by Native Americans in the Pacific Northwest has been discussed previously, but without resolution (Boyd 1999, Norton et al. 1999, Whitlock and Knox 2002; Walsh et al. 2010a,b). High-elevation meadows in the Andrews Forest are relicts of a more extensive complex of montane meadows used by native peoples up to 250 years ago, prior to significant European influence. After the extirpation of native peoples, the high elevations may have been subjected to sheep grazing and associated burning in the late 1800s and early 1900s (Burke 1980). Since 1945 about 25% of the Andrews Forest has been clearcut in small patches linked by an extensive network of roads (Jones and Grant 1996; Wemple et al 1996). We assessed change in meadow area over the period 1949-2005 using aerial photographs. We aged trees along meadow edges to identify the position of meadow edges prior to air photos. We surveyed plants in 17 meadows and adjacent non-meadows of different sizes and configurations using 20 by 50 m Stohlgren-Whittaker vegetation plots. We then examine the patterns of archeological sites in relation to our assessment of vegetation patterns 200-300 years ago to identify likely usage patterns and preferences for occupation and resource utilization exhibited by prehistoric occupants of the high ridges of the western Cascades.

Archeological Site Records and Attributes

Most archeological records were obtained from the Oregon State Historic Preservation Office (SHPO), but the author also identified and recorded previously unrecorded archeological sites in his field investigations. Most of the site records that were obtained from the SHPO had been recorded during cultural resource surveys accompanying potentially disturbing events, such as timber harvests, road construction, or dam/reservoir construction. About 14.6% of the McKenzie River watershed has been surveyed for archeological sites; these areas are concentrated in the western Cascades portion of the Willamette National Forest, but some areas of the High Cascades and the lower McKenzie River valley also have been surveyed (Figure 2.2).

Such surveys are typically conducted utilizing meandering transects spaced 15 m apart, during which time archeological artifacts are identified and recorded. An artifact locality typically was labeled a "site" if more than 10 artifacts or at least one feature (depression, stripped tree, rock cairn, etc) was identified within a 30 m radius. GIS shapefiles of all recorded archeological sites and surveyed areas were generated in ArcGIS 9.3 for this analysis.

New archeological site survey

One hundred eighty hectares of the high ridges that designate the eastern boundary of the Andrews Forest were surveyed for archeological sites. These surveys include areas designated as steep and flat meadows, steep and flat forests, and saddles. This survey was conducted following the standard procedure of meandering transects spaced 15 m apart.

Archeological site classification and dating

Three groups of archeological sites were analyzed for their relationship to landscape features and vegetation types. Archeological sites were grouped into three categories according to the presence or absence of artifact types: (1) projectile points, (2) scrapers, (3) all sites. Sites with projectile points were indicative of camps where large mammals were being hunted. Sites with end and side-scrapers (hereafter referred to as scrapers) are one of the few artifacts known to have limited and definite purposes. These artifacts were used to prepare hide and wood and are, therefore, likely to be found in camps where the processing of such materials would have taken place. All sites, regardless of their inclusion or exclusion of projectile points and scrapers, were analyzed as a group. Archeological sites in the western Cascades mostly consist of lithic scatters, with small to large amounts of debitage. Other artifacts that were potentially present include retouched flakes, utilized flakes, bifaces, unifaces, hammerstones, and groundstone.

Archeological sites with projectile points were also subdivided by date into the Late Archaic (200-1800 BP), middle archaic (1800-6000 BP), and early Archaic (6000-8000 BP) periods, as projectile points are the only hunter-gatherer lithic artifact type that is consistently diagnostic of specific time frames. The distributions of prehistoric archeological sites and artifacts in the McKenzie River watershed are informative as a representation of the behavior of prehistoric hunter-gatherers over the past 6-10 thousand years, but are less informative about the behavior of people in smaller time scales

GIS of landforms and vegetation

A set of GIS layers was constructed to analyze the relationship between archeological site location, topographic position, and vegetation communities. A 10-m digital elevation model (DEM) of the McKenzie River watershed was obtained from the State of Oregon's Geospatial Clearinghouse. Slope and aspect raster layers were created from this DEM using the Surface Tool in the Spatial Analyst toolbox in ArcGIS 9.3. A raster layer classifying the landscape into topographic categories was created using a combination of slope, DEM (simplified into a few categories using the Reclassify tool), and a 300-m radius Topographic Position Index (TPI300) raster layer generated from the DEM following Weiss (2010). Using raster calculator, these three raster layers were summed to generate a fourth raster layer, which was categorized into a set of landforms using a decision-tree (Figure 2.3). These classification decisions follow from multiple assumptions and observations. First, some categories (Willamette Valley and Mountain peaks) were identified based on elevation. Second, field visits indicated that TPI300 accurately captured some landforms, but not others: TPI300 captured ridgetops, flat areas (including flat areas in the high Cascades and wide flat valley bottoms), and steep

narrow valley bottoms. TPI300 did not effectively differentiate low, middle, and upper slopes, or steep, and gentle slopes. Therefore, various combinations of the DEM, slope, and TPI300 were used to define different landforms.

Vegetation structure was constructed based on two raster datasets. The vegetation of the Willamette National Forest portion of the McKenzie River Watershed was identified using a vegetation raster file generated by Dailey (2007) from Landsat TM (30-m resolution) imagery. The vegetation of the lower elevation portion of the McKenzie River Watershed was identified using a shapefile of the reconstructed 1851 vegetation of the Willamette River Valley as reconstructed using original surveyors notes taken prior to 1851 (PNW-ERC 2001). A small portion of the McKenzie River Watershed was not covered by either of these two GIS layers. Vegetation data for the Willamette National Forest were used to examine the relationships between vegetation types and archeological sites in the upper portion of the McKenzie River Watershed. The 1851 vegetation data were used to examine the relationships between vegetation types and archeological sites in the lower portion of the McKenzie River watershed. The contemporary distribution of vegetation communities differs from the distribution of prehistoric vegetation communities. Specifically, meadows have been shrinking rapidly since the late 1940s (Miller and Halpern 1999; Takaoka and Swanson 2008) and perhaps since the late 1700s. Up to 50% of many former meadow environments has been converted into open forests/very open forests since the late 1940s (Takaoka and Swanson 2008). Nevertheless, much of the study site contains forests that predate Euro-American colonization, so the comparison of archeological site location with contemporary vegetation is useful.

Meadow Identification and Change Rate

All meadows larger than 0.1 ha in and immediately adjacent to the Andrews Forest were mapped by interpretation of aerial photographs obtained in 1949 and 2005. A 2005 one meter resolution National Agricultural Imagery Program (NAIP) imagery of Lane County, OR was used as the basis for digitizing the 2005 meadow layer. Separate aerial photographs of the area in 1949 (black and white, 1:20,000) were acquired and scanned at the U.S. Forest Service Pacific Northwest Research Station, then geo-rectified, using permanent or semi-permanent landscape markers, such as rock outcrops and large, easily identifiable individual old growth trees. The outline and extent of meadows were mapped in ArcGIS 9.3, excluding all identifiable trees and tree clusters in meadows. Meadows were classified into three meadow classes (xeric, mesic, wet) based on tone and color of the aerial photograph, with darker green tones assumed to indicate mesic meadows and lighter colors xeric meadows. Wet meadows were identified by field visits only.

The extent of meadows prior to 1800 was estimated by identifying and aging mature and old growth forests along meadow edges. Tree cores were taken from 220 trees within mature/old growth forest stands from 22 20 x 30-m rectangular plots in between and surrounding meadows. The plots were distributed within the four largest meadow complexes (Carpenter Mountain, Meadow 2, Meadow 1, and Lookout Mountain). The locations for the plots were determined by first visually surveying the forest surrounding the meadows, identifying the location of the mature/old growth section of the forest as identified by widely spaced trees approximately 1+-m in diameter at breast height. The plots were then distributed in this section of the forest, with the long edge parallel to the meadow's edge. All trees were mapped and recorded, but only those larger than approximately 75-cm at breast height were cored, unless the tree species was known to grow slowly in shaded environments (*Tsuga heterophylla*, *Tsuga mertensiana*), which were cored at much smaller diameters. The cores were extracted using a 28-inch Haglof increment borer approximately 70 cm above the ground surface on the uphill side of the tree. Char and other evidence of fire were surveyed for on all trees in the sample plot. The ground was examined for dead and downed wood of all stages within the sample plots as well to estimate the antiquity of the mature portions of the forest. Tree cores were air dried, mounted on wooden mounts, sanded with coarse then fine sandpaper until the approximate center of the core was exposed and finely sanded. Once the cores were dried, mounted, and sanded, each growth ring was counted using a 10x hand lens magnifier until all rings were counted. This process was then repeated until the same total number of rings was acquired three times. If the center of the tree was not identified in the core, the ring count was identified as incomplete. Only a very small percentage of trees surrounding meadows were cored and analyzed within a subjective sampling strategy, so results should be taken as a first attempt to approximate the prehistoric boundaries of the forest.

Vegetation cover by species was determined in 17 Stohlgren-Whittaker plots in 15 meadows and two non-meadow areas adjacent to meadows. Stohlgren-Whittaker plots consist of a 20x50 m plot containing one 5x20 m, two 2x5 m, and ten 0.5x2 m subplots. The percent cover of all plant species was recorded in each subplot. For the purposes of this study, all plot totals were combined, relative to subplot size, into a single percent cover value for the entire plot per plant species.

Statistical analyses

Patterns of human occupation in the western Cascades were identified using a GIS-based analysis of the locations of known prehistoric archeological sites in the McKenzie River watershed in relation to dominant vegetation derived habitats and physical landform locations. The observed distribution of sites and artifacts was tested against the expected distribution of sites and artifacts

using a chi-square test. For each test, the expected proportions of sites were based on the proportions of landforms (or vegetation types) in the portions of the study area that had been surveyed for prehistoric sites. Observed proportions were based on counts of prehistoric sites of various types grouped by landform or vegetation type.

Plant cover data from the Stohlgren-Whittaker plots were analyzed using hierarchical agglomerative cluster analysis (CLA), multiple response permutation procedure (MRPP), indicator species analysis (ISA), and non-metric multidimensional scaling (NMS). For the CLA, MRPP, ISA, and NMS analyses, I used PC-ORD version 5.31 (McCune and Mefford 2006). CLA was used to identify vegetation classes, using Sorensen distance and Flexible Beta (-0.25) linkage method (McCune and Grace, 2002). MRPP was used to test the significance of differences in environmental space among the vegetation classes identified by CLA, after relativizing the environmental matrix and switching the species and environmental matrix so as to not test species clusters for significance in species space (McCune and Grace, 2002). MRPP also was used to test the significance of differences among other, a-priori defined vegetation groups. Descriptors of the vegetation categories were derived from an Indicator Species Analysis (ISA) conducted on the a-priori and CLA-defined vegetation groups that were shown to be significant ($p < 0.05$) and to have high-moderate to high biological effect ($A > 2$) (Dufrene and Legendre 1998), using only species with a significant p-value (< 0.05) and an Indicator Value (IV) of over 50%.

NMS was used to assess patterns in meadow plant communities and their relationships to relevant environmental variables. Only species that were present in more than 5% of all sample units were used in the NMS analysis. Plant cover data were transformed using $\log+1$. An Outlier Analysis was conducted on the species and sample units, with outliers equaling values more than two standard deviations from the grand mean. No species or samples were found to be outliers. The NMS was conducted using a Sorensen/Bray-Curtis similarity matrix with a flexible beta linkage (-0.25). For the NMS analysis, the following procedure was employed: (1) a random starting configuration was chosen, (2) 250 runs were made for the Monte Carlo test, (3) dimensionality was selected based on a better than random solution as determined by the results of the Monte Carlo test and reduction in stress, (4) up to 250 iterations were allowed to calculate a stress stability of $< .000001$ over the last 15 iterations, and (5) the NMS plots were overlaid with the environmental variables (Kruskal 1964, McCune and Grace 2002).

RESULTS

Distribution of archeological sites by landform and vegetation, McKenzie River

Altogether, 363 known prehistoric archeological sites have been identified in the McKenzie River watershed (Figure 2.4). Of these, 359 were previously identified and 4 sites were newly discovered and recorded during this study. Although only 14.6% of the McKenzie River study area has been surveyed, the density of archeological sites is rather high, with 359 sites located out of 541 km² (54000 ha) surveyed area (Table 2.3). On average there were about 0.66 archeological sites/ km² (Table 2.3).

Archeological sites were significantly concentrated in particular landforms in the McKenzie river valley study site. Archeological sites were significantly associated with wide valley bottoms, <5 degree midslopes, < 35 degree ridges, and < 5 degrees slopes in the High Cascades subareas of the McKenzie river valley (Table 2.4). There were 2 sites/ km² in wide valley bottoms (88 sites/42 km²) and <5 degree midslopes (18 sites/9.1 km²), and <35-degree ridges (24 sites/10.8 km²) (Table 2.4). Archeological sites were significantly absent (0.59 sites/259 km²) from mid-slopes greater than 35 degrees, the most common landform in the McKenzie River watershed (Table 2.4). Observed numbers of archeological sites were no different than expected in other landforms (narrow valleys, lower slopes, midslopes >5 degrees, ridges >35 degrees, High Cascade ridges >5 degrees, and volcanic peaks (Table 2.4).

Archeological sites were significantly concentrated in particular vegetation types in the Willamette National Forest portion of the McKenzie River valley study site. Archeological sites were significantly associated with shrub/very open forests (Table 2.5). There were 5 sites/km² in shrub/very open forests (39 sites/33.4 km²). Observed numbers of archeological sites were no different than expected in other vegetation types (meadow, open forest, closed forest, rock/ice, not classified) (Table 2.5).

Archeological sites were significantly concentrated in reconstructed particular vegetation types from 1851 in the lower portion of the McKenzie River valley study site. Archeological sites were significantly associated with closed riparian forests and wetlands, prairies, and woodlands (Table 2.6). There were 6 sites/ km² in closed riparian forests and wetlands (16 sites/2.3 km²), 4 sites/ km² in prairies (19 sites/4.6 km²), and 5 sites/ km² in woodlands (12 sites/2.3 km²) (Table 2.6). Archeological sites were significantly absent from closed upland forests (Table 2.6). There was 1 site/ km² in closed upland forests (16 sites/80.2 km²). Observed numbers of archeological sites were no different than expected in other vegetation types (savanna, shrubland) (Table 2.6).

Contrasting archeological site distributions, Mohawk vs. Blue River watersheds

The Mohawk River occupies the western portion of the study area, at lower elevation and closer to the Willamette Valley than the Blue River watershed (Figure 2.5). In the Mohawk River watershed, significantly more archeological sites than expected are present in wide valley bottoms (Table 2.7). Also, significantly more archeological sites than expected are present in areas classified as riparian/wetland forests, prairies, and woodlands as of 1851 (Table 2.8). Archeological sites were not significantly associated with other landforms or vegetation types in the Mohawk River watershed. In the Blue River watershed, significantly more archeological sites than expected are present in wide valley bottoms and on ridges less than 35 degrees in slope, and in shrub/very open forests and meadows (Tables 2.9 and 2.10). Archeological sites were not significantly associated with other landforms or vegetation types in the Blue River watershed.

Contrasting archeological site distributions, western Cascades vs. High Cascades

The eastern high-elevation portions of the McKenzie River watershed drain both the western Cascade and High Cascade mountain ranges; the western Cascades are much older and more highly dissected than the High Cascades, which is a broad volcanic platform (Figure 2.5). In the western Cascades, significantly more than expected numbers of archeological sites are present in wide valley bottoms, ridges less than 35 degrees in slope, and mid-slopes less than 5 degrees in slope (Table 2.11). Significantly more than expected numbers of archeological sites also are present meadows and shrub/very open forests (Table 2.12). Significantly fewer than expected archeological sites are present in mid-slopes over 35 degrees and closed forests in the western Cascades (Tables 2.11, 2.12). In the high Cascades, archeological sites were not significantly associated with landforms or vegetation types, except that a higher than expected number of sites are associated with rock and ice (Tables 2.13 and 2.14).

Distributions of Projectile Points

Of the 363 prehistoric archeological sites recorded in the McKenzie River watershed, 73 include projectile points (Figure 2.6). Significantly more projectile points than expected are present in wide valley bottoms (Table 2.15). Thirty-seven of the 73 sites with projectile points were dated to the Late Archaic period (200-1800 BP) (Figure 2.7), twenty-three to the Middle Archaic period (1800-6000 BP) (Figure 2.8), and six to the Early Archaic (6000-8000 BP) (Figure 2.9). However, when the sites with projectile points are subdivided by date, the sample sizes are too small to detect associations with landforms.

Distributions of End and Side-Scrapers

Of the 363 prehistoric archeological sites recorded in the McKenzie River watershed, 37 have scrapers (Figure 2.10). Significantly more scrapers than expected are present in wide valley bottoms; no other significant relationships are evident (Table 2.16).

Distribution, history, and recent status of montane meadows in the Andrews Forest

Meadow distribution and change, 1949-2005

Montane meadows occupy broad ridgetop landforms in the Andrews Forest (Figure 2.11). Five meadow complexes are evident in aerial photographs from 1949. By 2005, the area of these meadows had contracted by a total of 66.0 ha, a 54.8% decline since 1949. The greatest loss of meadow area has occurred in the meadow complexes associated with old volcanic peaks at Carpenter Mountain (27.1 ha lost) and Lookout Mountain (28.8 ha lost) (Table 2.17). The smaller meadow complexes along the eastern ridge (BCM, Meadow 1, and Meadow 2) have, comparatively, lost little area (3.7, 4.5, and 0.2 ha, respectively). No aerial photographs or maps of the meadows are known to exist prior to 1946.

Meadows in the Andrews Forest were more likely to be associated with mid-slopes and ridges <35° (Figure 2.12) (Table 2.18). As these two landforms are distinguished only by elevation, with ridges being above 1829-m and mid-slopes below, these two landforms are related. These two landforms appear to have lost the most area since 1949, as well. Minor landform types associated with meadows include steep valley bottoms and mid-slopes 6-20°. Meadows were moderately associated with mid-slopes 21-35° and ridges 1-35°.

Archaeological sites in the Andrews Forest

Archaeological sites of prehistoric occupation occur along the eastern bounding ridge of the Andrews Forest in all meadow complexes except the BCM meadow complex (Figure 2.13). However, only about half of the thirteen archeological sites occur within areas mapped as meadow as of 1940 or 2005 (Figure 2.13). Six archeological sites occur in or near the Carpenter Mountain meadow complex (Figure 2.14); three of these sites were not in meadows as of 1949. No archeological sites have been found in or near the BCM meadow complex (Figure 2.15). One to two archeological sites occur in or near the Meadow 2 complex (Figure 2.16), and two to three archeological sites occur in or near the Meadow 1 complex (Figure 2.17). Two archeological sites also occur in the Lookout Mountain meadow complex (Figure 2.18).

Four previously unrecorded archeological sites were identified on the ridges of the Andrews Forest (Figure 2.19). One of these sites includes the only known temporally diagnostic artifact from Andrews Forest: a Late Archaic projectile point. One site was located on Lookout Mountain in a flat open meadow. A second site was located on a wooded saddle near the largest meadow in the

Andrews. A third site was located on a high, flat, rocky locality approximately 500 m south of the largest meadow in the Andrews Forest, in an open forest. The fourth site was located north of the western ridge of Carpenter Mountain., in a flat locality on a north-facing slope in a fragmented meadow.

Prehistoric extent of montane meadows

The ages of cored trees in 22 20 x 30-m plots where trees were cored ranged from less than 50 to almost 450 years (Table 2.19, Figure 2.20). The cored plots account for a very small percentage of the trees surrounding the meadows. Tree species included *Pseudotsuga menziesii*, *Abies procera*, *Abies amabilis*, *Abies lasiocarpa*, *Abies grandis*, *Pinus monticola*, *Tsuga heterophylla*, and *Tsuga mertensiana*. Additionally, no evidence of old downed trees in the form of late stage decay dead and downed wood was identified in the tree plots. Fifteen trees were >200 years and six trees were >250 years; all of the trees older than 250 years and four of nine trees aged 200-250 years are *Pseudotsuga menziesii*. The four trees older than 300 years (336, 349, 367, 426) were all located in the central portion of the ridge. Two (ages=336 and 349) are located northwest of the largest meadow in Meadow 1 complex (M1-x1a) (Figure 2.17) and two (ages=367 and 426) were located northwest of the largest meadow in Meadow 2 complex (M1-x21a) (Figure 2.16). All three of these trees had well-developed lower limbs less than 4-m above the ground, while many of the surrounding trees had much higher limbs (Figure 2.21). All but two of the eleven trees aged 200-250 years also have well-developed lower limbs less than 2 m above the ground. The 200-300 year old trees occur in all four complexes.

Native American use and prehistoric trail systems in the Andrews Forest

Native Americans occupied and claimed the lands within the McKenzie River study area until they were obliged to cede these lands to the US Government in the mid-1800s. In 1855, a map created by the General Land Office in Oregon in 1855 (General Land Office 1855) showing the approximate locations of tribal groups in the southern Willamette valley and western Cascades and the lands ceded by them in 1855 (Figure 2.22). What appears to be the broad portion of the middle McKenzie River valley, including the areas of the present-day towns of Blue River and McKenzie Bridge, was identified as belonging to the Moolack band of the Callapooyas (Kalapuya) (Figure 2.23). The Andrews Forest lies just north of this part of the McKenzie river valley and was likely utilized and occupied by this group of Native Americans prior to 1855. A Cascade National Forest map from 1912 (Figure 2.24) shows that the Andrews Forest area was still somewhat unknown to Euro-Americans in 1912, because the map misidentifies the drainage patterns of Lookout and McRae Creeks. The locations of Carpenter Mountain and Lookout Mountain, though, do appear to be correct.

Native Americans had a system of trails along ridges in the McKenzie River watershed that appeared on early maps of the area; these trails may have been areas where burning occurred, creating or expanding meadows. The 1912 map (Figure 2.24) identifies a trail connecting Lookout Mountain with the McKenzie river valley floor; this trail still exists today. The trail also was shown as connecting Lookout Mountain to Carpenter Mountain along Frissell ridge, and north to Wolf Rock. This trail passes through the general locality of at least seven archeological sites, suggesting that a trail system created by the Native Americans was later utilized by the Euro-Americans, and subsequently became a gravel road. A Cascade National Forest map from 1925 (Figure 2.25) correctly identifies the drainage patterns of the Andrews Forest and surrounding area. The 1925 map also includes the Frissell ridge trail, as in the 1912 map, and identifies a trail -- potentially another Native American trail -- along Blue River ridge (the ridge between Lookout Creek and Blue River). Native Americans in the western Cascades generally kept trails open by frequent burning. Figure 2.26 shows an illustration by Henry Eld in 1841 of a recently burned Native American trail in the western Cascades foothills approximately 100 km south of the study area.

Current vegetation of montane meadows and relationship to archeological sites

Current vegetation of montane meadows in the Andrews Forest consists of four taxonomically-based categories (identified using CLA, Figure 2.27). These categories were significantly different ($p=0.00000031$) with a high degree of effect ($A=0.693$) (Table 2.20). The four vegetation categories are characterized by the following indicator species: category 1, *Eriophyllum lanatum*, *Festuca idahoensis*, *Gilia capitata*, *Lathyrus torreyi*, *Lupinus caudatus*, *Potentilla arguta*, *Rumex acetosella*, *Castilleja sp.*; category 2, *Cirsium undulatum*, *Orthocarpus imbricatus*, *Vaccinium membranaceum*; category 3, *Arctostaphylos nevadaensis*, *Penstemon procerus*, *Xerophyllum tenax*; category 4, no indicator species.

Meadow vegetation composition was related to meadow area in 1949 and 2005, slope, distance to forest, distance to nearest meadow, 2005 complex area, and aggregated fragment area (NMS final stress 7.15262, final instability 0.00000) (Figure 2.28). Axes 1, 2, and 3 explained 58.0%, 12.4%, and 21.0% of the variance for a total r^2 of 91.4%. Variables quantifying the areas of the sampled meadows are the most correlated with the ordination axes (Table 2.21). Meadow area in 1949, meadow area in 2005, aggregated fragment area, and 2005 complex area are all highly to moderately correlated with Axis 1, the dominant axis, and moderately correlated with Axis 3. Distance to forest, distance to the nearest meadow and slope also explain some of the variance in plant community composition (Table 2.21).

The four vegetation classes identified using CLA produce distinct clusters of points in the ordination (Figure 2.28). Cluster 4 was very distinct and separate from the other three clusters in ordination space. Cluster 1 was moderately distinct. Clusters 2 and 3, though, were somewhat mixed.

Six archeological sites are associated with clusters 3 and 4 in the vegetation plot cluster analysis and NMS analysis. Sample plots CM-x44c, LOM-x4c, LOM-x4a, and M2-21f (vegetation cluster 3, Figure 26) and sample plots FR-gs, M1-pt, and CM-28 (vegetation cluster 4) are associated with archeological sites. These sample localities are relatively flat broad, flat ridges with slopes <35 degrees (CM-x28, M1-pt, FR-gs, LOM-x4a, LOM-x4c) or midslopes of 6-20 degrees (CM-44c, M2-21f) adjacent to broad, flat ridges. Three of these localities with both archeological sites and plant samples are semi-forested saddles located near very large meadows (CM-x28, M2-x21f, M1-pt). *Vaccinium membranaceum*, a known foodplant of the Kalapuyans and Mollala that was widely used and traded, was an indicator species of cluster 3. Field visits indicate that FR-gs and M1-pt, from cluster 4, are also associated with *Vaccinium* spp.

DISCUSSION

Prehistoric population(s) of the McKenzie River watershed followed a collector-like lifestyle much more than a forager lifestyle, as predicted by the resource and landform distributions in the McKenzie River watershed. Archeological sites and artifacts are distributed unevenly across the landscape and demonstrate that the indigenous people preferred certain landforms and vegetation communities above others. Archeological patterns evident in the McKenzie River watershed as a whole indicate a definite preference for wide valley bottoms, gentle mid-slopes (<5°), and gentle to moderately sloped ridges (<35°), and an avoidance of steep slopes (>35°). Vegetation preferences of the prehistoric people in the McKenzie River watershed indicate a preference for shrub/very open forests, including riparian forests and high elevation open forests and shrubs.

The distribution of artifacts with known uses – projectile points and scrapers – also indicates selective use of certain landforms and time periods. Because few individual artifact types have clear and limited functions or temporal association, it is difficult to interpret the age or usage of a site from an artifact type. However, the functions of scrapers and projectile points are known and projectile points are temporally diagnostic. Scrapers were largely used to scrape hides for leather for clothing, housing, and other purposes. Projectile points were used for hunting large mammals and warfare. Because there is little evidence of warfare in the McKenzie River watershed, projectile points found there probably represent hunting locations or campsites where broken projectile points were being repaired or discarded. Additionally, since over 90% of the recorded projectile points are Middle or

Late Archaic in age (<6000 years) and largely follow the same pattern whether Middle or Late Archaic, these landform preferences are likely to be consistent for the past 4000-6000 years. Scrapers and projectile points are both positively associated with wide valley bottoms. Wide valley bottoms, therefore, are the primary places where campsites were located and where hunting took place. This is consistent with the likely prehistoric distribution of deer and elk, which likely highly favored lower valleys and only secondarily upland meadows and prairies (Matzke, personal communication).

The distribution of prehistoric sites in the western Cascades is similar to that for the McKenzie River watershed as a whole, indicating a preference for wide valley bottoms, gentle mid-slopes, and gentle to moderately sloped ridges. Sites in the western Cascades were positively associated with shrub/very open forests (upland and riparian) and meadows and negatively associated with closed forests, using the Willamette National Forest vegetation layer. Similarly, archeological sites were concentrated in riparian forests, woodlands, and prairies and scarce in closed upland forests in the portion of the western Cascades where vegetation was surveyed in 1851. The riparian forests favored by prehistoric people are located in wide valley bottoms. The upper McKenzie River valley, the lower McKenzie valley, and the Mohawk River valley, in the lower McKenzie River watershed, are wide river valleys containing many archeological sites. Archeological sites were rare in the central portion of the McKenzie River valley, which is relatively narrow.

Although the vegetation data used in this analysis are much more recent (last 150 years) than the archeological sites (dating back to potentially 8000 BP), vegetation in western Oregon has not changed much since these archeological sites were being used by prehistoric peoples, as the projectile point record suggests that prehistoric people intensified their use of the Cascades in the past 2000 years, with a much smaller presence prior to that time. In the Oregon Coast Range, after 5600 yr BP, Douglas-fir, western hemlock, and western red cedar dominated the pollen record, marking the introduction of the present-day cool, moist climate; conditions may have become slightly drier, as indicated by increased Douglas-fir and decreased cedar, after 4800 BP (Worona and Whitlock 1995). In the western Cascades, Douglas-fir dominated the pollen record after 11,000 cal yr BP at Gordon Lake, 1177 m elevation about 5 km NW of Carpenter Mountain in the Andrews Forest (Grigg and Whitlock 1998). The modern vegetation, Douglas-fir and western hemlock-dominated forests, were established beginning 4500-4000 14-C yr BP in Indian Prairie, also located about 5 km NW of Carpenter Mountain (Sea and Whitlock 1995).

The combination of wide valley floors and open riparian forest apparently was a highly desirable location for prehistoric people in the western Cascades portion of the McKenzie River watershed. Multiple food resources utilized by the Kalapuya and Molalla are present in riparian

forests. Common camas (*Camassia quamash*), one of the major food resources of the Kalapuya in the Willamette Valley, is common in open riparian forests and wet meadows adjacent to riparian forests. White-tailed deer (*Odocoileus virginianus*) and Roosevelt elk (*Cervus canadensis roosevelti*) are also common in and around riparian forests and surrounding wet meadows (Matzke, personal communication). These two ungulates were the most important prey animals for the Kalapuya and Mollala at the time of Euro-American contact and likely throughout most of the Holocene (Zenk 1990; Juntunen et al. 2005). Moreover, riparian forests provide easy access to water and aquatic organisms like fish, but there is no evidence that the Kalapuya, Mollala, or other prehistoric group in the McKenzie River watershed or upper Willamette Valley utilized fish as major portions of their diets.

Non-riparian shrub/very open forests in the western Cascades are typically located on upper ridges near meadows. Although forests may have been less extensive and meadows larger prior to 1800, ridgetop vegetation may well have consisted of a mosaic of meadow and open forest. The shrub/very open forests on these upper ridges are dominated by Noble fir (*Abies procera*), Pacific silver fir (*Abies amabilis*), and Mountain hemlock (*Tsuga mertensiana*), with patchy but substantial understories of various huckleberry species, including *Vaccinium deliciosum* and *Vaccinium membranaceum*. Ericaceae are present in the pollen record in nearby sites since before 10,000 yrs BP (Sea and Whitlock 1995). Huckleberries were highly desired resources that were traded at Celilo falls and Willamette falls (French 1999). Dried huckleberries also provided food throughout the winter. Ridge shrub/very open forests and meadows also provide the edge environment with herbaceous plants and deciduous shrubs favored by deer and elk, so were likely locations utilized for hunting.

Throughout the McKenzie River valley, archeological sites are very scarce in areas of closed conifer forest in the uplands, indicating that prehistoric people avoided these forests. In western Oregon, forest vegetation has been dominated by Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) since 4000 to 6000 yrs BP (Sea and Whitlock 1995; Worona and Whitlock 1995). Far fewer human food resources are available in coniferous forests than in prairies, meadows, and deciduous forests and woodlands.

In contrast, archeological sites in the High Cascades show no association, positive or negative, with any vegetation community. Prehistoric sites in the High Cascades were rather evenly distributed among different landforms and vegetation types. Although the High Cascades contain montane and subalpine meadows (Halpern et al 2010, Miller and Halpern 1998), archeological sites were not significantly associated with these areas. This lack of pattern suggests that prehistoric people were not using the High Cascades for the acquisition of resources associated with particular landforms and

vegetation types; instead they may have been using the High Cascades for collecting obsidian and travel.

Prehistoric sites were distributed differently in the Mohawk River watershed (lower McKenzie River valley) and Blue River watershed (upper McKenzie River valley). In the Mohawk River watershed, prehistoric people favored wide valley bottom riparian forests, prairies, and woodlands whereas in the Blue River watershed, they preferred shrub/very open forests and meadows on gentle to moderate ridges and gentle (<5°) mid-slopes. Differences in the prehistoric preferences for sites in these two watersheds probably reflect different subsistence activities and resources available in these two locations. Prior to Euro-American settlement, much of the lower McKenzie River watershed, including the Mohawk River watershed, were dry and wet prairie, Oregon oak (*Quercus garryana*) woodland, and Oregon oak savanna. These communities possess important food plant species that are less common in Blue River watershed, including western hazelnut (*Corylus californica*), tarweed (*Madia* spp.), and Oregon oak (*Quercus garryana*) (Thilenius 1968, Johannessen et al 1971, Franklin and Dyrness 1988, Zobel et al 1976). Western hazelnut and oak both provide edible nuts. The prairie habitat preferred by prehistoric residents of the Mohawk valley also provided tarweed, camas, deer, and elk.

In contrast, prehistoric people in the Blue River watershed preferred upland shrub/very open forests and ridgetop meadows, which provided resources such as huckleberries, upland bulbs and roots, deer, and elk. The concentration of sites on gentle mid-slope positions in the Blue River watershed may indicate that these were camps or stops on trail systems connecting lower valleys to upper ridges. Most of the archeological sites located on Frissell ridge in the Andrews Forest (Blue River watershed) are small lithic scatters, indicative of temporary specialized camps. These camps may have been used for hunting of deer and elk, which frequent the meadows, although only one projectile point has been found. Meadows also may have been used for collection of huckleberries, because site locations are associated with small meadows and adjacent open forests that contain *Vaccinium* spp. shrubs. In addition, many other food plants are located in meadow and meadow-forest edge environments. Columbia lily (*Lilium columbianum*), Bracken fern (*Pteridium aquilinum*), various lupines (*Lupinus* spp.), and multiple Lomatium species (*Lomatium* spp.) all occur in and around xeric meadows and adjacent shrub/open forest edges, and are known food plants of western Oregon Native Americans.

No direct evidence of fire exists on the upper ridges of the western Cascades, but indirect evidence suggests that frequent, low severity fire was a likely component of Native American life in the area for maintaining huckleberry patches, good hunting localities, and open trails. In Blue River,

the high-elevation ridgetop sites previously favored by prehistoric people are a mosaic of meadows, open forests, and shrubs. Present-day forests are dominated by mature Noble fir (*Abies procera*), but prehistorically these upper forests may have been Douglas fir (*Pseudotsuga menziesii*) savannas, with much more extensive meadows and/or open *Vaccinium* spp. patches. All aged trees older than 250 years on Frissel Ridge are Douglas fir (*Pseudotsuga menziesii*), a much more fire resistant tree than Noble fir (*Abies procera*). In some mountainous areas of the Pacific Northwest, *Pseudotsuga menziesii* /*Vaccinium* spp. forests experienced fire at 14 year intervals (Agee 1993). Native American groups in parts of western Washington were known to burn openings in otherwise densely forested mountains to attract deer and elk (Agee 1993; Norton et al. 1999). Native Americans also burned ridgetops to maintain trail systems, such as those shown along Frisell ridge in historic maps of the area (Norton et al. 1999).

CONCLUSIONS

Patterns of use by prehistoric indigenous groups in the McKenzie River watershed display strong geographic patterns at several spatial scales, indicating particular patterns of use of vegetation, wildlife, and mineral resources. Prehistoric people preferred particular parts of the landscape, and these preferences varied among the lower, middle, and upper portions of the McKenzie River watershed. The lower, western portion of the McKenzie River valley is similar to the Willamette Valley, and prehistoric site locations indicate preferences for wide river valley riparian forests, woodlands, and prairies. These preferences are consistent with the availability of unique plant species (tarweed, hazelnut, oak) in these areas. The middle portion of the McKenzie River valley, represented by the western Cascades portion of the Willamette National Forest, was utilized both for riparian and upland resources. The high concentration of scrapers and projectile points in this section of wide, open McKenzie River valley floor indicates that this area was used for hunting, as well as for gathering camas and other riparian plant resources. In the middle portion of the McKenzie River valley, prehistoric people also utilized meadows and shrub/open forests along broad, gently sloping ridges. These areas were probably utilized for gathering huckleberries, meadow plants, and, to a lesser extent, hunting.

In both the lower and middle portions of the McKenzie river valley, high concentrations of scrapers and large sites with many artifacts indicate that wide valley floors were preferred locations for major campsites. These major camps may have served as bases from which small groups of people would depart for specific gathering activities in the uplands and to which they would return with partially dried or prepared foods. None of these sites, and very few in the McKenzie River valley as a

whole, have been excavated and/or extensively investigated, so it is not known whether these camps were utilized all year or were seasonal in nature.

Prehistoric people utilized the upper McKenzie River watershed, as represented by the High Cascades, very differently from the lower and middle McKenzie River watershed. Archaeological sites are uniformly distributed among landform and vegetation types in the High Cascades. This suggests that the High Cascades were not intensively utilized for food resources. Although the High Cascades were not avoided (this area contains 92 of the 363 known prehistoric archeological sites in the McKenzie River valley), the uniform distribution of prehistoric sites, as well as the presence of only four projectile points located near the boundary of the West and High Cascades, suggests that the High Cascades were used primarily for other purposes than food collection. Maps of the area from the late 1800s show many trails oriented generally north-south in the High Cascades, whereas trails in the western Cascades are oriented in all directions. Tribal groups from as far away as Northern California gathered at Celilo and Willamette falls to trade, and many of them utilized trails in the High Cascades. It is possible that the High Cascades had little to offer concerning food resources, but was chiefly utilized as a travel corridor.

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Table 2. 1 Plants of the Western Cascades utilized by Indigenous inhabitants.

Plant Name	Habitat Type
<i>Pteridium aquilarium</i> (Bracken fern)	Meadow, very open forest
<i>Erythronium grandiflorum</i> (Glacier Lily)	Meadow
<i>Lilium columbianum</i> (Columbia lily)	Meadow, very open forest
<i>Camassia quamash</i> (Common camas)	Riparian, wet meadow
<i>Vaccinium membranaceum</i> (thinleaf huckleberry)	Very open forest, open forest, meadow
<i>Vaccinium deliciosum</i> (Cascade huckleberry)	Very open forest, open forest, meadow
<i>Lomatium spp.</i> (Biscuitroot)	Meadow (rocky)

Table 2. 2 Animals of the Western Cascades utilized by Indigenous inhabitants.

Animal Name	Habitat Type
<i>Odocoileus virginianus</i> (white-tailed deer)	Upland open forest, riparian forest, meadow
<i>Odocoileus hemonius</i> (black-tailed deer)	Upland open forest, riparian forest, meadow
<i>Cervus canadensis</i> (elk)	Upland open forest, riparian forest, meadow
<i>Ursus americanus</i> (black bear)	Upland open forest, riparian forest, meadow

Table 2. 3. Overview of total area in studied sub regions, the area surveyed, previously and newly recorded archeological sites, average number of sites per km², and related percentages.

Study Subregion	Total Area (km ²)	Percent of Study Area	Area Surveyed (km ²)	Percent of Total Surveyed Area	Previously Recorded Sites	Newly Identified Sites	Total Sites	Percent of Total Sites	Sites/ km ² surveyed area
Western Cascades	2,522.04	68.2	425.79	78.7	263	4	267	74.3	0.63
Mohawk River Watershed	483.86	13.1	43.42	8.0	53	0	53	14.8	1.22
Blue River Watershed	260.07	7.0	58.28	10.8	36	4	40	11.1	0.69
High Cascades	1174.42	31.8	115.11	21.3	92	0	92	25.6	0.8
Total	3696.46	100	540.9	100	355	4	359	100	0.66

Table 2. 4Expected versus observed densities of archeological sites of all types in twelve landform types in the McKenzie River watershed, based on a Chi-square analysis.

Landform Category	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Wide Valley Bottom	42.78	7.8	28	88	130.0	0.001
Narrow Valley Bottom	26.46	4.9	18	2	13.9	ns
Lower Slope	27.29	5.1	18	34	13.8	ns
Mid-Slope - <5 degrees	9.20	1.7	6	18	23.5	0.02
Mid-Slope - 6-20 degrees	15.77	2.9	11	18	5.3	ns
Mid-Slope - 21-35 degrees	35.84	6.6	24	35	5.2	ns
Mid-Slope - >35 degrees	254.40	47	169	59	71.5	0.001
Ridge - 0-35 degrees	10.82	2	7	24	39.1	0.001
Ridge - >35 degrees	54.63	10.1	36	14	13.7	ns
High Cascades - <5 degrees	39.66	7.4	26	47	16.0	ns
High Cascades - >5 degrees	24.09	4.5	16	19	0.5	ns
Volcanic Peak	0	0	0	1	na	na
Total	540.90	100	359	359		

Table 2. 5 Expected versus observed densities of archeological sites of all types in six 2007 vegetation types in the Willamette National Forest portion of the McKenzie River watershed, based on a Chi-square analysis.

Vegetation Community	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Meadow	22.02	4.7	12	21	6.8	ns
Shrub/Very Open Forest	33.44	7.1	18	39	24.5	0.001
Open Forest	105.34	22.5	58	69	2.1	ns
Closed Forest	306.38	65.5	169	127	10.4	ns
Rock/Ice	0.09	0.1	0	1	na	ns
Not Classified	0.78	0.1	1	1	0	ns
Total	468.06	100	258	258		

Table 2. 6. Expected versus observed densities of archeological sites of all types in six vegetation types as of 1851 in the lower elevation, western portion of the McKenzie River watershed, based on a Chi-square analysis.

Vegetation Community	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Closed forest; Riparian & Wetland	2.25	2.5	2	16	78.0	0.001
Closed forest; Upland	80.23	87.3	92	57	13.1	0.05
Prairie	4.56	5	5	19	36.5	0.001
Savanna	1.03	1.1	1	1	0.0	ns
Shrubland	1.51	1.6	2	0	1.7	ns
Woodland	2.31	2.5	3	12	33.3	0.001
Total	91.92	100	105	105		

Table 2. 7. Expected versus observed densities of archeological sites of all types in twelve landform types in the Mohawk River watershed portion of the McKenzie River watershed, based on a Chi-square analysis.

Landform Category	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Wide Valley Bottom	6.03	13.9	7	22	29.1	0.001
Narrow Valley Bottom	0.10	0.3	0	0	0.1	ns
Lower Slope	10.27	23.7	13	12	0.0	ns
Mid-Slope - <5 degrees	0.33	0.7	0	0	0.4	ns
Mid-Slope - 6-20 degrees	2.21	5.1	3	4	0.6	ns
Mid-Slope - 21-35 degrees	4.10	9.4	5	2	1.8	ns
Mid-Slope - >35 degrees	18.37	42.3	22	10	6.9	ns
Ridge - 0-35 degrees	0.86	2	1	2	0.9	ns
Ridge - >35 degrees	1.14	2.6	1	1	0.1	ns
Total	43.41	100	53	53		

Table 2. 8. Expected versus observed densities of archeological sites of all types in six vegetation types as of 1851 in the Mohawk River watershed portion of the McKenzie River watershed, based on a Chi-square analysis.

Vegetation Community	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Closed forest; Riparian & Wetland	0.21	0.5	0	10	370.6	0.001
Closed forest; Upland	39.86	91.8	49	28	8.8	ns
Prairie	0.96	2.2	1	7	28.8	0.001
Savanna	0.73	1.7	1	1	0.0	ns
Woodland	1.64	3.8	2	7	12.5	0.02
Total	43.41	100	53	53		

Table 2. 9. Expected versus observed densities of archeological sites of all types in nine landform types in the Blue River watershed portion of the McKenzie River watershed, based on a Chi-square analysis.

Landform Category	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Wide Valley Bottom	3.45	5.9	2	7	9.1	ns
Narrow Valley Bottom	4.98	8.5	3	0	3.4	ns
Lower Slope	1.35	2.3	1	0	0.9	ns
Mid-Slope - <5 degrees	0.64	1.1	0	4	28.9	0.001
Mid-Slope - 6-20 degrees	0.45	0.8	0	0	0.3	ns
Mid-Slope - 21-35 degrees	3.15	5.5	2	2	0.0	ns
Mid-Slope - >35 degrees	33.36	57.2	23	13	4.3	ns
Ridge - 0-35 degrees	1.33	2.3	1	9	71.4	0.001
Ridge - >35 degrees	9.56	16.4	7	5	0.4	ns
Total	58.27	100	40	40		

Table 2. 10. Expected versus observed densities of archeological sites in all four 2007 vegetation types in the Blue River watershed portion of the McKenzie River watershed, based on a Chi-square analysis.

Vegetation Community	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Meadow	2.84	4.9	2	6	8.3	0.05
Shrub/Very Open Forest	3.90	6.8	3	8	10.6	0.02
Open Forest	16.03	27.5	11	15	1.5	ns
Closed Forest	35.40	60.8	24	11	7.3	ns
Total	58.27	100	40	40		

Table 2. 11. Expected versus observed densities of archeological sites in nine landform types in the western Cascades portion of the McKenzie River watershed, based on a Chi-square analysis.

Landform Category	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Wide Valley Bottom	39.21	9.2	25	87	158.5	0.001
Narrow Valley Bottom	25.80	6.1	16	2	12.4	ns
Lower Slope	27.89	6.5	17	31	10.4	ns
Mid-Slope - <5 degrees	8.08	1.9	5	15	19.5	0.02
Mid-Slope - 6-20 degrees	8.39	2	5	14	14.5	ns
Mid-Slope - 21-35 degrees	27.69	6.5	17	27	5.4	ns
Mid-Slope - >35 degrees	227.75	53.4	143	53	56.5	0.001
Ridge - 0-35 degrees	9.17	2.2	6	24	57.9	0.001
Ridge - >35 degrees	51.81	12.2	32	14	10.5	ns
Total	425.79	100	267	267		

Table 2. 12. Expected versus observed densities of archeological sites in five 2007 vegetation types in the western Cascades portion of the McKenzie River watershed, based on a Chi-square analysis.

Vegetation Community	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Meadow	13.65	3.9	6	18	20.8	0.001
Shrub/Very Open Forest	21.08	6	10	25	22.8	0.001
Open Forest	81.22	23	38	45	1.2	ns
Closed Forest	235.52	66.9	111	77	10.4	0.05
Not Classified	0.78	0.2	0	1	1.1	ns
Total	352.25	100	166	166		

Table 2. 13. Expected versus observed densities of archeological sites in twelve landform types in the high Cascades portion of the McKenzie River watershed, based on a Chi-square analysis.

Landform Category	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Wide Valley Bottom	2.57	2.2	2	1	0.5	ns
Narrow Valley Bottom	.66	0.6	1	0	0.5	ns
Lower Slope	1.49	1.3	1	3	2.7	ns
Mid-Slope - <5 degrees	1.03	0.9	1	3	5.8	ns
Mid-Slope - 6-20 degrees	7.38	6.4	6	4	0.6	ns
Mid-Slope - 21-35 degrees	8.18	7.1	7	8	0.3	ns
Mid-Slope - >35 degrees	25.65	22.3	21	6	10.2	ns
Ridge - 0-35 degrees	1.65	1.4	1	0	1.3	ns
Ridge - >35 degrees	2.75	2.4	2	0	2.2	ns
High Cascades - <5 degrees	39.66	34.5	32	47	7.4	ns
High Cascades - >5 degrees	24.09	20.9	19	19	0.0	ns
Volcanic Peak	0	0	0	1	na	ns
Total	115.11	100	92	92		

Table 2. 14. Expected versus observed densities of archeological sites of all types in five 2007 vegetation types in the high Cascades portion of the McKenzie River watershed, based on a Chi-square analysis.

Vegetation Community	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Meadow	8.28	7.2	7	3	2.0	ns
Shrub/Very Open Forest	12.36	10.7	10	14	1.8	ns
Open Forest	24.12	20.8	19	24	1.2	ns
Closed Forest	70.26	61.2	56	50	0.7	ns
Rock/Ice	0.09	0.1	0	1	12.5	0.02
Total	115.81	100	92	92		

Table 2. 15. Expected versus observed densities of all archeological sites containing projectile points in twelve landform types in the McKenzie River watershed, based on a Chi-square analysis.

Landform Category	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Wide Valley Bottom	42.78	7.8	6	21	41.1	0.001
Narrow Valley Bottom	26.46	4.9	4	0	3.6	ns
Lower Slope	27.29	5.1	4	10	10.6	ns
Mid-Slope - <5 degrees	9.20	1.7	1	2	0.5	ns
Mid-Slope - 6-20 degrees	15.77	2.9	2	5	3.9	ns
Mid-Slope - 21-35 degrees	35.84	6.6	5	12	10.7	ns
Mid-Slope - >35 degrees	254.40	47	34	14	12.0	ns
Ridge - 0-35 degrees	10.82	2	1	5	8.6	ns
Ridge - >35 degrees	54.63	10.1	7	3	2.6	ns
High Cascades - <5 degrees	39.66	7.4	5	1	3.6	ns
High Cascades - >5 degrees	24.09	4.5	3	0	3.3	ns
Volcanic Peak	0	0	0	0	na	ns
Total	540.90	100	73	73		

Table 2. 16. Expected versus observed densities of all archeological sites containing scrapers in twelve landform types in the McKenzie River watershed, based on a Chi-square analysis.

Landform Category	Area Surveyed (km ²)	Percent of Total Surveyed Area	Expected Sites	Observed Sites	χ^2	p<
Wide Valley Bottom	42.78	7.8	3	11	22.8	0.02
Narrow Valley Bottom	26.46	4.9	2	0	1.8	ns
Lower Slope	27.29	5.1	2	7	13.9	ns
Mid-Slope - <5 degrees	9.20	1.7	1	0	0.6	ns
Mid-Slope - 6-20 degrees	15.77	2.9	1	3	3.5	ns
Mid-Slope - 21-35 degrees	35.84	6.6	2	3	0.1	ns
Mid-Slope - >35 degrees	254.40	47	17	9	4.0	ns
Ridge - 0-35 degrees	10.82	2	1	1	0.1	ns
Ridge - >35 degrees	54.63	10.1	4	0	3.7	ns
High Cascades - <5 degrees	39.66	7.4	3	1	1.1	ns
High Cascades - >5 degrees	24.09	4.5	2	2	0.1	ns
Volcanic Peak	0	0	0	0	na	ns
Total	540.90	100	37	37		

Table 2. 17. Summary of the area of meadows lost between 1949 and 2005 by complex.

<i>Complex Meadow Type</i>	1949 Number	1949 Area (ha)	2005 Number	2005 Area (ha)	Total Loss (Number)	TotalArea Change (ha)	Total Change (Percent)	Original Remaining (Fragments)
<i>Carpenter Mountain</i>								
Mesic	5	3.8	5	2.2	0	-1.6	-42.1	5(5)
Xeric	127	37.1	58	11.6	96	-25.5	-68.7	31 (58)
Wet	0	0.0	0	0.0	0	0.0	0.0	0
Total	132	40.8	63	13.7	96	-27.1	-66.4	36 (63)
<i>BCM</i>								
Mesic	0	0.0	1	0.2	0	0.2	100.0	0
Xeric	54	13.9	39	10.0	29	-3.9	-28.1	25(39)
Wet	0	0.0	0	0.0	0	0.0	0.0	0
Total	54	13.9	40	10.2	29	-3.7	-26.6	25 (39)
<i>Meadow 1</i>								
Mesic	9	3.8	5	2.3	4	-1.5	-39.5	5(5)
Xeric	44	18.0	39	13.5	21	-4.5	-25.0	23(39)
Wet	0	0.0	0	0.0	0	0.0	0.0	0
Total	53	21.8	44	15.8	25	-6.0	-27.5	28 (44)
<i>Meadow 2</i>								
Mesic	1	0.3	2	0.4	0	0.1	-33.3	1(1)
Xeric	43	17.6	30	16.9	36	-0.7	-4.0	7(32)
Wet	0	0.0	0	0.0	0	0.0	0.0	0
Total	44	17.8	32	17.3	36	-0.5	-2.8	8(33)
<i>Lookout Mountain</i>								
Mesic	25	4.6	10	1.5	17	-3.1	-67.4	10(10)
Xeric	108	45.7	70	20.9	73	-24.8	-54.3	35(70)
Wet	3	1.2	2	0.4	1	-0.8	-66.7	2(2)
Total	136	51.5	82	22.8	91	-28.7	-55.7	45(80)
<i>Total (All Complexes)</i>								
Mesic	40	12.5	23	6.6	21	-5.9	-47.2	21(21)
Xeric	376	132.3	236	72.9	255	-59.4	-44.9	121(243)
Wet	3	1.2	2	0.4	1	-0.8	-66.7	2(2)
Total	419	145.8	261	79.8	277	-66.0	-45.3	144(266)

Table 2. 18. Summary of the area (ha) of different landform types in each meadow complex in 1949 and 2005. Meadow complex abbreviations are as follows: CM=Carpenter Mountain, BCM=BCM, M2=Meadow 2, M1=Meadow 1, LOM=Lookout Mountain.

Landform Type	CM 2005	CM 1949	BCM 2005	BCM 1949	M2 2005	M2 1949	M1 2005	M1 1949	LOM 2005	LOM 1949
Narrow Valley Bottom	0.3	0.7	0.5	0.0	0.1	0.0	0.8	1.1	0.2	0.7
Mid-Slope 6-20°	0.0	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.0
Mid-Slope 21-35°	0.2	0.4	4.9	5.2	0.4	0.5	0.1	0.1	0.1	0.1
Mid-Slope >35°	8.5	25.1	0.7	0.7	4.2	5.7	8.9	10.1	10.6	27.1
Ridge 1-35°	0.6	1.6	6.9	7.9	1.4	1.0	1.0	1.1	2.7	3.1
Ridge >35°	4.5	13.0	0.0	0.0	9.7	10.7	8.3	9.3	9.2	20.3

Table 2. 19. Table showing the distribution of tree age classes by tree species.

Age Class (years)	<i>Abies</i> <i>amabilis</i>	<i>Abies</i> <i>grandis</i>	<i>Abies</i> <i>lasiocarpa</i>	<i>Abies</i> <i>procera</i>	<i>Pinus</i> <i>monticola</i>	<i>Pseudotsuga</i> <i>menziesii</i>	<i>Tsuga</i> <i>heterophylla</i>	<i>Tsuga</i> <i>mertensiana</i>	Total
0-50	4	3	2	9	0	1	1	1	21
51-100	15	0	0	54	0	6	3	6	84
101-150	11	0	0	29	5	10	0	18	73
151-200	4	0	0	8	2	7	0	2	23
201-250	0	0	0	1	0	4	0	4	9
251-300	0	0	0	0	0	1	0	0	1
301-350	0	0	0	0	0	2	0	0	2
351-400	0	0	0	0	0	1	0	0	1
401-450	0	0	0	0	0	1	0	0	1
Total	34	3	2	101	7	33	4	31	215

Table 2. 20. Results of the rank-transformed MRPP analyses based on vegetation communities defined from hierarchical agglomerative cluster analysis. Indicator species (including IV and p-value) are shown for each category.

Grouping Variable	MRPP		ISA Species	ISA		
	A	MRPP p		Category	ISA IV	ISA p-value
CLA Group	0.693	0.00000031	<i>Castilleja sp.</i>	1	79.3	0.0220
			<i>Eriophyllum lanatum</i>	1	66.6	0.0122
			<i>Festuca idahoensis</i>	1	100.0	0.0078
			<i>Gilia capitata</i>	1	80.0	0.0302
			<i>Lathyrus torreyi</i>	1	99.8	0.0004
			<i>Lupinus caudatus</i>	1	77.1	0.0018
			<i>Potentilla arguta</i>	1	72.7	0.0146
			<i>Rumex acetosella</i>	1	68.7	0.0012
			<i>Cirsium undulatum</i>	2	71.1	0.0122
			<i>Orthocarpus imbricatus</i>	2	68.8	0.0176
			<i>Vaccinium membranaceum</i>	2	89.9	0.0012
			<i>Arctostaphylos nevadensis</i>	3	75.9	0.0054
			<i>Penstemon procerus</i>	3	71.4	0.0310
			<i>Xerophyllum tenax</i>	3	53.9	0.0222

Table 2. 21. Pearson correlations of environmental variables with NMS axes.

Environmental Variable	Axis 1 Pearson Correlation (r^2)	Axis 2 Pearson Correlation (r^2)	Axis 3 Pearson Correlation (r^2)
Elevation	0.028	0.002	0.013
2005 Meadow Area	0.436	0.049	0.260
2005 Meadow Perimeter-Area Ratio	0.004	0.052	0.035
1949 Meadow Area	0.626	0.006	0.112
1949 Meadow Perimeter-Area Ratio	0.028	0.010	0.000
Slope	0.065	0.434	0.433
Bare Ground	0.178	0.065	0.006
Aggregated Fragment Area	0.441	0.016	0.060
1949 Complex Area	0.115	0.042	0.000
2005 Complex Area	0.298	0.123	0.000
Fragmentation	0.002	0.000	0.087
Distance to Road	0.089	0.116	0.043
Distance to Forest	0.429	0.029	0.167
Distance to Opening	0.185	0.006	0.041
Distance to Nearest Meadow	0.255	0.027	0.047

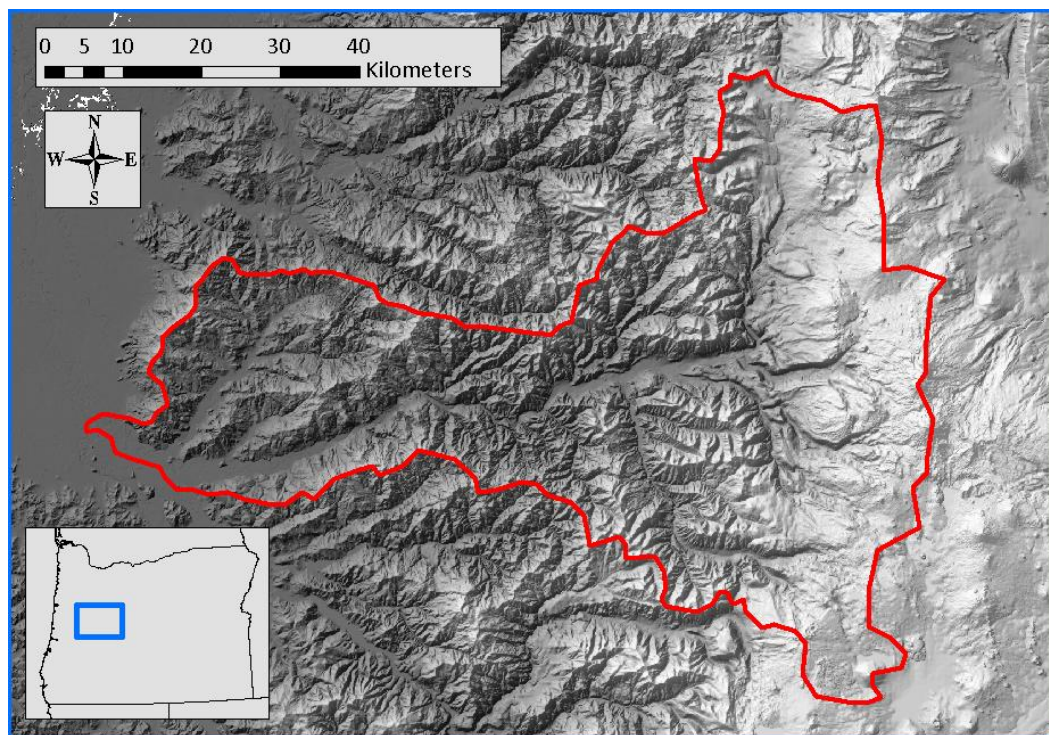


Figure 2. 1. Map showing the location of the McKenzie River watershed study area.

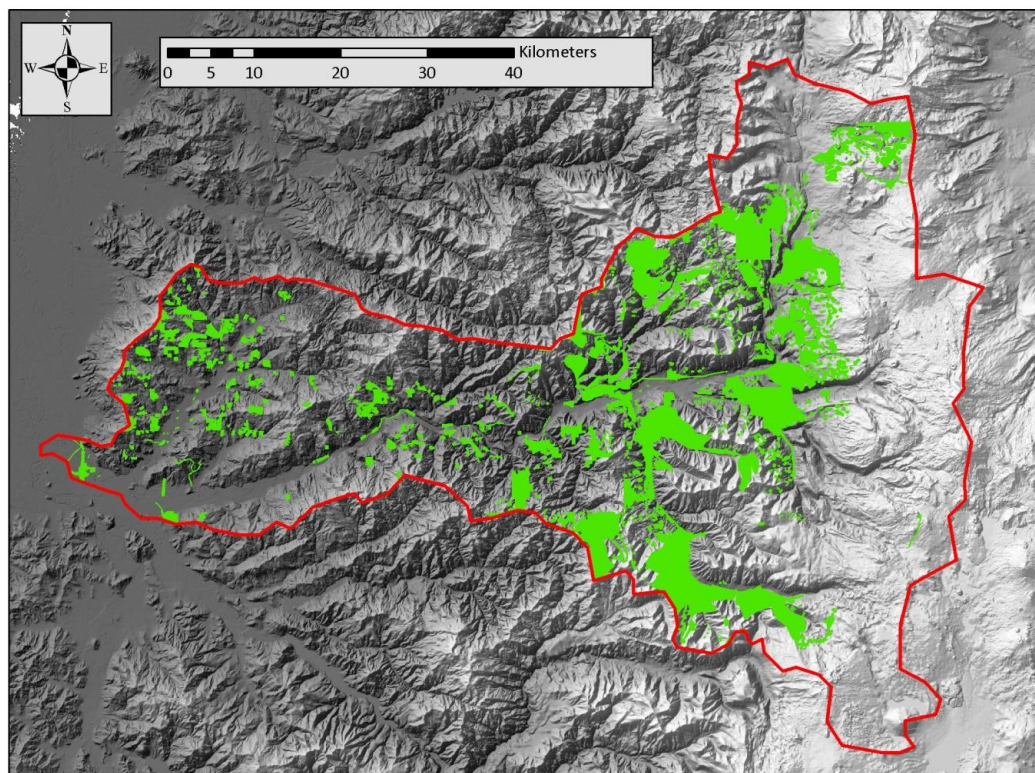
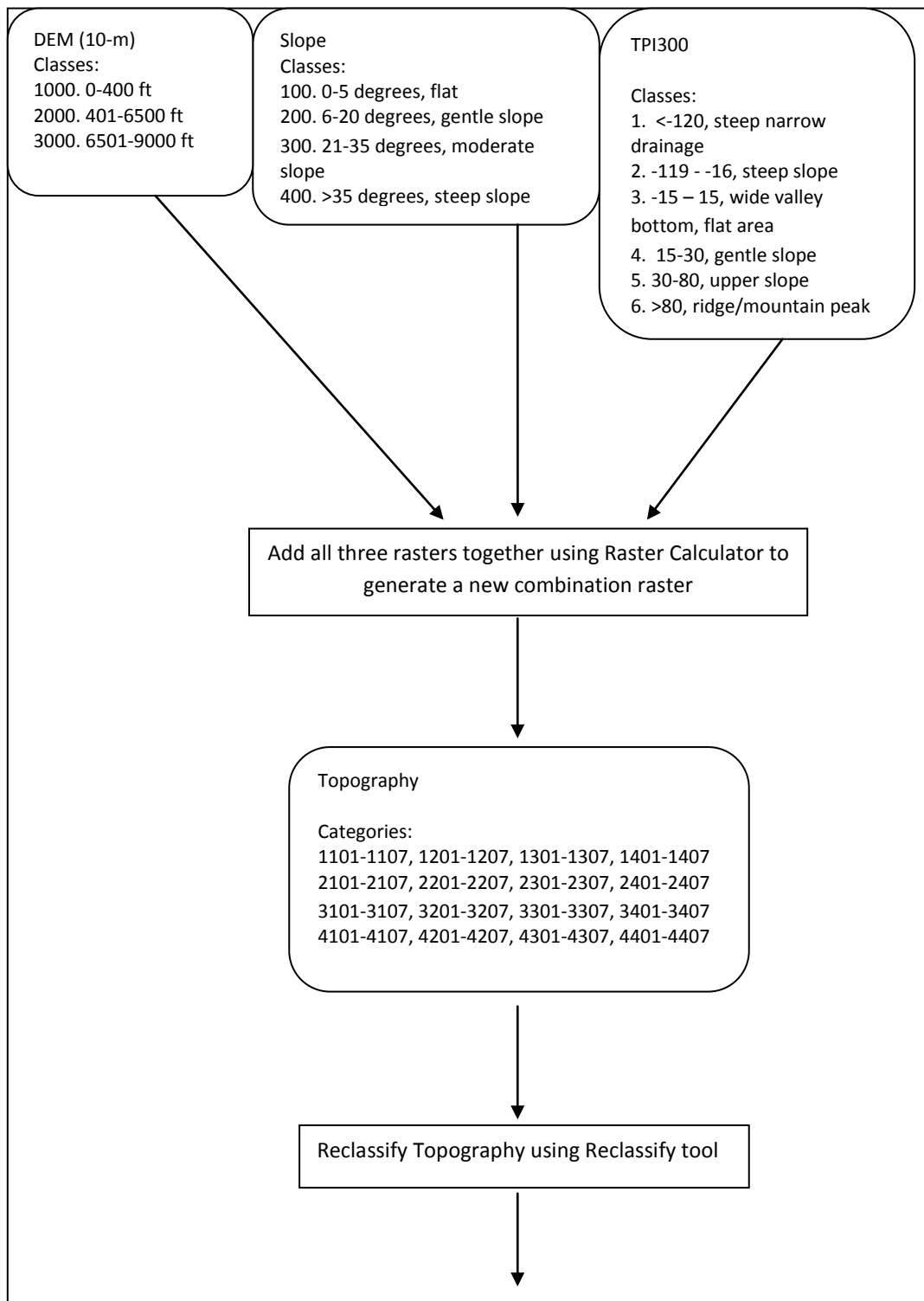
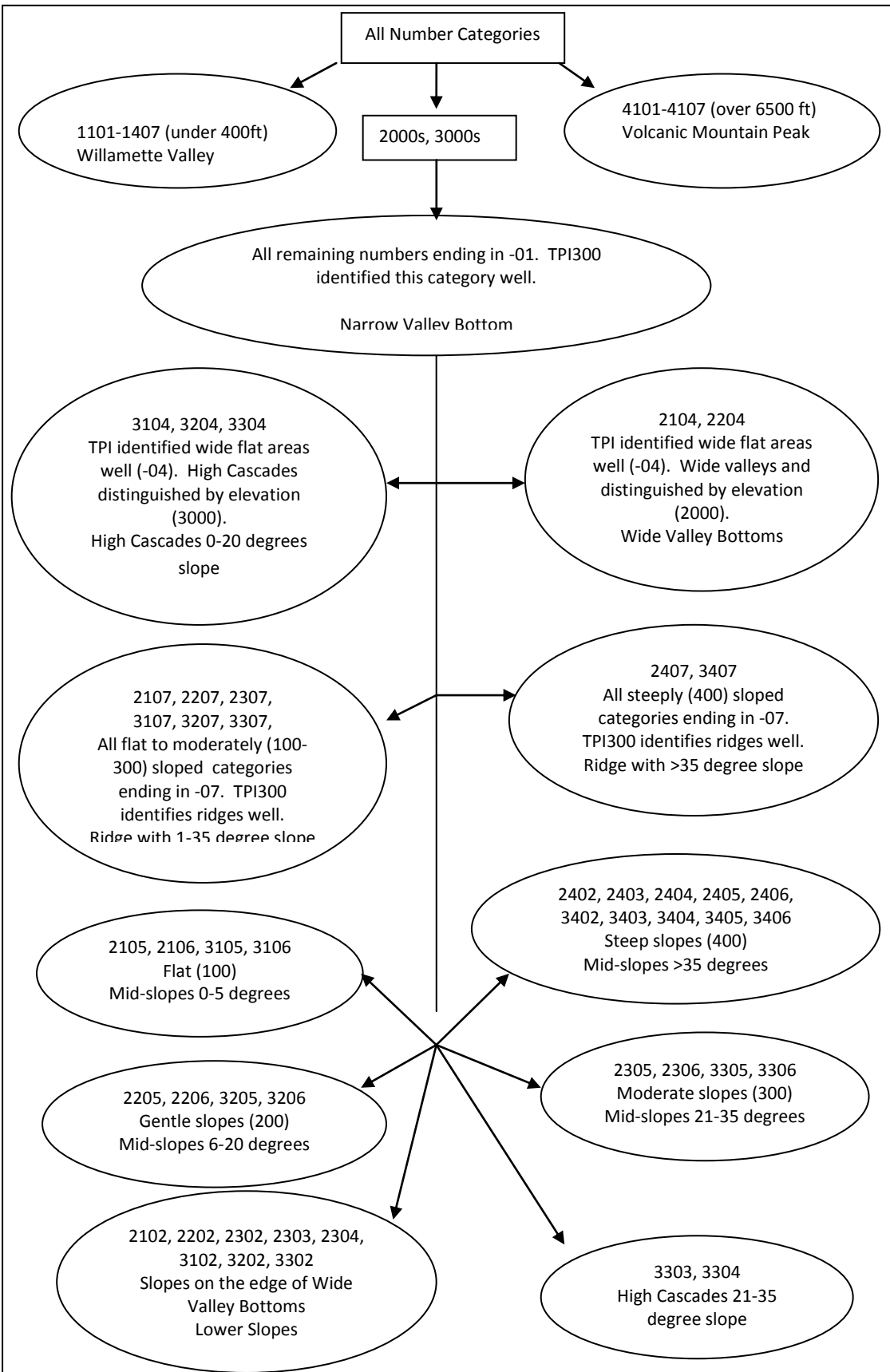


Figure 2. 2. Map showing the areas of the McKenzie River watershed surveyed for archeological sites (green polygons).





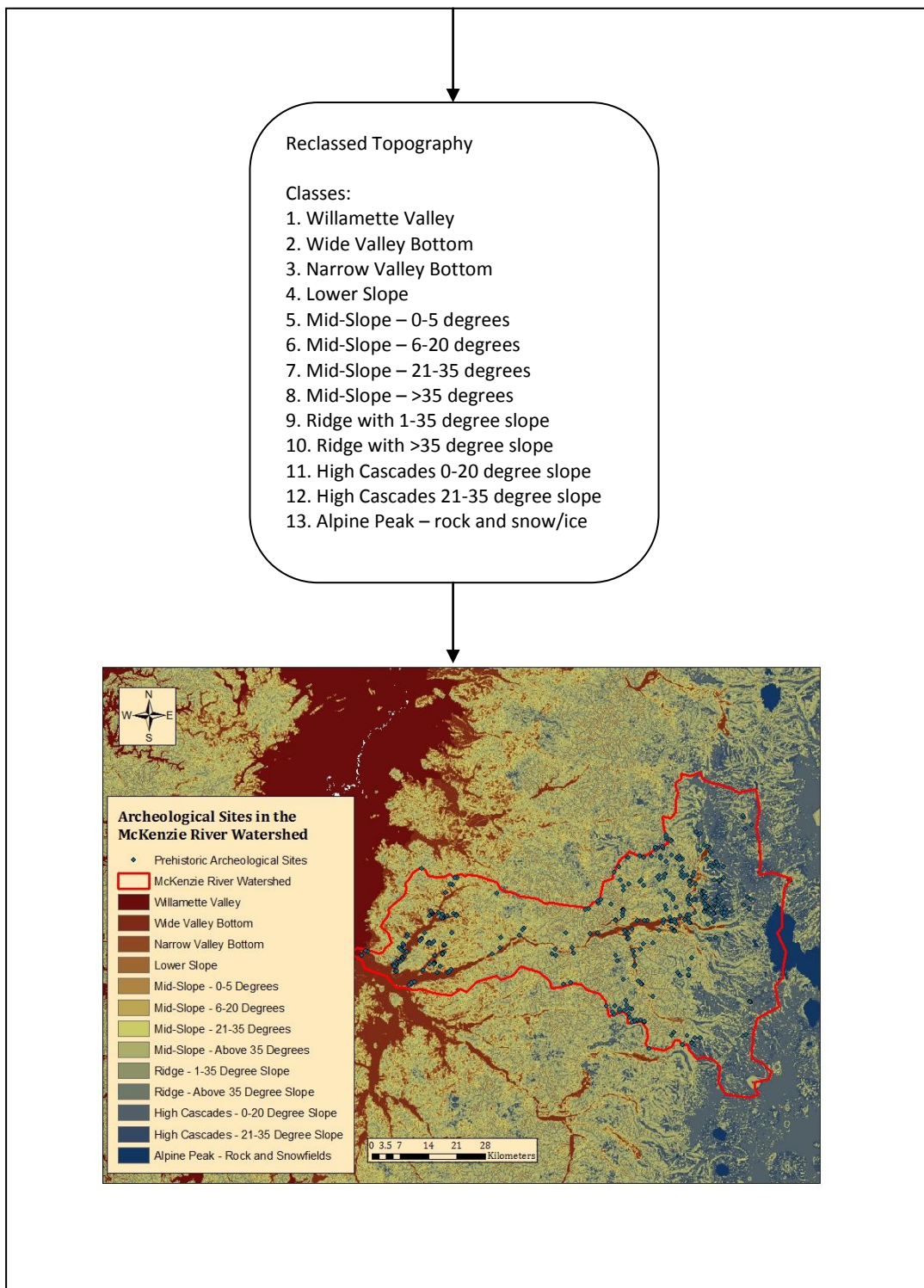


Figure 2. 3. Decision-tree showing the method for classifying the final topographic landform GIS raster.

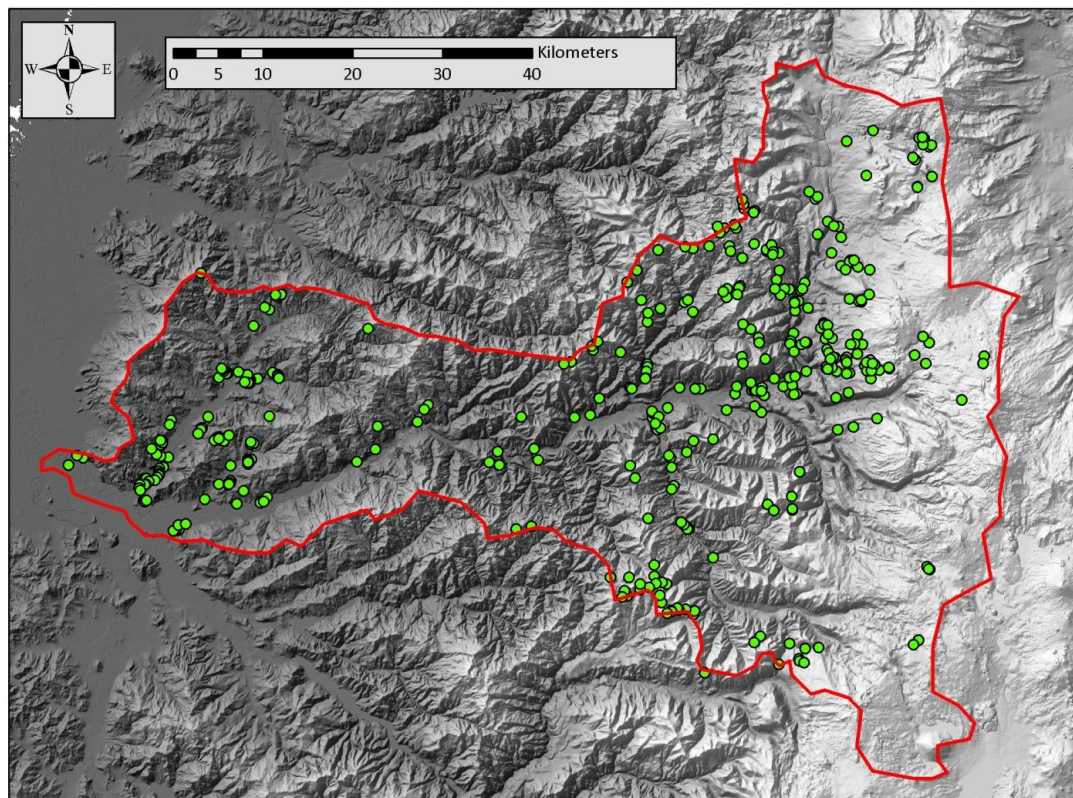


Figure 2. 4. Overview map of the known archeological sites (green dots) in the McKenzie River watershed.

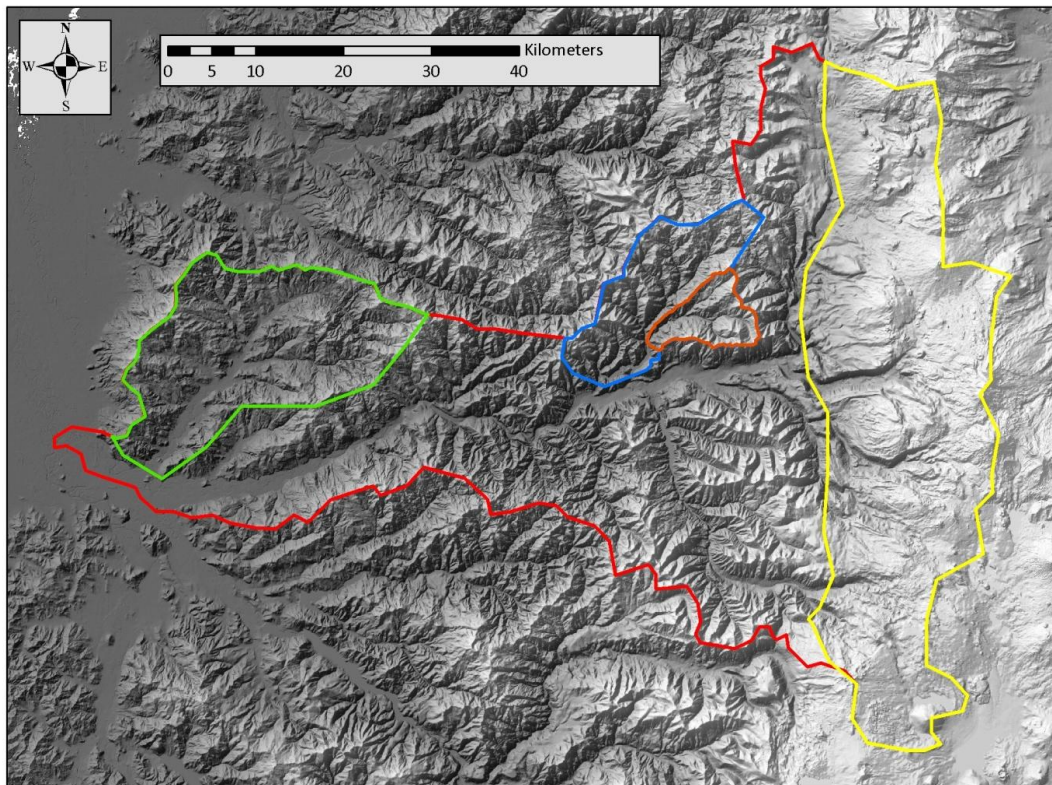


Figure 2. 5. Map showing the Mohawk River watershed (green line), Blue River watershed (blue line), the Andrews Forest (orange line) within the Blue River watershed, high Cascades (yellow line), and western Cascades (red line plus everything excluding the high Cascades), within the McKenzie River watershed.

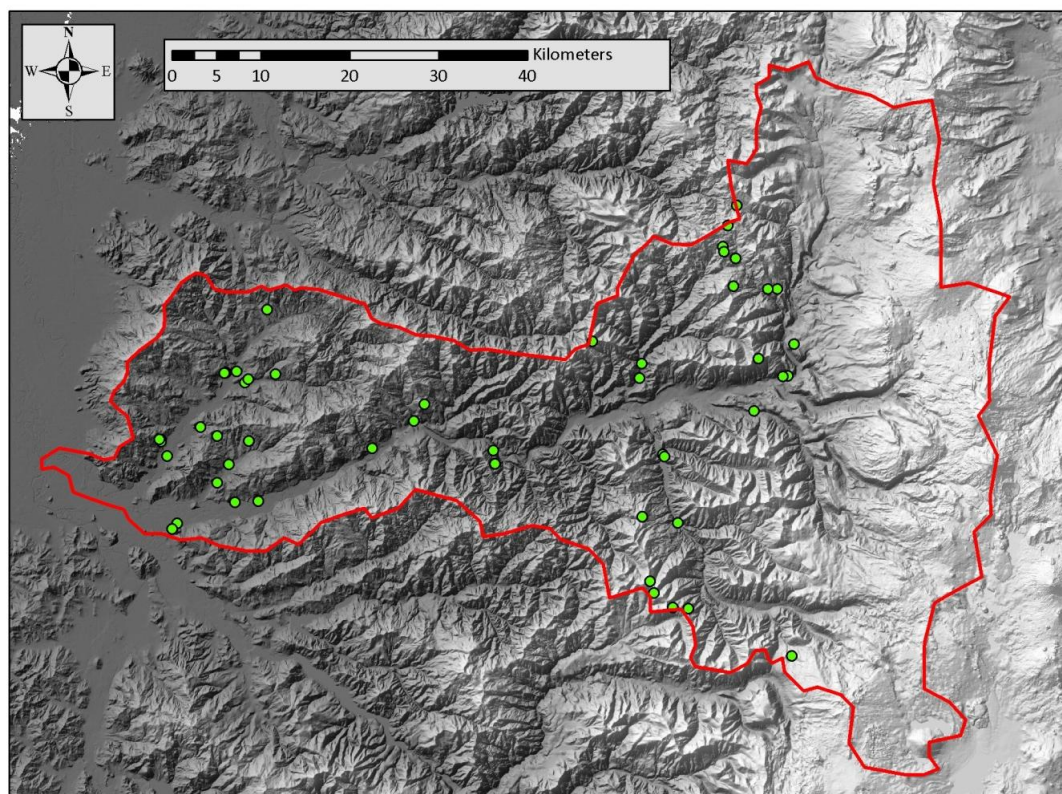


Figure 2. 6. Map showing the location of all known sites containing projectile points (green points) in the McKenzie River watershed.

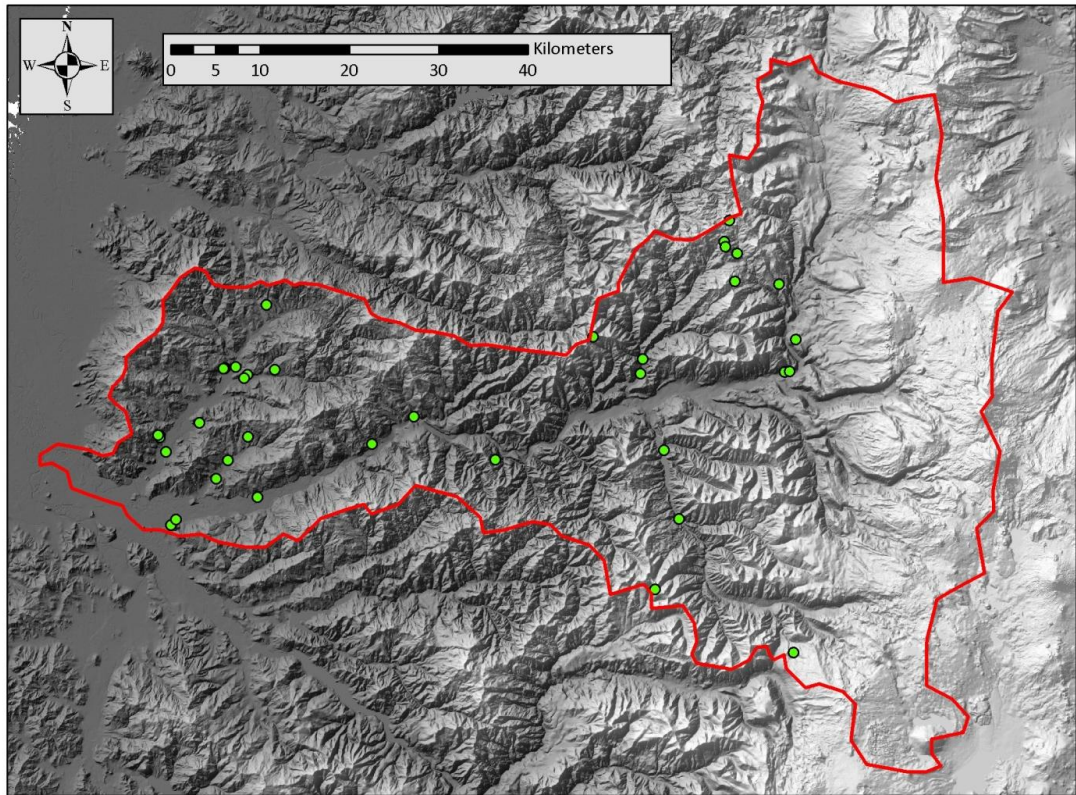


Figure 2. 7. Map showing the locations of all known sites containing Late Archaic projectile points (green dots) in the McKenzie River watershed.

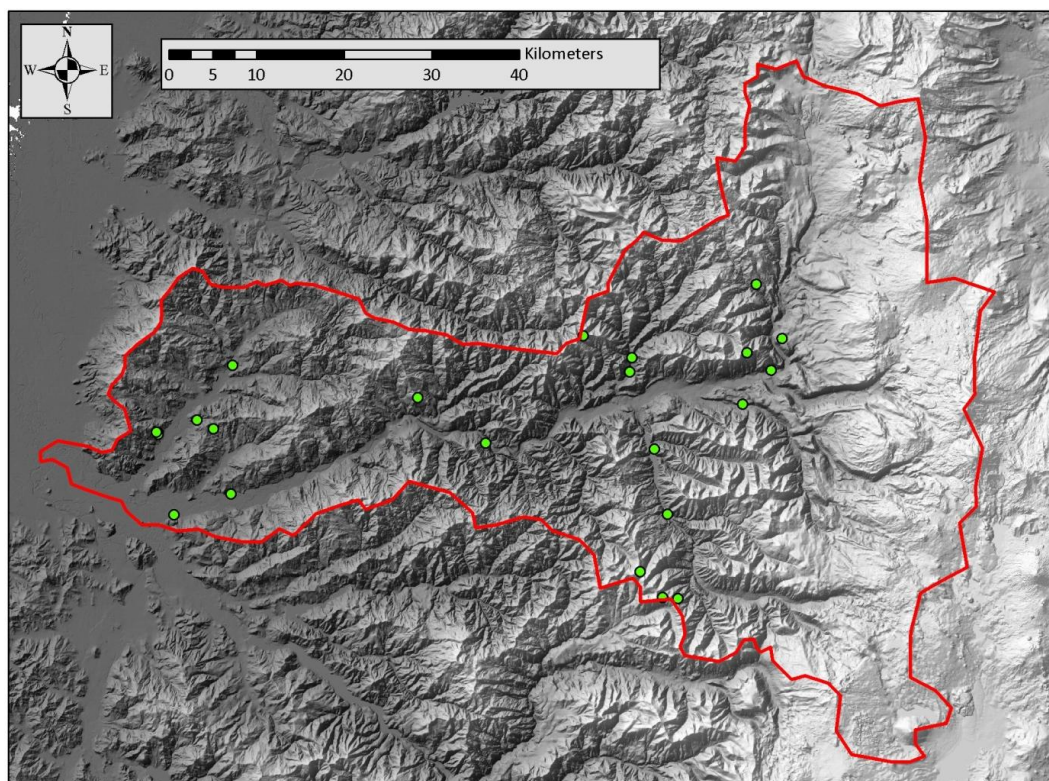


Figure 2. 8. Map showing the locations of all known sites with Middle Archaic projectile points (green dots) in the McKenzie River watershed.

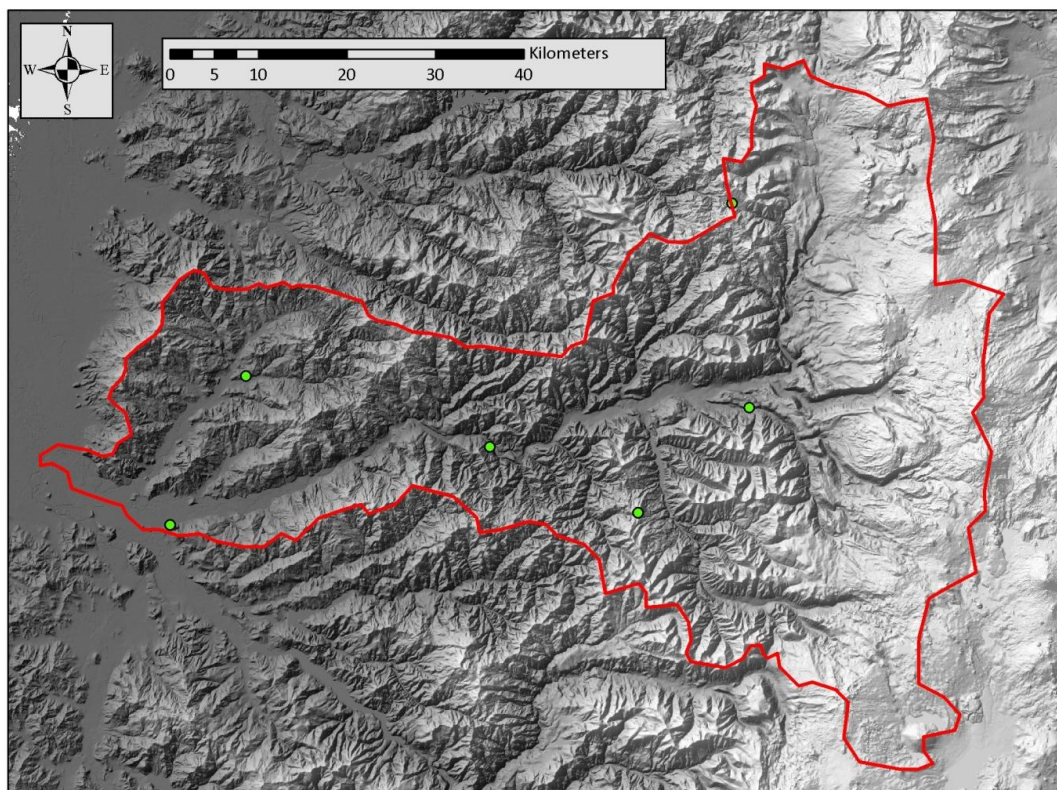


Figure 2. 9. Map showing the locations of all sites containing Early Archaic projectile points (green dots) in the McKenzie River watershed.

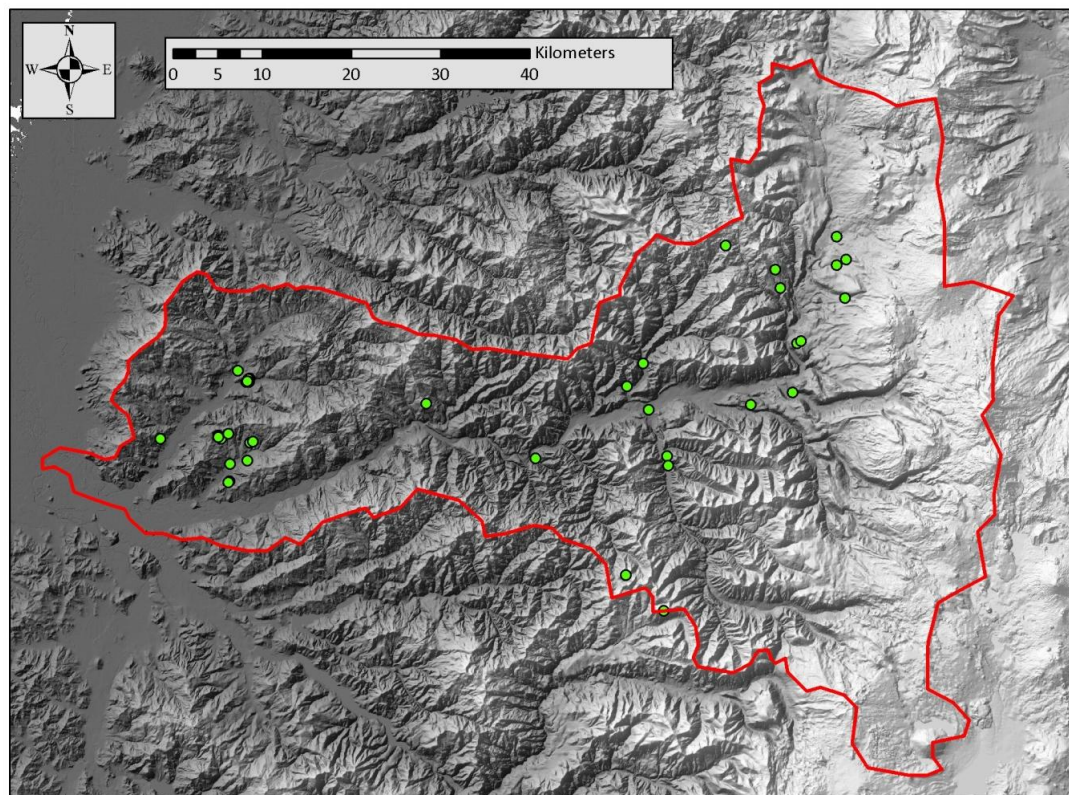


Figure 2. 10. Map showing the locations of all sites containing scrapers (green dots) in the McKenzie River watershed.

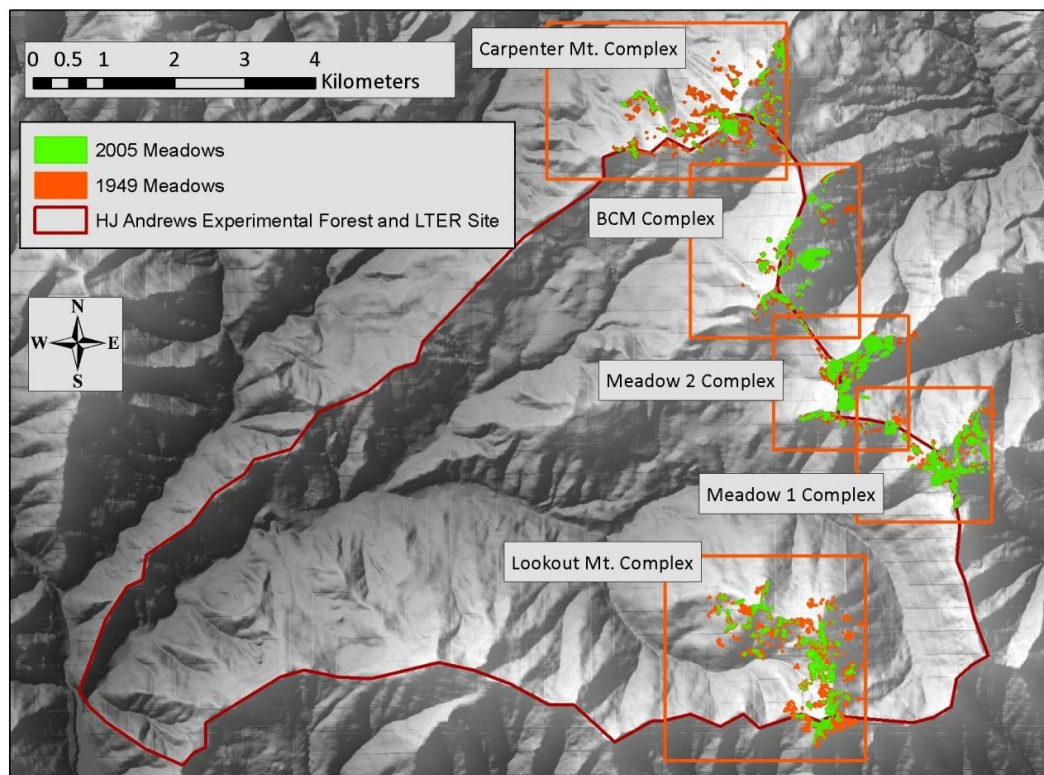


Figure 2. 11. Map showing extent of meadows in 1949 and 2005 (orange and green polygons), designated complexes (orange boxes), and Andrews Forest boundary (red line).

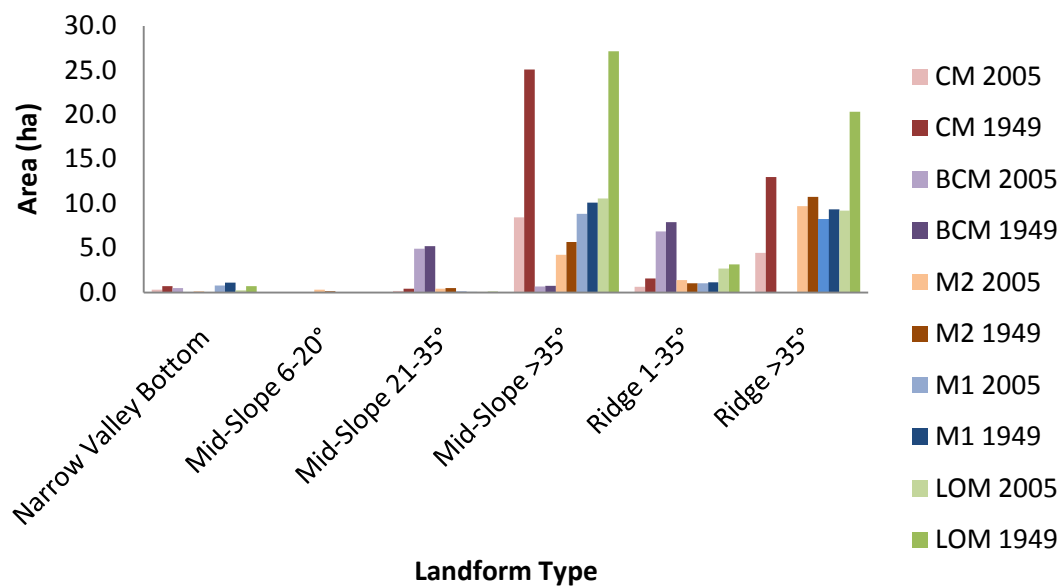


Figure 2. 12. Chart showing the area (ha) of different landform types in each meadow complex in 1949 and 2005. Meadow complex abbreviations are as follows: CM=Carpenter Mountain, BCM=BCM, M2=Meadow 2, M1=Meadow 1, LOM=Lookout Mountain.

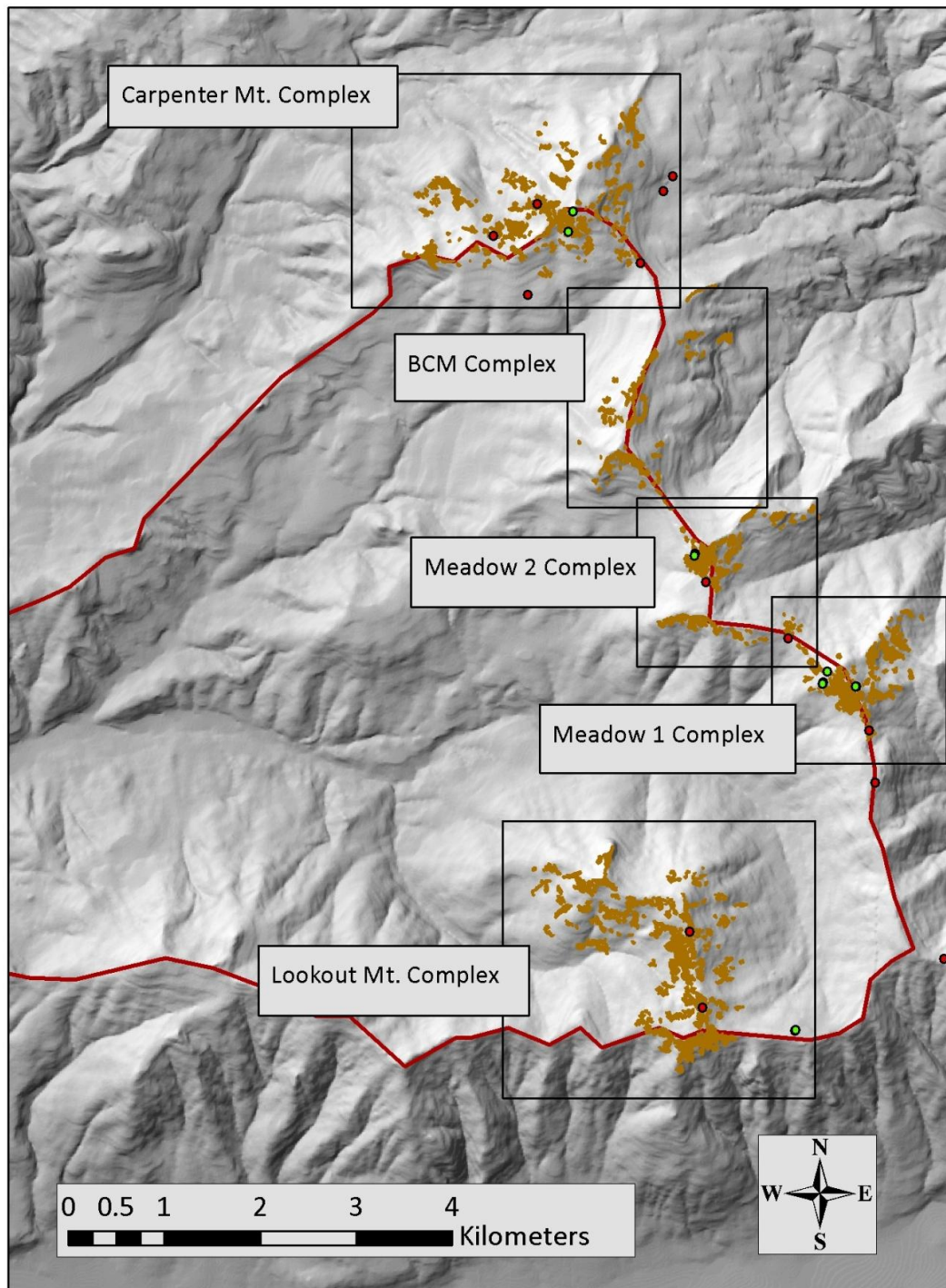


Figure 2. 13. Locations of the tree core plots (green rectangles), Stohlgren-Whittaker plots (blue rectangles), extent of meadows in 1949 (brown polygons), locality of archeological sites (red dots), and locality of individual trees confirmed to be older than 200 years (green dots) in five meadow complexes on the eastern ridge of the Andrews Forest (red line).

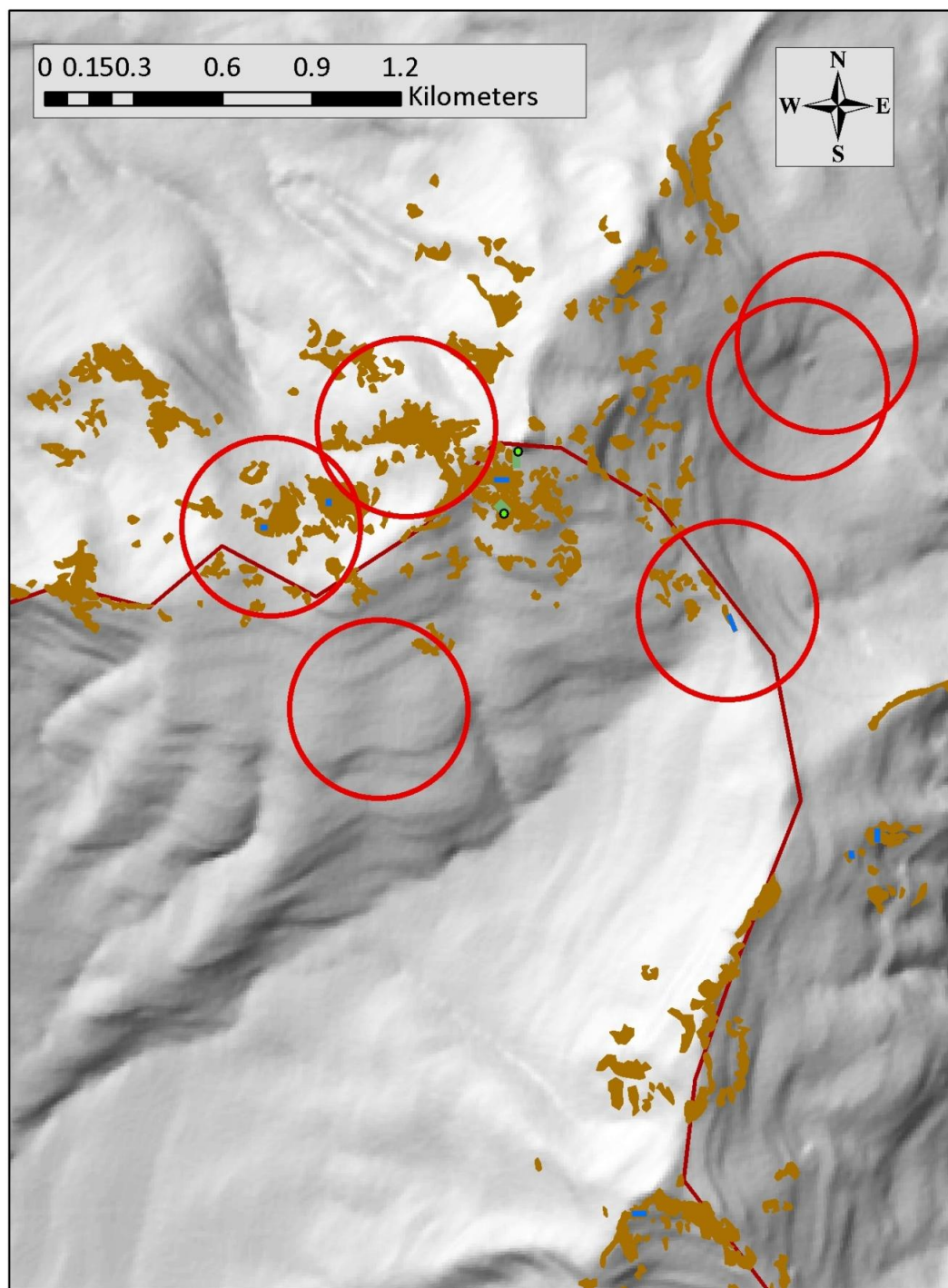


Figure 2. 14. Air-photo-based map of meadows in 1949 (brown polygons), tree plots (green rectangles), trees older than 200 years (green points), Stohlgren-Whitaker plots (blue rectangles), and buffered archeological sites (large hollowed red circles) in the Carpenter Mountain meadow complex.

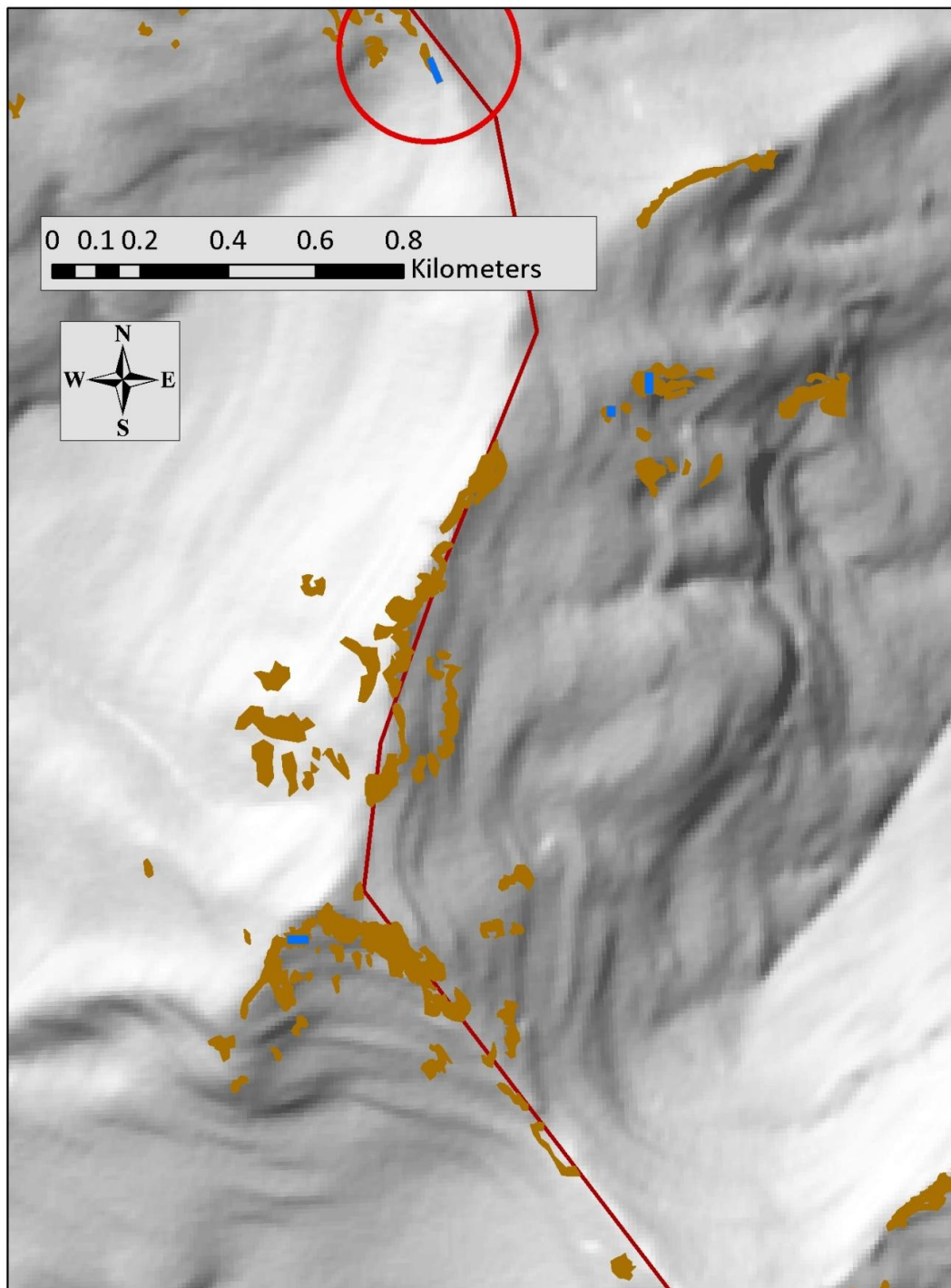


Figure 2. 15. Air-photo-based map of meadows in 1949 (brown polygons), tree plots (green rectangles), trees older than 200 years (green points), Stohlgren-Whitaker plots (blue rectangles), and buffered archeological sites (large hollowed red circles) in the BCM meadow complex.

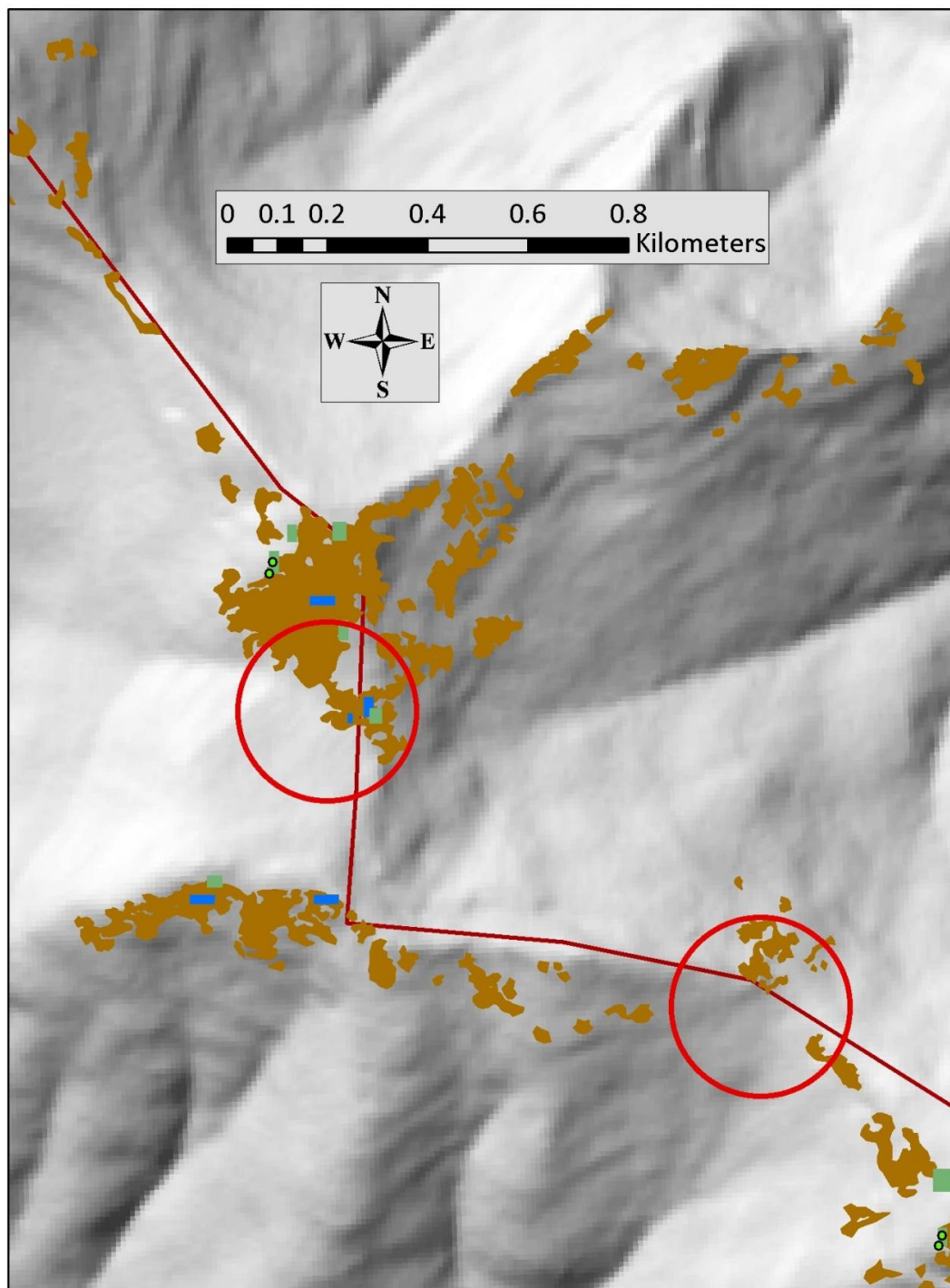


Figure 2. 16. Air-photo-based map of meadows in 1949 (brown polygons), tree plots (green rectangles), trees older than 200 years (green points), Stohlgren-Whitaker plots (blue rectangles), and buffered archeological sites (large hollowed red circles) in the Meadow 2 meadow complex.

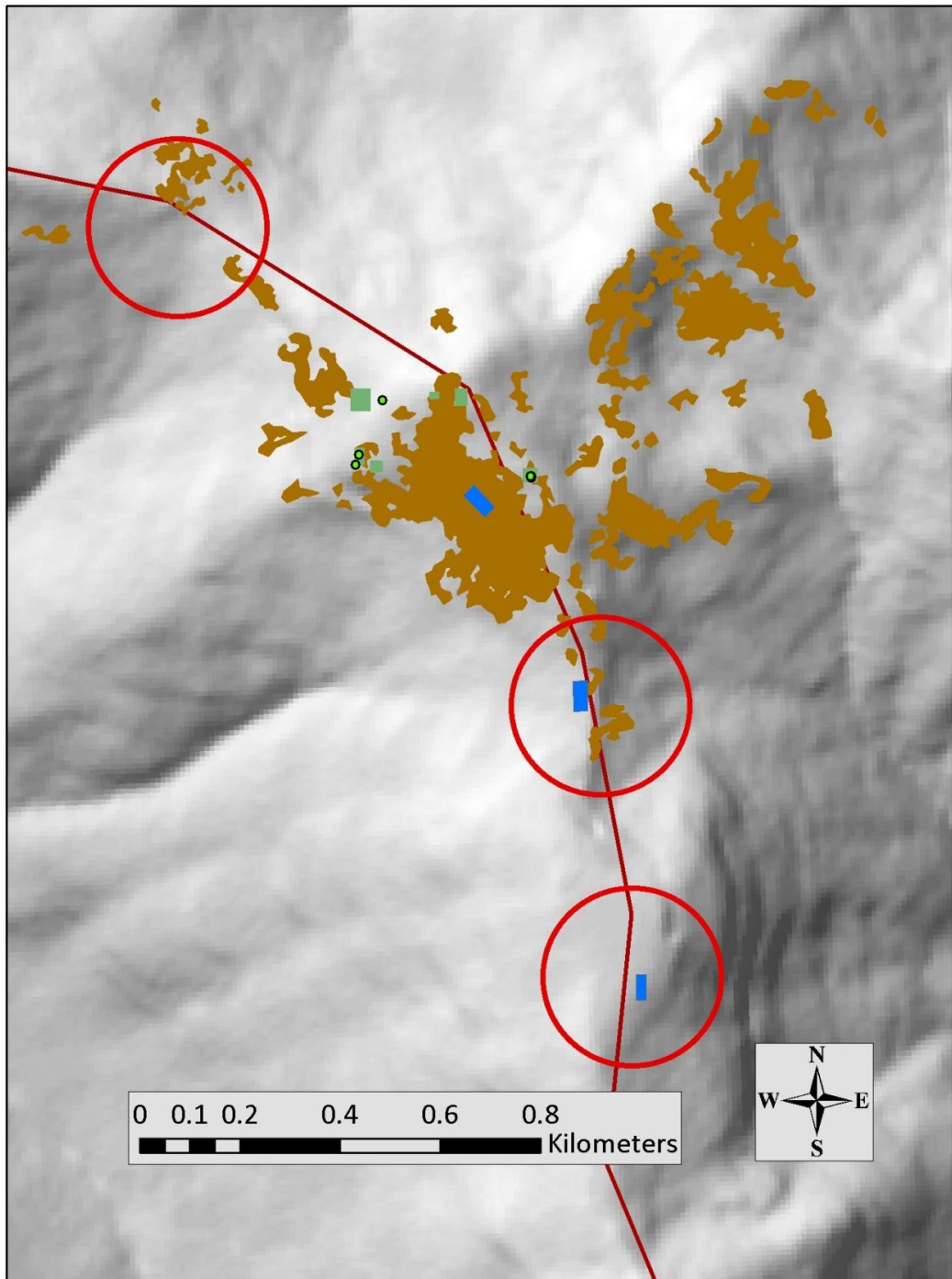


Figure 2. 17. Air-photo-based map of meadows in 1949 (brown polygons), tree plots (green rectangles), trees older than 200 years (green points), Stohlgren-Whitaker plots (blue rectangles), and buffered archeological sites (large hollowed red circles) in the Meadow 1 meadow complex.

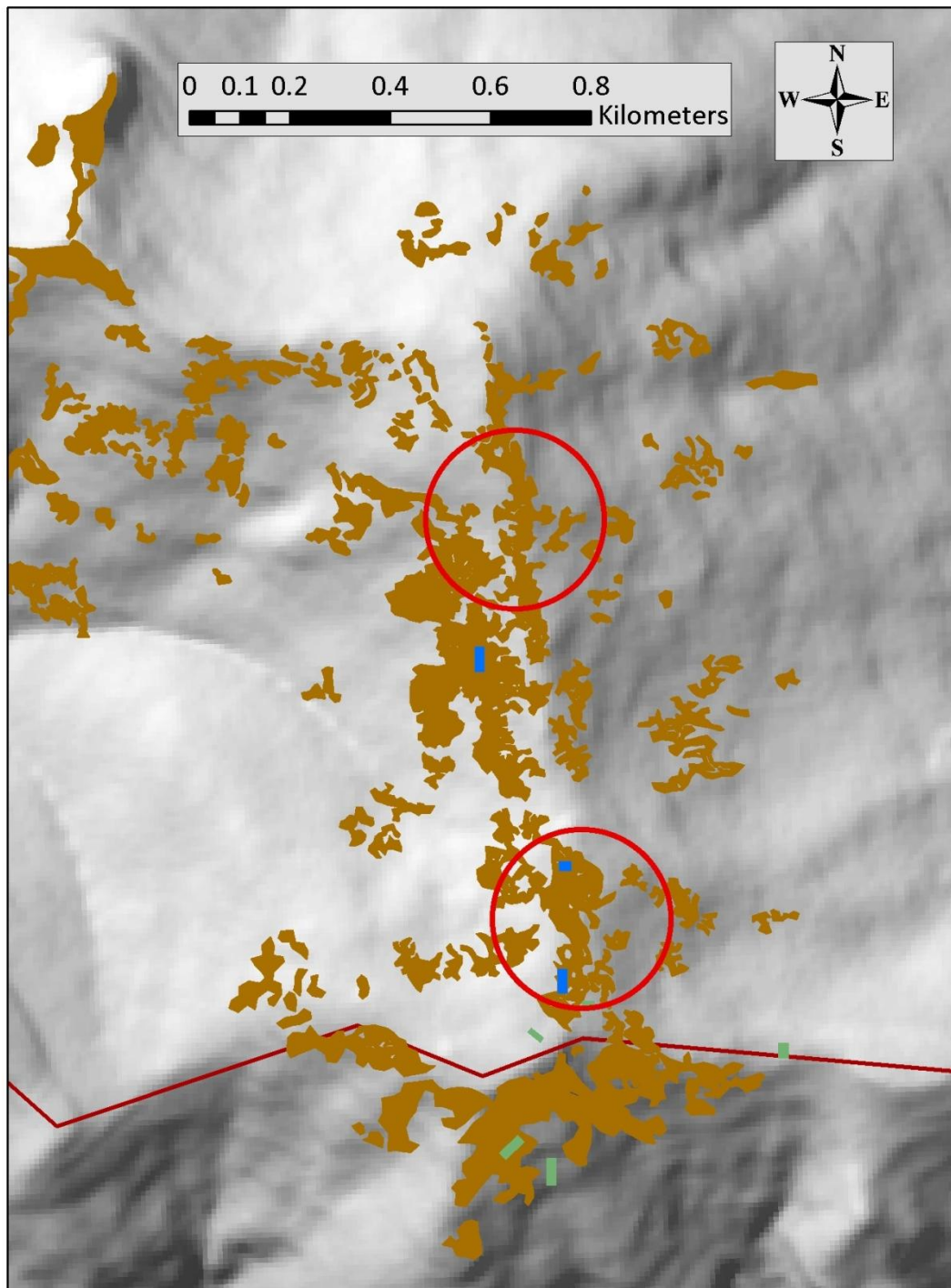


Figure 2. 18. Air-photo-based map of meadows in 1949 (brown polygons), tree plots (green rectangles), trees older than 200 years (green points), Stohlgren-Whitaker plots (blue rectangles), and buffered archeological sites (large hollowed red circles) in the Lookout Mountain meadow complex.

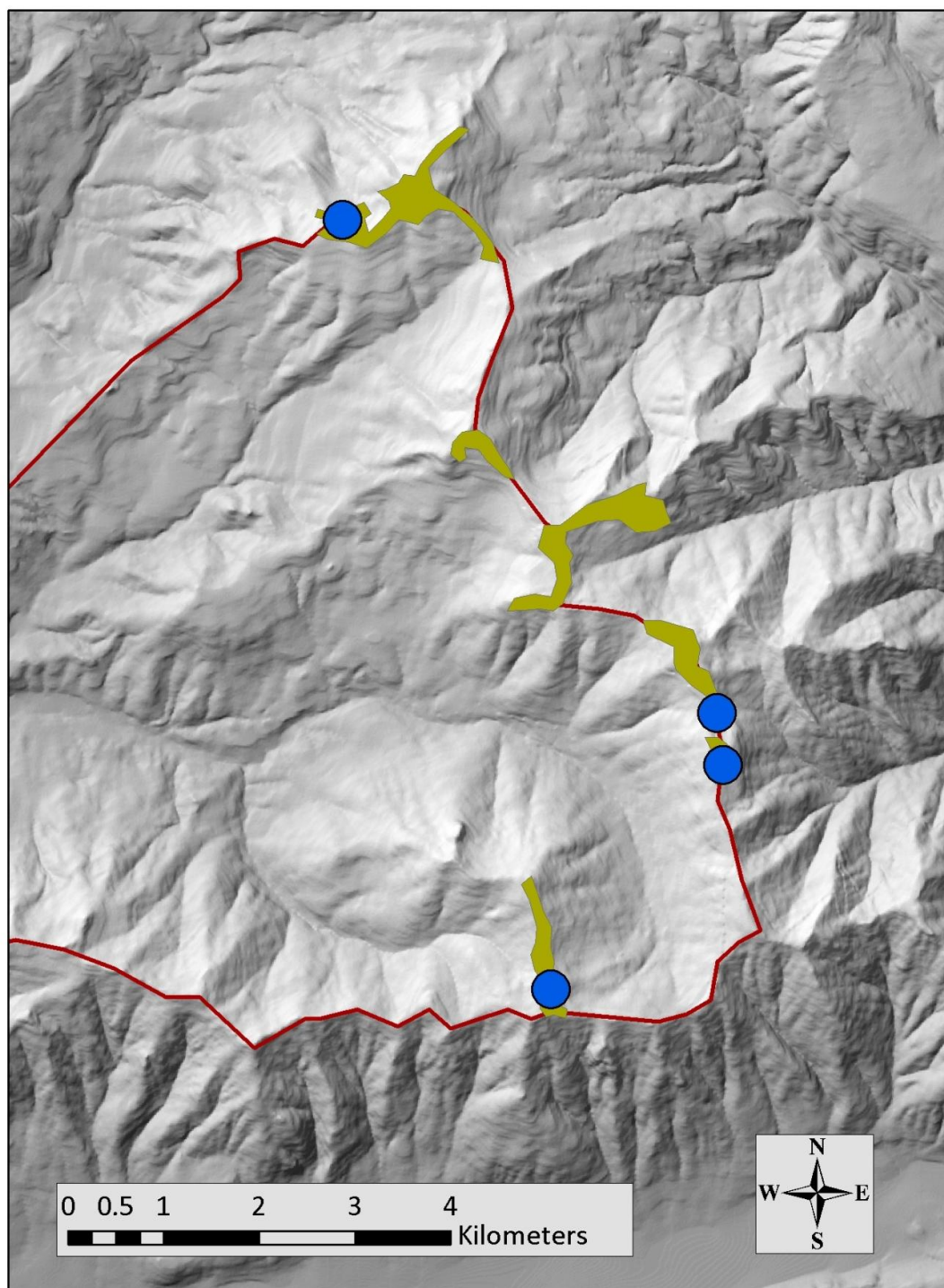


Figure 2. 19. Map showing the ridge portions of HJA newly surveyed for archeological sites and the new sites recorded.

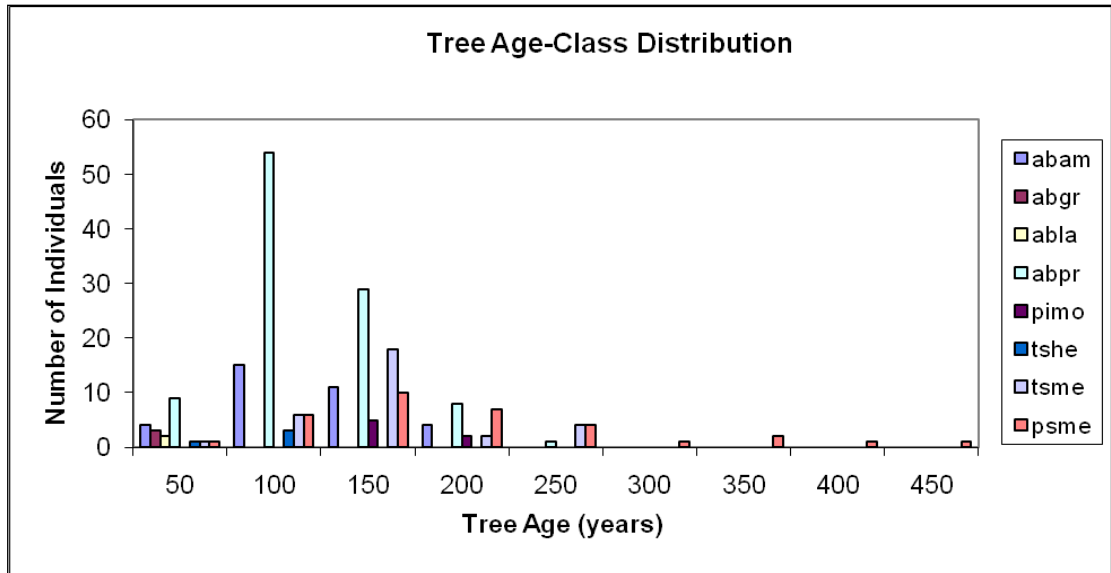


Figure 2. 20. Histogram showing the distribution of the ages of the 220 trees cored and aged.



Figure 2. 21. Photographs of two Noble fir (*Abies procera*) trees older than 200 years (top two photos) and nearby younger trees (lower photo) from a tree plot northwest of m1-x1a in the Meadow 1 complex. Note the well-developed large, lower limbs on the older trees and the lack of lower limbs on the younger trees.

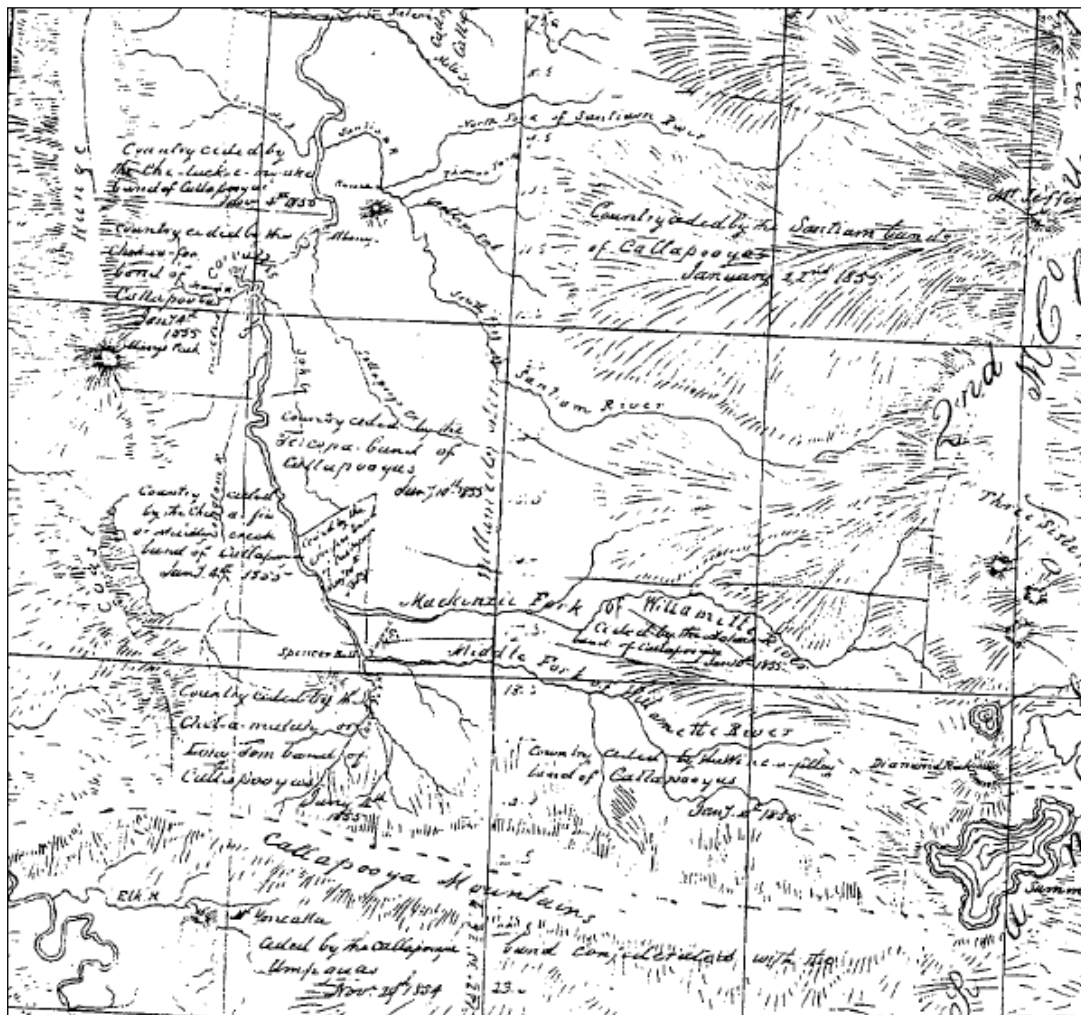


Figure 2. 22. Map showing the locations of tribal groups and dates of land cession in the southern Willamette valley and western Cascades in 1855.

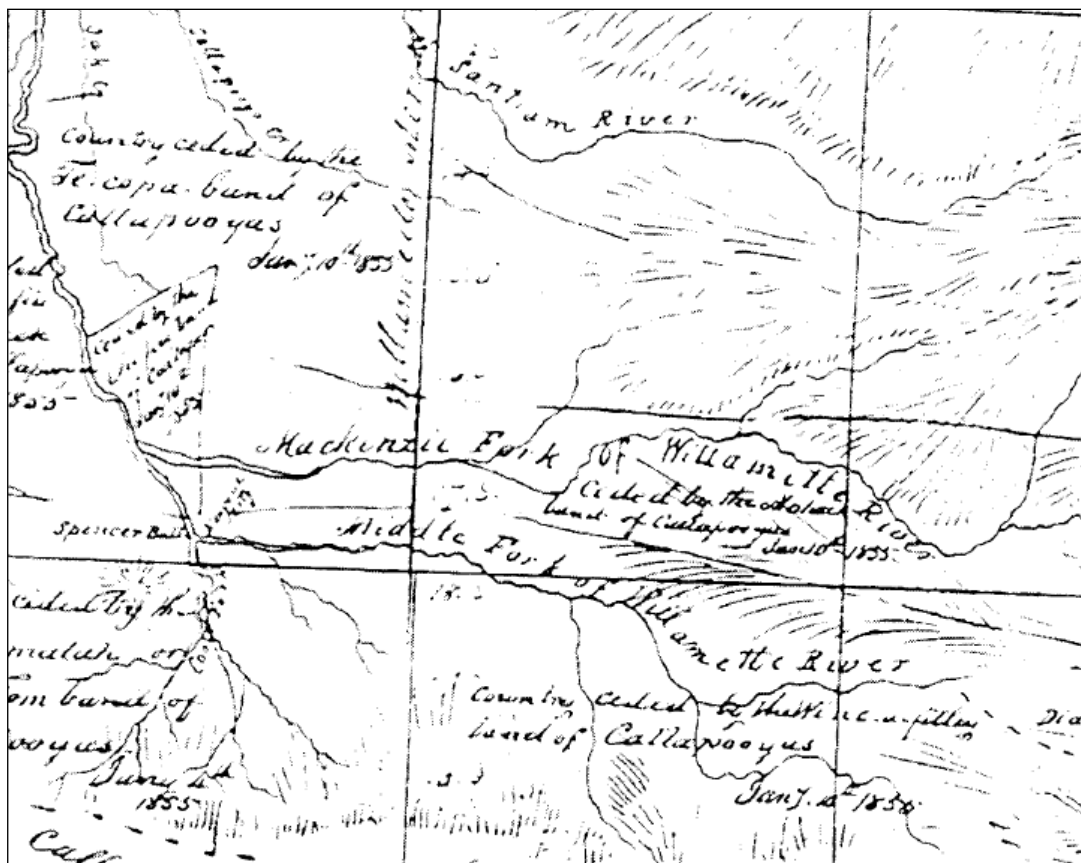


Figure 2. 23. Map showing the locations of tribal groups and dates of land cessation in the McKenzie River valley and surrounding area in 1855. The approximate location of the Blue River, Lookout Mt., and Carpenter Mt. are identified.

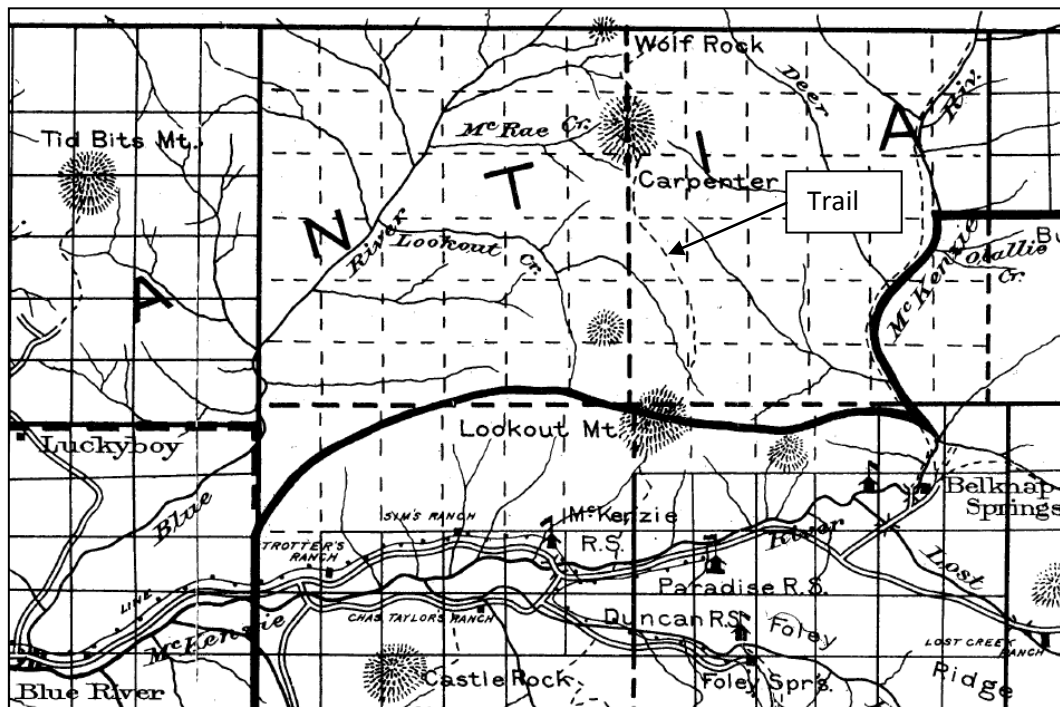


Figure 2. 24. 1912 Cascade National Forest map showing the location of HJA. Note that Lookout Creek and McRae Creek, among others, is identified as draining into the Blue River incorrectly, as if the Blue River ridge did not exist. Trail localities are identified with a dashed line.

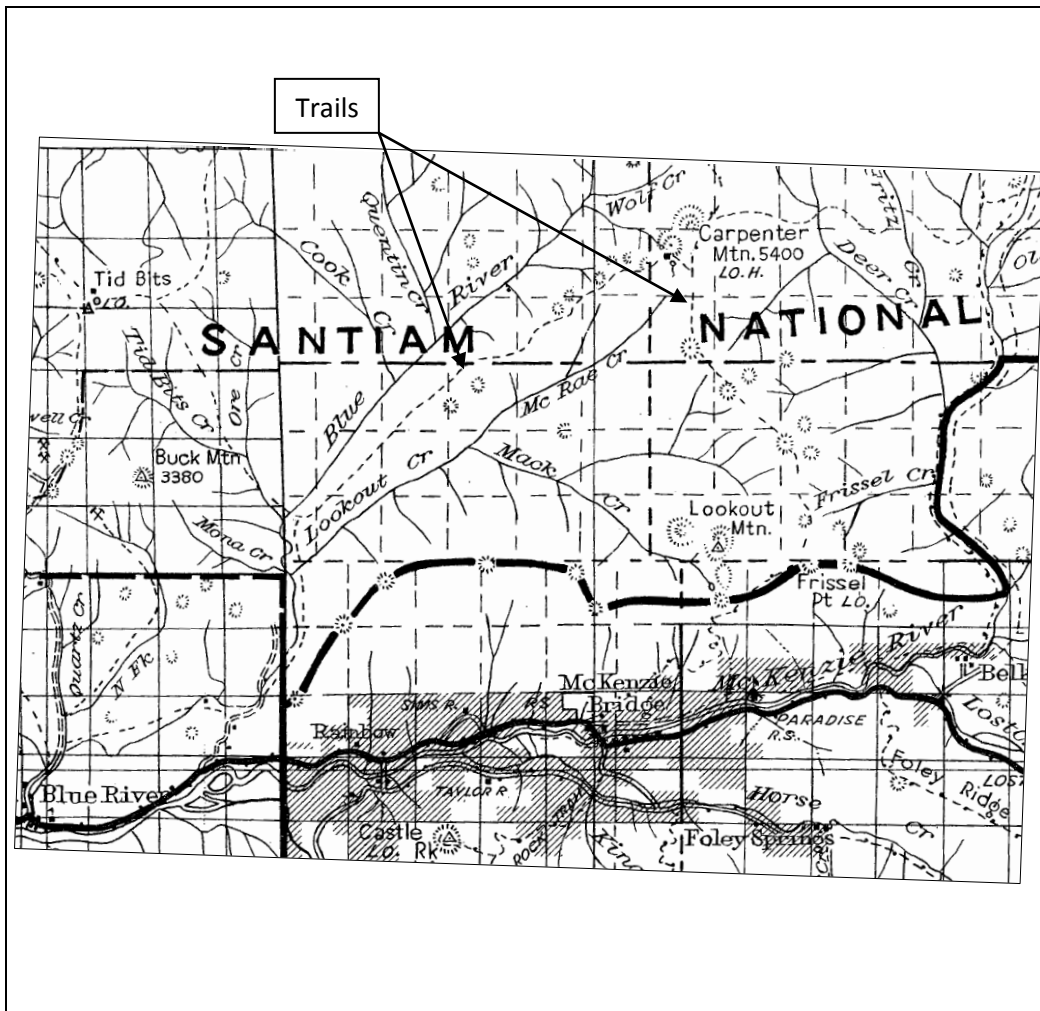


Figure 2. 25. 1925 Cascade National Forest map showing the location of HJA. Note that Lookout Creek and McRae Creek are correctly mapped, with the Blue River ridge now present. Trail localities are identified with a dashed line.



Figure 2. 26. Illustration by Henry Eld from the Umpqua Mts, approximately 100 km south of the study area, showing a burned upland Native American ridgeline trail, Sept. 22, 1841.

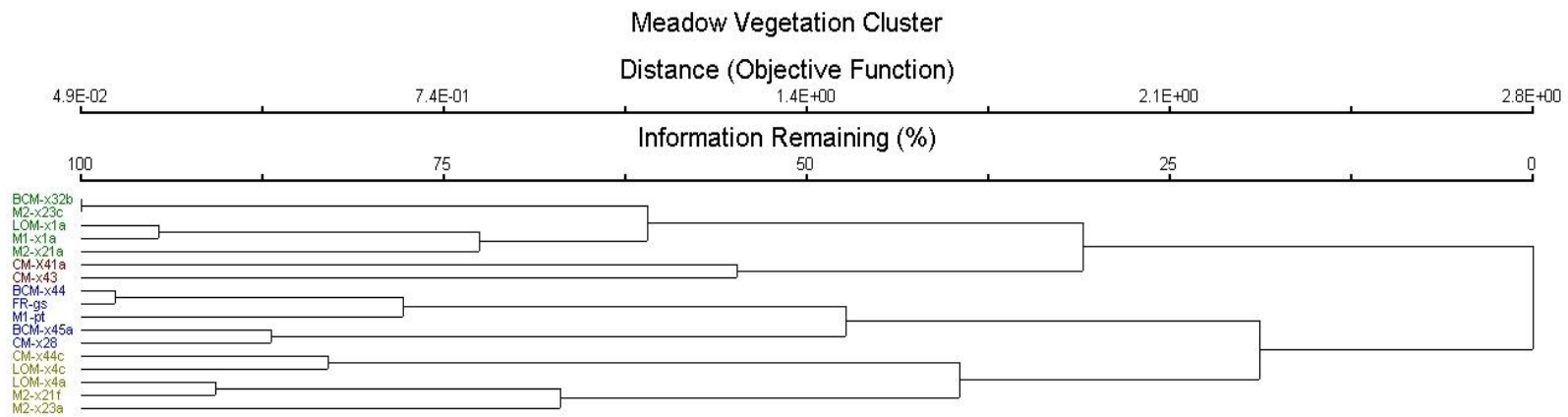


Figure 2. 27. Dendrogram showing the resulting clusters from the Hierarchical Agglomerative Cluster Analysis of the vegetation samples.

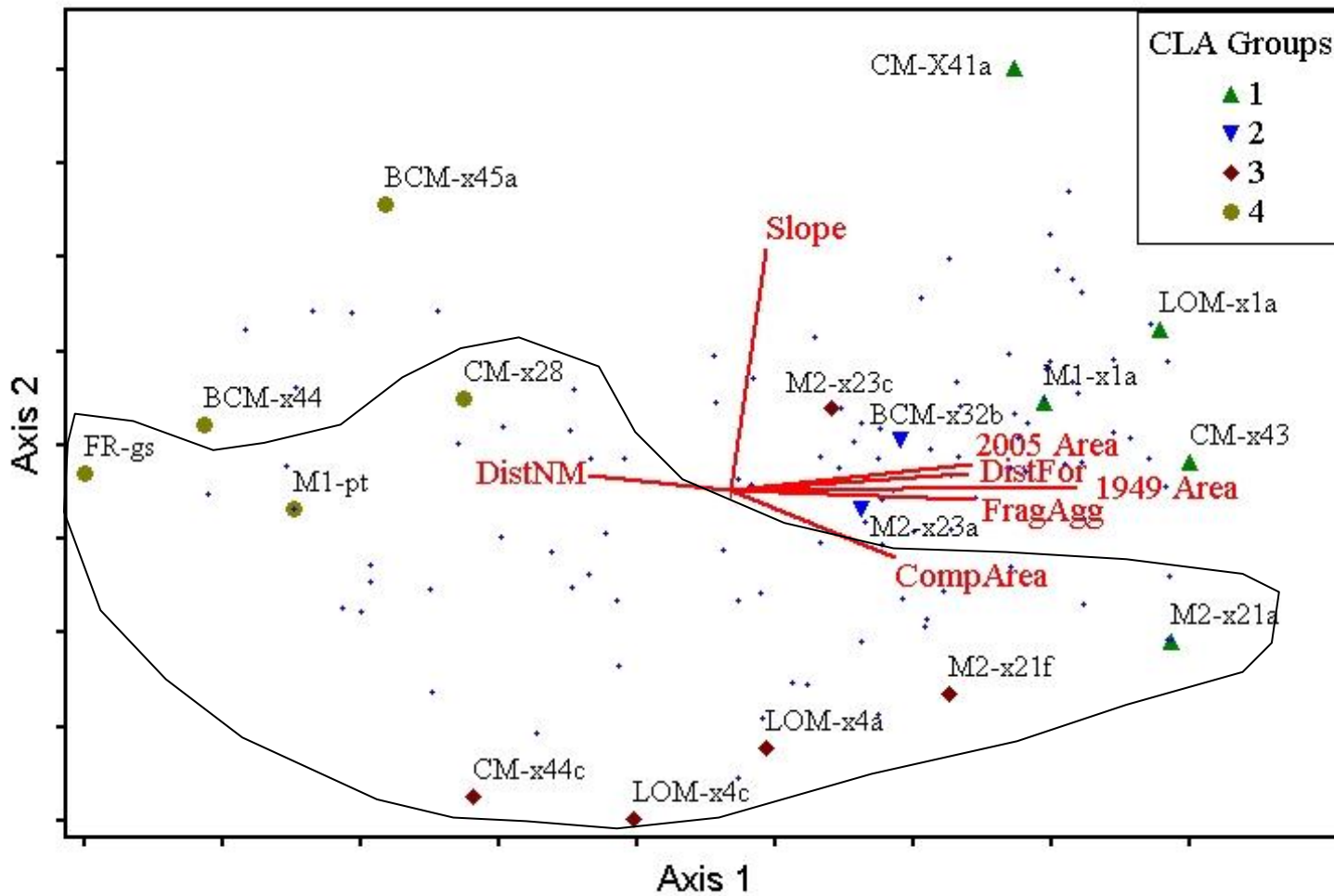


Figure 2. 28. 3-D NMS ordination graphs of vegetation plots using grouping variables derived from Hierarchical Agglomerative Cluster Analysis. The circle indicates samples associated with archeological site.

CHAPTER 3: THE DISTRIBUTION AND ABUNDANCE OF MOTHS IN THE HJ ANDREWS FOREST, OREGON:
COMPLEMENTARY INSIGHTS FROM STATISTICAL ANALYSIS AND A NEW VISUALIZATION TOOL

ABSTRACT

The relationship between moth and plant communities in the west Cascades of Oregon is poorly understood at the landscape scale. We analyzed a 5-year dataset of moths sampled at the HJ Andrews Experimental Forest to identify the overall patterns of rare and common moth distribution as well as moth community relationships to structural and taxonomically derived vegetation classes and seasonality. Rare moths were associated with rare, upland habitats including montane meadows and shrub fields on the high ridges of the west Cascades. The most common moths were present in lowland Douglas-fir forests. If the landscape is to be managed to maximize or maintain biodiversity, it is important to identify and preserve the location and associations of rare species.

INTRODUCTION

Moth species are ecologically important due to their diversity of ecological roles and overall biomass in certain ecosystems, including temperate forests (Schowalter et al. 1986, Miller 1993). Ecological roles include herbivory, pollination, and their function as food for birds and bats. Lepidoptera, and moths in particular, are also potential indicators of ecosystem health and change, including ecosystem functioning, landuse changes, and climate change (Erhardt and Thomas 1991, Parmesan et al. 1999, Summerville and Crist 2004, Kitching et. Al. 2007).

Many insects and Lepidoptera, in particular, should be good indicators of contemporary ecosystem properties, environmental change, and sensitive indicators of landscape dynamics due to their limited mobility and phytophagy (Holloway 1985; Luff and Woiwood 1995; Smith and Remington 1996; Niemela 1997; Hammond and Miller 1998; Kitching et al. 2000; Ricketts et al. 2001). Lepidoptera, including macromoths, are highly specialized, often utilizing a single species or genus as a host-plant (Hammond and Miller 1998, Miller and Hammond 2003). Moth species abundance is coupled to that of their host-plants so their abundance and distribution may reflect both the distribution of vegetation types and the phenology of those plants in the local area (Novotny et al. 2005, Illan et al. 2010a). Many studies have related moth species distribution and communities to vegetation factors, including amount of rare habitat (Miller et al. 2003), vegetation disturbance (Kitching et al. 2000; Beck et al. 2002; Summerville and Crist 2004; Kuussaari et al. 2007), land use and habitat changes (Erhardt and Thomas 1991, Baur et al. 2006), and habitat size and distribution (Usher and Keiller 1998; Summerville and Crist 2004; Ober and Hayes 2010).

Lepidoptera are also sensitive to climatic changes. Alterations in pre-winter and spring conditions affect their survival rates (Han and Bauce 1998). Overall climatic warming can increase the survival rates of species of Lepidoptera and drive range expansions (Parmesan et al. 1999). Populations of Lepidoptera have also been shown to be synchronous in their responses to weather conditions, so any changes in the climate will likely lead to population-wide changes in distribution and abundance changes (Raimondo et al. 2004). Additionally, butterflies have been shown to be sensitive to local climatic conditions in mountainous regions and models show climatic changes to be influential in alterations of species distributions (Illan et al. 2010b).

Moths pass through multiple morphological stages during their lifetimes: egg, caterpillar, pupa, and adult. A fertile female will lay fertilized eggs on or near a host-plant. Depending on the species, a female may lay less than 100 to over 1000 eggs either singly or in batches (Miller and Hammond 2000). Caterpillars emerging from the eggs will feed on the host plant and may pass through multiple instars (typically five) as it grows. Once the final instar has matured, it will pupate. Many pupae in the Pacific Northwest pupate over the winter, but some species pupate for only a few weeks (Miller and Hammond 2000). Once the pupal stage ends, the adult moth emerges. Most moths fly, though some (typically females), do not. Adult moths typically disperse and mate, after which the female will lay fertilized eggs on or near a host-plant.

Spatial and temporal partitioning of habitat use can produce high diversity and abundance of moths. Spatial partitioning occurs as a result of host-plant preferences of moth larvae. Moth species can be grouped into multiple feeding-guilds, including moths whose larvae feed on conifers (“gymnosperm-feeders”), hardwood trees and shrubs (“hardwood-feeders”), and herbs and grasses (“herb-feeders”) (Hammond and Miller 1998). Temporal partitioning is a consequence of the coupling of larval feeding (caterpillar stage) to particular phenological stages of plants, and short adult life spans. Temporal turnover of moth species exceeded spatial turnover in eastern deciduous woodlands of North America (Summerville and Crist 2004) and in the forests of northern Japan (Hirao et al. 2007).

Many studies of the effects species, habitat, and climate take a single-species approach, however, the response of communities is also of interest (Ferrier and Guisan 2006). It is particularly important to determine how strongly groups of species are linked to habitats, and how sensitive they are to climate variability. However, it is difficult for ecologists to infer such patterns from large multi-species datasets. Therefore, we developed a scientific visualization tool to display diversity and abundance of multiple species and their relationships to environmental factors, using a new, unanalyzed dataset of macromoths in the HJ Andrews Forest, western Oregon. Based on a combination of statistical and visualization approaches, we asked:

- 1) how do spatial patterns of habitat and temporal variation in climate influence the diversity and distribution of moths in the HJ Andrews Forest landscape?
- 2) How does a scientific visualization tool assist ecologists in displaying connections, generating hypotheses, and explaining results from statistical analyses?

METHODS

Study Site

This study in the HJ Andrews Forest and LTER site (hereafter referred to as Andrews Forest) within the Willamette National Forest, Lane County, OR (Figure 3.1). The Andrews Forest is located on the west slope of the Oregon Cascade Range approximately 80 km east of Eugene, OR. The Andrews Forest consists of 6400 ha, representing the entire Lookout Creek watershed. Lookout Creek drains west from a high elevation (1,620 m) north-south trending ridge that defines the eastern border of the Andrews Forest and joins Blue River at an elevation of 425 m. High elevation ridges (1,000 – 1,500 m) also define the northern and southern boundaries of the Andrews Forest. Annual precipitation averages 230 cm/yr with most of the rain or snow falling between December and March. Annual temperatures range from 3°C in January to 20°C in July and August, with mean maximum daily air temperatures exceeding 31°C in the last week of July.

Approximately 95% of the Andrews Forest is forested, with slightly less than 5% consisting of open ridgetop meadows. Plant communities below 1,000 m are dominated by an overstory of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) that create a canopy 60-80 m high. Understory vegetation below 1,000 m consists of a wide diversity of hardwood trees and shrubs, including maples (*Acer* spp.), willow (*Salix* spp.), and alders (*Alnus* spp.). Steep south-facing slopes occur throughout the watershed, with distinct vegetation including evergreen trees and shrubs such as Manzanita (*Arctostaphylos* spp.), rhododendron (*Rhododendron macrophyllum*), and chinquapin (*Castanopsis chrysophylla*). Plant communities above 1,000 m on the eastern bounding ridge consist of a mix of subalpine forests dominated by a mosaic of forest and meadows. The subalpine forest overstory of 50-70 m is dominated by Pacific Silver fir (*Abies amabilis*) and noble fir (*Abies procera*) and the understory consists of various hardwood trees and shrubs including huckleberry (*Vaccinium* spp.) and ocean spray (*Holodiscus discolor*). The open montane meadows, on broad ridgetops, are dominated by herbaceous plants and grasses, such as lupines (*Lupinus* spp.) and fescues (*Festuca* spp.) (see Ch. 4, this dissertation).

Sampling Protocol

Moths were collected during the summers of 2004 to 2008 at twenty locations in the Andrews Forest, using UV light traps. The trap consists of a 5-gallon bucket on which is mounted a circular ultraviolet blacklight and containing an insecticide impregnated strip (Bioquip model #2851 trap, 22-watt circle light bulbs, 12-volt batteries, and “HotShot” strips). Moth traps were placed in each trapping site for a single night (excluding periods of near full moon) and collected the following day. Moths are attracted to the light and overcome by the insecticide, falling into the bottom of the bucket. Moths were collected at 20 sites (Figure 3.2), 10 times per year during the summers of 2004 to 2008. At each site, moths were trapped for two consecutive nights every two weeks, beginning in early to mid May and ending in late September. Ten traps were set each night, one per site. Trapping dates were adjusted when snow prevented access (to higher elevations in May and early June) or to avoid the full moon. Moths were collected, transported to Corvallis, identified, counted, and recorded according to date and location of collection. Moth abundance refers to the number of individuals caught in a single trap in a single night, or the total number of individuals in any aggregated assemblage of trapping events. All moths were identified to species level when possible and genus level otherwise by Dana Ross and the author. Host plants for moths, if known, were based on Miller and Hammond (2000, 2003), who captured caterpillars in the field and successfully reared them to adulthood using the vegetation on which they were found.

Questions and Hypotheses

We asked the following questions, and tested the associated hypotheses, concerning the distribution of moths in the Andrews Forest, using statistical methods and the visualization tool.

1. What are the community structures of plants and moths at moth trapping locations in the Andrews Forest landscape?

H1: Community structures of plant and moths are similar to one another.

2. What environmental variables (elevation, vegetation species composition, vegetation structure) and moth grouping variables (sample period, moth feeding guild) explain moth community structure?

H2a: Moth richness and abundance are high in common structural and taxonomic vegetation types (low elevation mature/old-growth conifer forest and low elevation young conifer plantation) and low in rare vegetation types (low elevation riparian hardwood vegetation and open ridgetop meadows).

H2b: Moth richness and abundance decrease with elevation.

H2c: Moth assemblages change with the season.

3. What factors explain the distributions of common and rare moth species?

H3a: Common moth species are associated with commonly occurring vegetation types.

H3b: Rare moth species are associated with rare vegetation types.

4. How are temporal patterns of moth emergence related to temperature?

H4: Adult moth emergence is delayed in colder years compared to warmer years.

Environmental Data

The following environmental variables were used to explain the abundance and richness of moths in the Andrews Forest: calendar day (sampling period), temperature, vegetation type, watershed, and elevation (Table 3.1).

Calendar Day

The date of each moth sample was converted into a consecutive calendar day (ex: February 15=46) for multiyear comparison and multivariate analysis. Calendar dates were grouped into two-week sampling periods.

Temperature

Accumulated heat-units were calculated for each calendar day of moth sampling in 2004 to 2008, based on mean daily air temperature data from the Andrews Forest Primet Climate Station (Figure 3.3). Primet is located at an elevation of 430 meters in the lower valley of Lookout Creek, the major drainage of Andrews Forest, near the Andrews Forest headquarters. Heat-units were determined as the sum of the numbers of degrees above 6°C of mean daily temperature for every calendar day beginning January 1. Moths in the Andrews Forest are sensitive to temperatures above 6°C (J. Miller, personal communication). Mean daily temperatures were summed by day from January 1 to the end of September in each year to determine the accumulated heat units on each day of sampling. If the mean daily temperature was above 6°, the number of temperature points above the 6° threshold were included. If the mean daily temperature was below the threshold, a value of zero was used for that day.

Vegetation type

Each moth trap site was classified according to structural and taxonomic vegetation categories. Taxonomic vegetation categories were defined based on presence-absence data for known host plants of moth caterpillars at the 20 trap sites, which were sampled by Oregon State University's Ecosystem Informatics Summer Institute students (supervised by the S. Highland) during the July of 2010 (Appendix A). These data were grouped into six major fine-scale vegetation groups using Hierarchical Agglomerative Cluster Analysis, and the significance of the categories was tested for significance using Multi-Response Permutation Procedure (MRPP) in environmental space. Structural vegetation categories (mature/old growth forest, young forest plantations, open meadows, regenerated clearcuts, and riparian hardwood forests) were defined based on vegetation

physiognomy within a 100-m radius of each moth trap location, interpreted from 2005 aerial photography (Figures 3.4 to 3.13) and validated by field visits by S. Highland during the summers of 2008 and 2009. Young forest plantations and mature/old-growth forests were subdivided into low elevation (<1000 m) and high elevation (>1000 m) categories following Franklin and Dyrness (1988). *Roads and Streams, Sub-watershed, Elevation*

Each trap was assigned four values describing percent cover of, and distance to, major roads and streams within a 100-m radius. These four variables were calculated using 2005 aerial photography and ArcGIS 9.2. Each moth trap site was assigned a variable according to the sub-watershed of Lookout Creek in which it was located. The Lookout Creek watershed includes five sub-watersheds: upper, middle, and lower Lookout Creek, Mack Creek, and McRae Creek. The elevation, aspect, and slope of each moth trap site were calculated using a 10-m Digital Elevation Model (DEM) in ArcGIS 9.2. Aspect and slope raster layers were generated from the DEM using the Spatial Analyst function in ArcGIS.

Visualization Tool

The original data on moth abundance by trap site and trapping date to a table format, where each column corresponds to an attribute and each row represents a moth species with non-zero individual abundance collected at a particular trap site on a particular sampling date (Table 3.2). Each moth individual has four attributes associated with it: species, family, genus, and feeding guild (herb-feeder, hardwood-feeder, gymnosperm-feeder) (Table 3.2). Each moth individual also is associated with a trapping site and date, which provide five environmental attributes: calendar day, elevation, vegetation type, watershed, and temperature (heat units). Continuous attributes (calendar day, elevation, temperature) were grouped into categories.

The original data set contains 18911 records that consist of 69168 individuals of 514 species of moth captured at twenty trapping sites on ten sampling dates in each year from 2004 to 2008. The visualization was constructed for two subsets: 26 common and 66 rare moth species. Common moths were defined as those species for which 500 or more individuals were captured over the entire five years, and rare moths were defined as those species for which a total of 5-10 individuals were captured during the five-year sampling period (2004 – 2008) (Appendix B).

The classified moth data were visualized using a “diversity map” visualization (<http://web.engr.oregonstate.edu/~pham/moth/flash/CommonMoth.html> and <http://web.engr.oregonstate.edu/~pham/moth/flash/RareMoth.html>) (Figure 3.14). The diversity map representation is based loosely on the parallel coordinates and small multiple histograms techniques for visualizing multivariate data. In the diversity map visualization, each attribute is

represented as one of a set of parallel (vertical) axes, similar to the layout of a parallel coordinates visualization. Unlike traditional parallel coordinates, however, each moth individual is represented with a semi-transparent rectangle placed on each attribute axis at the discretized range (or bucket) corresponding to the individual's value for that particular attribute. The representation is designed primarily for categorical data, so continuous numerical attributes are discretized into bins called "buckets." The sizes and numbers of buckets for discretized continuous attributes were determined based on convenient divisions of the data (e.g., 1000-m intervals for elevation, two-week intervals for calendar date, 500-degree intervals for accumulated heat units).

The visualization represents biological diversity as richness (number of species) and abundance (number of individuals) in a defined unit of study. All individual moths are treated equally; each semi-transparent rectangle representing one moth individual contributes an equal, fractional amount of opacity to the bucket in which it is placed. Because the range of opacity levels is limited, the number of individuals in each bucket is scaled according to the total abundance of all individuals in the visualization. Thus, the opacity of each bucket x is calculated as $f(x) = |x|/|\text{total}|$, where $|x|$ denotes the number of individuals in bucket x , and $|\text{total}|$ is the total number of individuals from the visualized data set. Although linear scaling was used, the method can accommodate other forms of scaling, such as logarithmic, for species whose abundances span multiple orders of magnitude. White was chosen as the background color and blue as the foreground color, because the human eye is known to be more sensitive to changes in blue than in other colors. Opacity values were mapped to values in the CIELAB color space, which is perceptually uniform, meaning that perceived visual differences in color (opacity) correspond to numerically different values. The CIELAB values are converted to RGB values for representation on a computer screen.

Alternatively, the Diversity Map visualization can be understood by imagining each attribute axis as a histogram over the values of that attribute, constructed in 3D space by stacking semi-transparent tiles on top of each other. When viewed from above, the taller stacks of tiles appear darker, while the shorter stacks appear lighter, according to the total combined contribution of the tiles in each stack to that stack's opacity (Figure 3.15).

The Diversity Map created in this analysis expresses richness of variety for a single attribute (e.g. moth species) by the number of buckets with non-zero opacity and evenness of abundance by the uniformity of the color distribution across the opaque buckets of that attribute. The diversity map, as described above, produces a static overview of the data set. Several interaction modes were added to help users transform the view to alternative views that may provide additional insight into the data.

These interaction features are relevant to two important tasks: (1) identifying relationships between attributes and (2) identifying the spatial and temporal patterns of diversity and abundance in moths.

Poly-lines and filtering features extend the static diversity map to facilitate direct comparison of the attributes of a subset of specific samples. The diversity map view can be converted to the traditional poly-line representation used in parallel coordinates visualizations; this view is particularly useful in comparing the relationships between samples in two adjacent attributes (Figure 3.16). Alternatively, filtering can be used to answer questions of the form, “What are the attributes Y of the subset of moths in a specified bucket in attribute X?” For example, a user can constrain (“filter”) a single attribute to one or more particular values (buckets). The remaining attributes then display the distribution of only those individuals that fall within the specified range of the filtered attribute. To further support comparison of attributes of interest, users are also given the ability to reorder the axes horizontally and to sort the buckets in a single attribute value by abundance if desired. Users can also hold the mouse pointer over a particular bucket to display the number of individuals falling into that bucket. Filtering also facilitates investigation of temporal and spatial relationships. For example, users can filter the moth records by COLLECT_YEAR and/or COLLECT_PERIOD to observe temporal trends and by ELEVATION, HABITAT, and/or WATERSHED to observe spatial trends. In addition to filtering, users may initially pre-define the ordering of moth species buckets (e.g., by abundance) and then test whether the ordering pattern remains consistent for the filtered subsets of the data set. Thus users can answer questions such as “How does the abundance of moths vary over time or space?”

The Diversity Map was developed using the Java programming language and the Prefuse information visualization toolkit (available at prefuse.org). The application is currently distributed to users as a Java Webstart application. Java Webstart Applications can be deployed over the web, requiring only a single click from the user. This approach ensures that the most current version of the application will be deployed and that the user has the correct version of the [Java Runtime Environment \(JRE\)](#), allowing developers to make updates and push those updates to users without the need for reinstallation.

Statistical Analysis

Data were analyzed using t-tests, ANOVA, hierarchical agglomerative cluster analysis (CLA), multi-response permutation procedure (MRPP), and non-metric multidimensional scaling ordination (NMS). Microsoft Excel 2007 was used for the t-test and ANOVA, and PC-Ord 5.31 (McCune and Mefford 2006) was used for the CLA, MRPP, and NMS. Three subsets of the entire moth dataset were used in these analyses: 26 common moth species, 66 rare moth species, or 366 common and rare

moth species. Common moth species ($n=26$) were defined as those for which 500 more individuals were captured over the entire five-year sampling period. Rare moth species ($n=66$) were defined as those for which a total of 5-10 individuals were captured over the five year sampling period. Common and rare moth species ($n=366$) were defined as those for which 5 or more individuals were captured over the five-year sampling period.

A two-tailed t-test was conducted to compare the mean date of first capture for all common moths between 2004 (warm year) and 2008 (cool year) to assess moth sensitivity to annual fluctuations in temperature. A single factor ANOVA with post-hoc Tukey test was used to compare the mean date of first capture for all common moths between all years (2004 to 2008). Oneway ANOVA with post hoc Tukey test also was used to compare the mean number of rare and common moths captured in traps by vegetation type and by feeding guild. Data were normally distributed, so no transformations were necessary. Hierarchical agglomerative cluster analysis (CLA) using Euclidean distance and Ward's linkage method (McCune and Grace, 2002) was used to designate taxonomic vegetation categories from field-sampled presence-absence data about plant species. Rank-transformed Multi-Response Permutation Procedure (MRPP) was used to test the groups resulting from the CLA for differences in environmental space, after relativizing the environmental matrix and switching the species and environmental matrix so as to not test species clusters for significance in species space (Mielke 1984, Mielke and Berry 2001, McCune and Grace, 2002). An Indicator Species Analysis (ISA) was conducted on the taxonomic vegetation categories/clusters to provide descriptions for the categories (Dufrene and Legendre 1998), using only species with a significant p-value and an Indicator Value (IV) of over 50%. Generalized Linear Mixed Models (GLMM) were used to assess the relationships between abundance and richness (dependent variables) versus elevation and vegetation type (independent variables). GLMMs are linear models that allow for the response variable to be non-Gaussian and allows for a correlation matrix to be built into the model, accounting for repeat measures correlation errors (Zuur 2009). The GLMMs of annuals totals of moth species richness and abundance, 2004 to 2008, and 20 moth trapping sites in the Andrews forest were fit by the Laplace approximation with $n=100$. The models were begun with a single variable and built in a forward stepwise fashion, adding variables until the Akaike Information Criterion (AIC) value was lowest. The variables used in the model included the continuous covariates elevation, aspect, slope, year, percent cover of mature/old growth conifer forest, young conifer plantation, open vegetation, shrub vegetation, distance to stream, distance to road, and the categorical covariates taxonomic vegetation and structural vegetation. In these models, the variables trap ID and year were used to designate the yearly repeated measures in the trap locality, accounting for the correlation error. Non-Metric

Multidimensional Scaling Ordination (NMS) was used to quantify community structure of moth species, and to test the effect of calendar day, year, and vegetation type on community structure. Two datasets were created to examine seasonal and yearly patterns. The seasonal analysis was conducted on 876 sample units, each with abundances of 514 species, where each unit is a single trapping event (number of individuals of a species caught on a given night of trapping). The yearly analysis was conducted on 100 sample units, each with abundances of 514 species, where each unit is the total of all sampling periods at an individual trap site in a single year. Rank-transformed MRPP was used to test the significance of structural and taxonomic vegetation variables, followed by ISA to identify moth species associated with the plant communities.

Moth and plant species that were present in <5% of all sample units were omitted from NMS analyses. Moth abundance data were cube-root transformed before conducting the NMS to reduce skew and limit the impact of very abundant species. An Outlier Analysis was conducted on the species and sample units. One plant species (*Phlox diffusa*) was identified as an outlier, with an outlier statistic of 3.66 standard deviations from the grand mean of the species distances. One sample unit (15D) was also identified as an outlier, with an outlier statistic of 2.37 standard deviations from the grand mean of the sample unit distances. *Phlox diffusa* was deleted from the data as it was only present in one sample unit and likely unimportant to the community structure. Sample unit 15D was kept, as it is the sole representative of a rare but potentially important vegetation type – low elevation clearing. The coefficient of variation (CV) of the species totals was 98.6%, while the CV of the sample unit totals was 30.6%.

NMS analyses were conducted using a Sorensen/Bray-Curtis similarity matrix with a flexible beta linkage (-0.25). For the NMS analyses, the following procedure was employed: (1) a random starting configuration was chosen, (2) 250 runs were made for the Monte Carlo test, (3) dimensionality was selected based on a better than random solution as determined by the results of the Monte Carlo test and reduction in stress, (4) up to 250 iterations were allowed to calculate a stress stability of <.000001 over the last 15 iterations, (5) the NMS plots were overlaid with the environmental variables, and (6) the ordination was rotated to maximize the correlation between the major axis and the most highly correlated environmental variable (Kruskal 1964, McCune and Grace 2002).

RESULTS

Vegetation

Of the 71 plant species, including trees, shrubs, and herbs, known to be host plants for moth species, only 52 species occurred in the 20 trap sites (Appendix A). Moth trapping sites had between 1 and 5 coniferous tree species, 3 and 9 hardwood species, and 1 and 11 herb species, with an average species richness of 13. The most frequently occurring conifer tree species were Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), occurring at 19 and 14 sites, respectively (Appendix A). The most frequently occurring hardwood tree species were vine maple (*Acer circinatum*), salal (*Gaultheria shallon*), and rhododendron (*Rhododendron macrophyllum*), occurring at 16, 11, and 14 sites, respectively (Appendix A). The most frequently occurring herb species were swordfern (*Polystichum munitum*), brackenfern (*Pteridium aquilinum*), unidentified grasses, *Rubus* spp., and unidentified lupine (*Lupinus* spp.), occurring at 12, 12, 12, 12, and 9 sites, respectively (Appendix A). Rare conifer tree species were grand fir (*Abies grandis*), subalpine fir (*Abies lasiocarpa*), unidentified fir (*Abies* spp.), and mountain hemlock (*Tsuga mertensiana*), occurring at 1, 2, 2, and 2 sites, respectively (Appendix A). Rare hardwood species were red alder (*Alnus rubra*), madrone (*Arbutus menziesii*), *Prunus* sp., western serviceberry (*Amelanchier alnifolia*), kinnikinnick (*Arctostaphylos nevadensis*), common buckbrush (*Ceanothus cuneatus*), mountain mahogany (*Cercocarpus montanus*), unidentified juniper (*Juniperus* sp.), and salmonberry (*Rubus spectabilis*), each of which occurred at only one site (Appendix A). Rare herbaceous species were angelica (*Angelica* sp.), Indian paintbrush (*Castilleja* sp.), delphinium (*Delphinium* sp.), fireweed (*Epilobium angustifolium*), penstemon (*Penstemon* sp.), creeping phlox (*Phlox diffusa*), each of which occurred at only one site (Appendix A).

Six taxonomically derived vegetation type categories were identified using hierarchical agglomerative cluster analysis (Table 3.3 Figure 3.17). Two of the clusters were defined by single traps. Taxonomically derived vegetation categories were significantly different (MRPP $p=0.00003$) with a relatively high degree of difference ($A=0.402$) (Table 3.3). Plant species with significant ($p<0.05$) indicator values (IV) $> 50\%$ include western red cedar (*Thuja plicata*) for the riparian category; salal (*Gaultheria shallon*) for the low elevation coniferous forest category; western columbine (*Aquilegia formosa*), *Ligusticum grayii*, *Carex* spp., *Vicia* spp., and snowberry (*Symphoricarpos albus*) for the high elevation opening category; and Pacific silver fir (*Abies amabilis*) for the high elevation forest and clearcut category (Table 3.3). Based on these indicator species and air photo interpretation of vegetation surrounding each trap, the following taxonomic vegetation categories were defined:

riparian (3 trap sites), low elevation conifer forest (10 sites), low elevation opening (1 trap sites), high elevation opening (3 sites), high elevation forest and clearcut (2 sites), and high elevation forest (1 sites) (Table 3.4).

Six structurally defined vegetation type categories were identified using aerial photography and vegetation descriptions from field visits (Table 3.4). The six categories are: low elevation riparian hardwood vegetation (5 trap sites), low elevation young conifer plantation (2 sites), low elevation mature/old growth conifer forest (4 sites), ridgetop meadow >800- (2 sites), high elevation mature/old growth conifer forest (5 sites), high elevation unregenerated clearcut (2 sites) (Table 3.4). Most moth trapping sites contained two or more vegetation types (mature conifer forests, young conifer forests, shrub, and open/meadow vegetation), and several trapping sites had three or four of these within 100 m (Table 3.5).

Vegetation at 17 moth trapping sites was classified similarly based on taxonomic and structural vegetation characteristics; in cases where they differ, the taxonomic classification is more accurate (Table 3.6). Although six of the ten trap sites taxonomically classified as low elevation conifer forest were structurally classified as low elevation mature/old growth conifer forests or low elevation young conifer plantations, two sites were structurally classified as high elevation mature/old growth conifer forest, and two sites were structurally classified as low elevation riparian hardwood vegetation. Trap sites 26B and 26H were taxonomically classified as low elevation conifer forest, but structurally classified as high elevation forests; these sites, at 1114 and 1049-m, occur just above the 1000-m elevation used to distinguish low from high elevation forest in the structural classification but they contain low elevation species. Trap sites 23A and 28C were taxonomically classified as low elevation conifer forest but structurally classified as low elevation riparian hardwood vegetation. The taxonomic classification is correct; site 23A is old-growth conifer forest on the terrace along Lookout Creek (a 5th order stream) adjacent to the Andrews headquarter site, and site 28C is located in conifer forest just upslope of Mack Creek (a 3rd order stream). Disparate classifications for trap sites 13C, 15D, and 3K reflect the presence in montane meadows of conifer trees typical of both low- and high-elevation forest (see Ch 4, this dissertation), and the fact that slowly-regenerating clearcuts are taxonomically similar to montane meadow complexes.

Overall the vegetation classification analysis reveals that, although moth-trapping sites have distinct plant species, they all contain a wide variety of vegetation types within short distances. This is especially true for high-elevation sites which are characterized by mosaics of small patches of conifer trees, hardwood shrubs and herbs, but also affects riparian sites, in which a hardwood understory is typically overtopped by conifer forest along adjacent slopes.

Moths

A total of 69,168 individual moths from 514 species were captured in the 20 trap sites from 2004 to 2008 (Figure 3.18). Species richness was high, but most species were rare, producing highly varied patterns of diversity in the diversity map (Figure 3.19). Fifty-four (10%) of the 514 moth species were represented by only 1 individual, and 46 (9%) were represented by 2 individuals. The 26 most common moth species (A in Figure 3.18) accounted for 41,889 individuals (60.6% of the total abundance). The most common moth species (*Semiothisa signaria*) accounted for 6,818 individuals (9.9% of the total abundance) (Figure 3.18). The 66 moth species considered as rare (B in Figure 3.18) accounted for 467 individuals (0.7% of the total abundance).

When moth species data were summed by year, elevation was the most significant predictor of moth species richness, followed by taxonomic vegetation categories, with percent young conifer plantation within 100-m of the trap site marginally significant (Table 3.7). Richness is negatively related to elevation and to the percent cover of young conifer forest within 100 m of the trap site. Richness is negatively related to the taxonomic vegetation categorical variable, as it increases from low to high elevation vegetation types as it increases in number. Percent cover of mature/old-growth forest within 100-m of the trap sites was the most significant predictor of moth species abundance, followed by elevation, percent cover of young conifer plantation, and percent cover of shrubs, and the interaction of elevation and percent shrub (Table 3.7). Moth species abundance was negatively related to elevation and elevation-shrub interaction, and positively related to percent cover of mature conifer forest, percent cover of young conifer plantation, and percent cover of shrubs within 100-m of the trap site.

Annual moth community structure is explainable by vegetation descriptions (Table 3.8). Moth communities differ significantly by both taxonomic and structural vegetation categories (MRPP $p < 0.00000000$), and both have strong explanatory values ($A = 0.51$ and 0.48 , respectively). Indicator species analysis provides more significant indicator species ($n = 28$) for taxonomic vegetation based groupings than for structural vegetation based groupings ($n = 4$) (Table 3.8). ISA provides indicators for only one structural vegetation group, ridgetop meadows, including *Chersotis juncta*, *Lacanobia liquida*, *Pseudothorsia variabilis*, and *Synedoida adumbrata* (Table 3.8) ISA provides indicator species for four taxonomic vegetation groups – low elevation riparian vegetation (*Polia nimbosa*), low elevation opening (*Aseptis ethnica*, *Hemeroplanis finitima*, *Homorthodes furfurata*, *Homorthodes hanhami*, *Lacinipolia illaudabilis*, *Lacinipolia patalis*, *Lacinipolia stricta*, *Lacinipolia strigicollis*, *Lophocampa argentata*, *Phobolusia anfracta*, *Phriganidia californiaria*, *Platyperigea montana*, *Semiothisa californicara*, *Spilosoma vestalis*), high elevation opening (*Chersotis juncta*, *Lacanobia Tacoma*, *Polia*

purpurissata, *Sphinx vashti*), and high elevation conifer forest (*Apamea auranticolor*, *Dysstroma brunneata*, *Dysstroma formosus*, *Eulithis propulsata*, *Itame decorata*, *Lacanobia nevadae*, *Lasionycta perplexa*, *Spargania magnoliata*). Elevation and the amount of open vegetation within 100 m strongly influenced moth community structure based on annual data, and distance to stream also was important (MRPP analysis, Table 3.9 and NMS ordination, Figure 3.20). Annual moth community structure, grouped by vegetation type (structural and taxonomic), was related to elevation, percent open vegetation, and distance to stream (NMS final stress 14.049, final instability 0.0000) (Figure 3.20). NMS axes 1 and 2 explained 13.5% and 82.7% of the variance in the data. Elevation was most associated with axis 2 of the moth community structure ordination (Pearson's $r = 0.80$), followed by percent open vegetation (Pearson's $r = 0.52$) and distance to stream (Pearson's $r = 0.23$) (Table 3.9, Figure 3.20).

However, when moth assemblages were broken out by two-week sampling period, only sampling period significantly influenced community structure (Table 3.10, Figure 3.21). Moth communities differ significantly by structural and taxonomic vegetation categories, as well as by the mean calendar day of the sampling period (MRPP $p < 0.0001$) but only sampling period has a strong explanatory value ($A > 0.10$) (Table 3.10). The three-dimensional NMS ordination solution (Figures 3.21 and 3.22) of species assemblages grouped by two-week sampling period showed a clear relationship to sample period, but not to vegetation type (structural or taxonomic), elevation, or water. The 3-D NMS solution had a final stress of 19.978 and a final instability of 0.00000. Axis 1 explained 17.4%, axis 2 explained 23.0%, and axis 3 explained 28.7% of the variance, for a total of 69.1%. Mean calendar day is the only variable with strong correlation (Pearson's $r = 0.81$) with any of the three axes (Table 3.11). When the samples in the NMS ordination were coded by vegetation type, no vegetation type-based clusters are identifiable (Figure 3.21). When the samples were coded by sampling period, clusters are evident, especially in late May (sampling period 6.75) through late August (sampling period 8.75) (Figure 3.22).

The abundance of moths of common species (more than 500 individuals trapped over the five year study) was highest in low elevation coniferous forests followed by low-elevation riparian forests and high-elevation conifer forests, and lowest in ridgetop meadows and high-elevation regenerating clearcuts (Table 3.12). Common species of moths were more abundant in young conifer plantation forests and mature/old forests at low elevation than in other structurally defined vegetation categories (ANOVA $F=14.5$, $df=5$, $p=0.00004$) (Table 3.12). Of the total of 41,889 common moths captured in twenty trapping sites over five years (2004-2008), on average 3683 individuals were captured in young conifer plantations and 3567 individuals were captured in mature and old conifer

forests at low elevation (Table 3.12). Abundance of common moths was lowest in ridgetop meadows (629 individuals per trap) and high elevation unregenerated clearcuts (352 individuals).

Common moths that feed on conifer species were significantly more abundant than moths that feed on hardwood or herbaceous species (ANOVA $F=26.8$, $df=3$, $p=0.000000000006$) (Table 3.13). Of the 41,889 common moths captured, over half (23,694) were conifer feeders, while only 3% (1354) were herb/grass feeders. No common moths were mixed feeders.

The abundance of moths of rare species (only 5 to 10 individuals trapped in all sites over five years) was significantly higher in open areas than other vegetation classes (Table 3.14). Rare species of moths were more abundant in open, ridgetop meadow vegetation types than other structurally defined vegetation types (ANOVA $F=3.70$, $df=5$, $p=0.02$) (Table 3.14). Rare moth abundance was weakly significantly different among taxonomically defined vegetation categories (ANOVA $F=2.96$, $df=5$, $p=0.07$). Of the total of 467 individuals of rare moth species were captured in 20 trapping sites from 2004-2008, on average 48 individuals of rare moth species were caught in trap sites in ridgetop meadows, whereas less than 30 individuals per trap site per night were caught in other vegetation types. Low-elevation conifer forest vegetation had the fewest individuals of rare moth species (13 to 17 individuals per trap) (Table 3.14).

Rare moths that feed on hardwood and herbaceous species were significantly more abundant than moths that feed on conifers (ANOVA $F=30.3$, $df=3$, $p=0.000000000005$) (Table 3.15). Of the rare moth individuals whose foodplant preference is known ($n=380$ of 467 individuals), over 90% are hardwood feeders or herb/grass feeders. On average 10 hardwood-feeder individuals and 8 herb-feeder individuals of rare moth species, but less than 1 conifer- or mixed-feeders were captured per trap (Table 3.15).

The visualization tool provides an opportunity to explore vegetation type associations of rare and common moth species in more detail than provided by the statistical tests (Figure 3.23). The visualization of common moths shows that common moths are much more likely to be associated with conifer forest (closed) vegetation types than open vegetation types; it also shows that common moths are mostly gymnosperm feeders, and none are herb feeders. The visualization shows that rare moths are more abundant in open compared to closed or low elevation riparian hardwood vegetation types, and that among rare moths, herb feeders are more abundant than conifer and mixed feeders.

The mean date of emergence of 26 common moth species varies significantly between some pairs of years in the sampling period. On average, common moth species emerged significantly earlier in 2004 than in 2008 (two-tailed t-test, $p=0.0009$). The mean calendar date of first capture for common moths was 166 (June 14) in 2004, the warmest year of the five-year sampling period and 175

(June 23) in 2008, the coolest year of the sampling period. However, the mean calendar date of first emergence did not vary significantly among all five years (Anova $F=1.53$, $df=4$, $p=0.196$). A post-hoc Tukey test revealed a significant difference between 2006 and 2008 only (Table 3.16).

The visualization tool provides an opportunity to explore vegetation type associations of rare and common moth species in more detail (Figure 3.19). Common moths were initially captured in a much more concentrated time span in 2004 than 2008, with many more moths initially captured later in the year in 2008 than in 2004 (Figure 3.19). The visualization tool shows moth capture by 2-week sampling period (8th column) and by degree days (last column). In 2004, most moths were captured in sampling periods 7.2 and 8.1 with very few/no moths captured after 8.1, whereas in 2008, moths were captured in sampling periods 7.1-8.1 and continued to be captured until 9.1 (Figure 3.19).

DISCUSSION

Previous research has provided strong evidence of the association between insects and vegetation (Hammond and Miller 1998; Knops et al. 1999). Insect abundance and richness have been reported to be associated with the abundance and richness of plants, respectively (Knops et al. 1999, Haddad et al. 2001). Insect abundance has also been reported to vary according to plant biomass (Knops et al. 1999, Haddad et al. 2001). Moths in the western Cascades are closely tied to the distribution of vegetation in the landscape through feeding-guild associations (Hammond and Miller 1998, Miller et al 2003). Moths are far more likely to be found in parts of the landscape that are associated with their host-plants. Our findings largely agree with these prior findings. We described the vegetation of the Andrews Forest structurally and taxonomically for each trap site to identify which method of describing the vegetation community was better for identifying and grouping moth communities. We found that, when aggregated by year, moth community structure was explained very well by both structural and taxonomic vegetation descriptors, as the two types of vegetation categorization matched closely. Grouping moths by host-plant taxonomically derived vegetation communities showed some advantages over structural vegetation descriptors, but both functioned well as identifiers of moth community structure. Taxonomically derived vegetation communities allowed for the identification of indicator plant species that can be used to identify localities of specific moth species assemblages, while structural vegetation descriptors cannot. Structural vegetation descriptors, though, are simpler and less time-consuming, yet still provide significant grouping descriptors for moth communities. While Ober and Hayes (2010) found that percent cover, similar to our structural vegetation categories, was a better indicator of moth community patterns than

taxonomic vegetation descriptors in the Oregon Coast Range, we found that using host-plant richness and distribution is slightly better at identifying moth community patterns.

We found that overall moth species richness and abundance patterns largely agree with previous work. We found that moth species richness and abundance was best explained by elevation and secondarily by vegetation characteristics. The Andrews Forest contains a moderate elevational gradient, beginning at 425-m and ending at 1,620-m. Moth species richness and abundance is higher in the lower elevations and lower in the higher elevations. While this elevational gradient is associated with changes in vegetation, our analyses specifically accounted for vegetation so it is most likely that elevation, here, represents a combination of changes in vegetation and climate. Elevation was found to be a primary driver of species distributions and abundance in the Sierra de Guadarrama in Spain (Illan et al. 2010b). Additionally, our findings show that moth communities at higher elevations experience much more year to year variability. After elevation, moth richness and abundance was found to be positively associated with mature/old-growth conifer forests and, secondarily, young conifer plantations. Mature/old-growth conifer forests have the highest overall biomass of any of our vegetation categories, so the positive association with moth abundance is consistent with previous findings. The host-plant richness in low elevation mature/old growth conifer forests and young forest plantations is typically lower than the plant richness in mid to higher elevation trap sites, although the moth species richness is higher. This does not agree with previous findings, which suggested a link between plant and insect richness (Knops et al. 1999, Haddad et al. 2001). This is possibly due to our sampling of only known moth host-plants and not overall plant richness. This finding supports the importance of linking host-plants to moth species in identifying landscape patterns, not just overall plant richness (Hammond and Miller 1998).

When not aggregated by year, moth diversity is driven by seasonality far more than by vegetation or landscape patterns. The changes in community structure and diversity in any one location is far larger over the course of a few months than the changes in community structure and diversity in very different habitats at any one time. Our findings agree with prior studies that show temporal turnover of moth species exceeded spatial turnover in eastern deciduous woodlands of North America (Summerville and Crist 2004) and in the forests of northern Japan (Hirao et al. 2007).

We found that rare moths were more likely to occur in rare, open habitats. This finding agrees with previous research (Miller et al. 2003), who found that the rare, open habitats on the higher ridges of the western Cascades were associated with rare moths. We also found that while rare moths are more likely to be associated with open habitats such as meadows, they are more likely to be hardwood-feeders and secondarily herb-feeders. Miller et al. (2003) found that the rare species

indicative of the open habitats were both herb and hardwood feeders as well. Adult moths are mobile, so the shrub fields and edges where hardwood shrubs are likely to be found are not necessarily the only locality to find the adults.

We found that common moths were more likely to occur in low elevation conifer forests. Hammond and Miller (1998) identified the conifer-feeding guild as containing the most abundant moth species in the western Cascades, though not the most species. This finding is supportive of prior findings that link biomass abundance to insect abundance (Knops et al. 1999) and is a driver in the overall abundance patterns that we found, as there are a few hyper-abundant moth species in the Andrews Forest and they are associated with lower elevation conifers and riparian hardwoods, secondarily.

Moths are temperature sensitive and their maturation and survival is partially influenced by alterations in climatic patterns. We found that common moths emerge as adults earlier in warmer years and later in colder years. While previous studies have linked moth survivorship and butterfly range expansions to warmer climates (Han and Bauce 1998, Parmesan et al. 1999), no studies have shown that slight changes in yearly climate will affect the emergence patterns of adult moths as a group.

As moth species are largely synchronous in their behavior regarding weather (Raimondo et al. 2004), this finding identifies alterations in moth behavior as a potential concern in regards to the landscape effects of climate change. Additionally, the effects of climate may have a larger impact on moth communities at a higher elevation. As survivorship of some moths has been found to be related to winter and spring temperature patterns (Han and Bauce 1998) and the upper elevations of the Andrews Forest experience heavier snow and freezing temperatures than the mid and lower elevations,

Collaboration

The integration of the DM into the analysis process of ecologists required a close collaborative effort between ecologists and computer scientists. We employed a user-centered, participatory design approach (Figure 3.24) (Schuler and Namioka 1993; Preece et al. 2002) where the ecologists were included as part of the design team from the beginning of the collaborative effort. This particular collaboration started after the initial prototype of the DM had been developed.

The initial prototype proved invaluable as a means for stimulating discussion and identifying design alternatives. It was initially used on a small subset of the data in question. In early meetings, the prototype served as a way to introduce the ecologists to the visual representation in the particular context of their data set. Subsequent meetings followed a very informative and dynamic process. In

particular, each session generally started with the computer science team running the visualization, projecting the view on to a large screen for the entire team to view. The ecologists would then begin to explore the data set in an iterative fashion, asking questions and modifying views to answer those questions, and repeating. The process was typically very fast paced and very collaborative with team members posing questions to each other and devising views, together, to answer those questions. When a question could not be answered using the provided representation and interactions, the entire team would break from the exploration cycle to discuss how the system could be modified to remedy the problem. In the weeks following each meeting, the computer science team would integrate the design modifications into the system in preparation for the next design meeting. As the design matured, the meetings began to move away from design and toward more dedicated exploration and analysis of the data set.

Characteristics/ Process

Given interactive tools, ecologists were able to quickly and iteratively explore data that was originally in a very inaccessible format. The visualization simply provided an environment in which they could rapidly answer questions and visually verify their hunches. The process was typically iterative with several cycles of starting with a question, taking an exploration path, getting insight, and then starting over with a different path through the data.

Implications

Prototypes: An initial prototype is a key component in starting the 'discussion' and allowing the design team to understand the exploration process. While the prototype may not be the final design, some means for rapidly exploring the data allows the team members to begin to understand the typical process and types of questions they can and would like to ask of the data.

Data Queries

In this particular collaborative effort, the visualization served as a means for rapid high-level exploration of the data that was then followed with detailed statistical analyses. Data exploration tools, such as the DM, which overview the data, should provide mechanisms for exporting subsets of data associated with the current view so that scientists can run the statistical analyses.

Creative Process

Hypothesis generation turns out to be a very creative process given rapid exploration tools. Ecologists often took a path through the data to arrive at additional questions. They would then back up, possibly to the beginning to generate an alternative path. In some cases, they felt the need to explore two paths simultaneously to observe the differences in the outcome data. This process, of

allowing multiple path exploration is a fundamental requirement of creativity tools. Data analysis through visualization must support the creative process of hypothesis generation.

Communication

There were several occasions in which an ecologist sought to explain a particular insight or finding by walking the team through the necessary interactions to produce a specific view. Exploration tools must provide mechanisms for storing and retrieving history in order to help users tell their data stories. In addition, the tools need the ability to mark and recreate paths of exploration in order to explain to each other.

Context of Collaboration

Our meetings were typically held in a conference room in the computer science building. On several occasions, the team would have benefited from being located in the context of the ecologist so that the team could refer to or use artifacts that are typically at their disposal – such as topological maps. A more contextual design process that included, for example, sessions in the office of an ecologist, might have uncovered additional useful views/tools that when combined with the visual representation would provide powerful insight capabilities.

CONCLUSIONS

Our findings are relevant to land managers concerned about managing for current and future biodiversity in the landscape. Moth diversity is linked with the diversity of their host-plants. Knowledge of and management for moth host-plants is an important step in managing for moth diversity. This is especially true when managing for rare species. Rare moth species are linked to rare habitats, specifically high elevation openings in the Andrews Forest and, likely, western Cascades. As these habitats are rare and are currently contracting (Miller and Halpern 1998, Takaoka and Swanson 2008, Ch 2 and 4 of this dissertation), management for the preservation and expansion of these habitats is a priority. Additionally, as the moth communities in these habitats are subject to higher variability from year to year and are potentially more at risk due to climate change, effective management strategies for conserving and expanding these habitats now and under potential future scenarios is needed. The visualization tool that we developed has the capacity to help managers identify these trends and others and to help direct the focus of managers to important but vulnerable parts of the landscape. Collaboration between ecologists and computer scientists can potentially provide powerful tools for ecologists and managers for identifying important ecological trends. Collaboration from the beginning of a project and interactive construction of the tools is important and can result in the creation of relevant and useful tools for creating, focusing, and generating

ecological hypotheses as well as providing a useful, easy, and interactive tool for managers interested in exploring patterns of biodiversity on a landscape.

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Table 3. 1. Identification number, elevation, aspect, slope, and watershed of twenty sites sampled for moths in summers of 2004 through 2008 in the HJ Andrews Forest.

Trap ID	Elevation (m)	Aspect	Slope	Watershed
13B	1431	309	33	Upper Lookout
13C	1483	233	59	Upper Lookout
15D	805	149	69	Lower Lookout
15E	777	103	63	Lower Lookout
16B	529	180	19	Lower Lookout
16M	591	140	51	Lower Lookout
18A	610	197	28	Middle Lookout
18G	676	195	37	Middle Lookout
23A	446	135	12	Lower Lookout
23Q	543	105	63	Lower Lookout
26B	1114	299	66	Lower Lookout
26H	1049	237	57	Lower Lookout
28C	820	260	71	Mack
28D	809	316	65	Mack
39B	1335	90	24	Upper Lookout
39H	1334	22	53	Upper Lookout
3G	1417	168	52	McRae
3K	1364	167	53	McRae
5O	863	113	41	McRae
5P	811	153	19	McRae

Table 3. 2. Variables used in the visualization of moths sampled in the summers of 2004 through 2008 in the Andrews Forest.

Attribute Name	Type	Description
LEP_NAME	categorical	Lepidoptera (moths) scientific name; includes genus and species
LEP_FAMILY	categorical	Lepidoptera (moths) taxonomic family
LEP_GENUS	categorical	Lepidoptera (moths) taxonomic genus
FOOD_PLANT	categorical	Host functional feeding group (caterpillar food plant)
ELEVATION	quantitative	Elevation. This attribute will be discretized by 100 meter band.
HABITAT	categorical	Habitat
WATERSHED	categorical	Watershed
COLLECT_PERIOD	categorical	2-week collect period
COLLECT_YEAR	categorical	Collect year
TEMPERATURE (HEAT UNIT)	quantitative	Temperature (Heat unit). This attribute will be discretized by 100 unit band.
NO_INDIV	quantitative	Number of individuals

Table 3. 3. Taxonomic vegetation category, associated moth traps, and related indicator species. Indicator species are shown with their associated indicator value (IV), followed by the significant p-value.

Group	Description	Traps	Indicator Species	Indicator Value (IV)	p-value
1	Riparian	16B, 5P, 18A	<i>Thuja plicata</i>	58.8	0.007
			<i>Polysticum munitum</i>	55.6	0.002
2	Low Elevation Conifer Forest	15E, 28C, 5O, 16M, 23A, 23Q, 18G, 26H, 28D, 26B	<i>Gaultheria shallon</i>	51.7	0.009
3	Low Elevation Opening	15D	None		
4	High Elevation Opening	13C, 3K	<i>Aquilegia formosa</i>	100.0	0.005
			<i>Ligusticum grayii</i>	100.0	0.005
			<i>Carex</i> spp.	100.0	0.005
			<i>Vicia</i> spp.	100.0	0.005
			<i>Symphoricarpus albus</i>	75.0	0.02
5	High Elevation Forest and Clearcut	39B, 3G, 39H	<i>Abies amabilis</i>	66.7	0.04
6	High Elevation Forest	13B	None		

Table 3. 4. Structural vegetation categories and associated moth traps.

Vegetation Category	Vegetation Description	Associated Traps
Low Elevation Riparian Hardwood Vegetation (400-850 m)	Moderately dense forest dominated by Red Alder (<i>Alnus rubra</i>), willow (<i>Salix</i> spp.), and Western Red Cedar (<i>Thuja plicata</i>), within 50 m of a stream	23A, 16B, 18A, 5P, 28C
Low Elevation Young Conifer Forest Plantation	Dense forest dominated by young Douglas fir (<i>Pseudotsuga menziesii</i>), below 1000m elevation	23Q, 16M
Low Elevation Mature/Old Growth Conifer Forest	Dense forest dominated by mature Douglas fir (<i>Pseudotsuga menziesii</i>) and Western Hemlock (<i>Tsuga heterophylla</i>), below 1000 m elevation	18G, 15E, 28D, 5O
Ridgetop Meadow (>800 m)	Open area dominated by grasses and herbaceous vegetation that was not historically forested	15D, 13C
High Elevation Mature/Old-Growth Conifer Forest (>1000 m)	Moderately dense forest dominated by mature Noble fir (<i>Abies procera</i>) and Pacific Silver fir (<i>Abies amabilis</i>), above 1000m elevation	26H, 26B, 39B, 3G, 13B
High Elevation Unregenerated Clearcut	Open area dominated by grasses and herbaceous vegetation that was historically forested	39H, 3K

Table 3. 5. Percent cover of mature forest, young forest, shrub, and meadow/open vegetation for each of the 20 traps based on interpretation of 2005, 1-m resolution Aerial photographs.

Trap_ID	Percent Cover of Mature/Old Growth Forest	Percent Cover of Young Plantation Forest	Percent Cover of Open Meadow Vegetation	Percent Cover of Shrub Vegetation
13B	70	10	15	0
13C	5	10	80	0
15D	20	10	40	25
15E	90	0	0	10
16B	50	0	0	35
16M	10	85	0	0
18A	35	0	0	40
18G	95	0	0	0
23A	50	10	0	15
23Q	75	20	0	0
26B	80	0	0	15
26H	85	5	0	5
28C	100	0	0	0
28D	95	0	0	0
39B	75	0	5	15
39H	5	20	35	35
3G	90	0	0	5
3K	30	10	40	15
5O	95	0	0	0
5P	90	0	0	0

Table 3. 6. Vegetation taxonomic and structural categories for each trap site.

Trap	Taxonomic	Structural
13B	High Elevation Forest II	High Elevation Mature/Old Growth Conifer Forest
13C	High Elevation Opening	Ridgetop Meadow
15D	Low Elevation Opening	Ridgetop Meadow
15E	Low Elevation Conifer Forest	Low Elevation Mature/Old Growth Conifer Forest
16B	Riparian	Low Elevation Riparian Hardwood Vegetation
16M	Low Elevation Conifer Forest	Low Elevation Young Conifer Plantation
18A	Riparian	Low Elevation Riparian Hardwood Vegetation
18G	Low Elevation Conifer Forest	Low Elevation Mature/Old Growth Conifer Forest
23A	Low Elevation Conifer Forest	Low Elevation Riparian Hardwood Vegetation
23Q	Low Elevation Conifer Forest	Low Elevation Young Conifer Plantation
26B	Low Elevation Conifer Forest	High Elevation Mature/Old Growth Conifer Forest
26H	Low Elevation Conifer Forest	High Elevation Mature/Old Growth Conifer Forest
28C	Low Elevation Conifer Forest	Low Elevation Riparian Hardwood Vegetation
28D	Low Elevation Conifer Forest	Low Elevation Mature/Old Growth Conifer Forest
39B	High Elevation Forest I	High Elevation Mature/Old Growth Conifer Forest
39H	High Elevation Forest I	High Elevation Unregenerated Clearcut
3G	High Elevation Forest I	High Elevation Mature/Old Growth Conifer Forest
3K	High Elevation Opening	High Elevation Unregenerated Clearcut
5O	Low Elevation Conifer Forest	Low Elevation Mature/Old Growth Conifer Forest
5P	Riparian	Low Elevation Riparian Hardwood Vegetation

Table 3. 7. Summary of the results of the Generalized Linear Mixed Models of annual totals of moth species richness and abundance, 2004 to 2008, at 20 moth trapping sites in the Andrews Forest, including the AIC of the final model, the variables in the final model, their estimates, and their p-values.

Subject	Variables in Final Model	Estimate	p-value
Moth Richness	Elevation	-0.0002	0.0009
	Taxonomic Vegetation	-0.02	0.005
	Percent Young Conifer Plantation	-0.002	0.03
Moth Abundance	Percent Mature/Old-Growth Conifer Forest	0.01	0.000007
	Elevation	-0.7	0.00008
	Percent Young Conifer Plantation	0.009	0.007
	Elevation-Shrub Interaction	-0.02	0.02
	Percent Shrub	0.02	0.04

Table 3.8. Table detailing the results of the rank-transformed MRPP analysis on grouping moth communities using structural and taxonomic vegetation categories, with associated indicator species (including IV and p-value).

Grouping Variable	MRPP A	MRPP p	Indicator Species	Vegetation Category	Indicator Value	p-value
Structural Vegetation	0.481	<<0.05	<i>Chersotis juncta</i>	4	50	0.0002
			<i>Lacanobia liquida</i>	4	69	0.0002
			<i>Pseudothorsia variabilis</i>	4	51.1	0.0004
			<i>Synedoida adumbrata</i>	4	51.8	0.0002
Taxonomic Vegetation	0.505	<<0.05	<i>Polia nimbosea</i>	1	50.2	0.0002
			<i>Aseptis ethnica</i>	3	50.9	0.0002
			<i>Hemeroplanis finitima</i>	3	50.8	0.0002
			<i>Homorthodes furfurata</i>	3	61.1	0.0002
			<i>Homorthodes hanhami</i>	3	76.4	0.0002
			<i>Lacinipolia illaudabilis</i>	3	56.6	0.0004
			<i>Lacinipolia patalis</i>	3	76.7	0.0002
			<i>Lacinipolia stricta</i>	3	54.7	0.0006
			<i>Lacinipolia strigicollis</i>	3	50.1	0.0014
			<i>Lophocampa argentata</i>	3	55.1	0.0002
			<i>Phobolosia anfracta</i>	3	93.3	0.0002
			<i>Phriganidia californiaria</i>	3	71.6	0.0002
			<i>Platyperigea montana</i>	3	51.3	0.0002
			<i>Semiothisa californicaria</i>	3	78.7	0.0002
			<i>Spilosoma vestalis</i>	3	58.2	0.0002
			<i>Apamea amputatrix</i>	4	55.4	0.0006
			<i>Chersotis juncta</i>	4	50	0.0004
			<i>Lacanobia tacoma</i>	4	55.4	0.0002
			<i>Polia purpurissata</i>	4	54.9	0.0002
			<i>Sphinx vashti</i>	4	54.9	0.0004
			<i>Apamea auranticolor</i>	6	61	0.0002
			<i>Dysstroma brunneata</i>	6	63.2	0.0002
			<i>Dystroma formosas</i>	6	70.3	0.0002
			<i>Eulithis propulsata</i>	6	63.3	0.0002
			<i>Itame decorata</i>	6	77.6	0.0002
			<i>Lacanobia nevadae</i>	6	68.6	0.0002
<i>Lasionycta perplexa</i>	6	51.9	0.0004			
<i>Spargania magnoliata</i>	6	62.2	0.0002			

^a Structural Vegetation Category (4=Ridgetop Meadow); Taxonomic Vegetation Category (1=Low elevation riparian forest; 3=Low elevation opening; 4=High elevation opening; 6=High elevation forest)

Table 3. 9. Pearson and Kendall correlations of environmental variables with NMS axes for the 2D NMS solution annual total moth abundances of 336 species in 20 moth trapping sites in the HJ Andrews Forest, 2004 to 2008. Pearson's correlations > 0.20 are shown in bold font.

Environmental Variable	Axis 1	Axis 1 Kendall	Axis 2	Axis 2 Kendall
	Pearson Correlation (r ²)	Correlation (tau)	Pearson Correlation (r ²)	Correlation (tau)
Elevation	.007	-.011	.888	.800
Aspect	.129	.347	.002	.084
Slope	.075	-.218	.033	.239
Distance to Road	.013	.044	.078	-.152
Distance to Stream	.112	-.190	.234	.360
Percent Mature/Old Growth Forest	.282	.361	.112	-.135
Percent Young Forest	.004	-.235	.005	.130
Percent Open Vegetation	.410	-.396	.516	.586
Percent Shrub	.078	-.276	.001	.012
Percent Stream	.010	.141	.185	-.510
Percent Road	.018	.061	.044	-.131

Table 3. 10. Significance of structural and taxonomic vegetation categories and sample period for explaining moth communities, based on MRPP analysis of the NMS ordination in Figure 20. .

Grouping Category	MRPP A-Statistic	MRPP p-value
Structural Vegetation Category	0.033	0.00000000
Taxonomic Vegetation Category	0.029	0.00000000
Sample Period	0.104	0.00000000

Table 3. 11. Pearson and Kendall correlations of environmental variables with NMS axes for the 3D NMS ordination of moth abundances of 336 species in 20 moth trapping sites by two-week sampling periods in the HJ Andrews Forest, 2004 to 2008. Pearson's correlations > 0.25 are shown in bold font.

Environmental Variable	Axis 1 Pearson Correlation (r^2)	Axis 1 Kendall Correlation (tau)	Axis 2 Pearson Correlation (r^2)	Axis 2 Kendall Correlation (tau)	Axis 3 Pearson Correlation (r^2)	Axis 3 Kendall Correlation (tau)
Mean Calendar Day	.021	-.118	.000	-.035	.806	-.709
Elevation	.001	-.026	.001	.018	.001	-.016
Aspect	.000	.004	.000	.008	.000	.002
Slope	.002	-.032	.001	-.018	.000	.016
Distance to Road	.000	-.011	.000	-.013	.002	.026
Distance to Stream	.001	-.032	.001	-.018	.000	-.004
Percent Mature/Old Growth Forest	.001	.008	.000	-.002	.001	.026
Percent Young Forest	.000	-.014	.001	-.011	.000	-.022
Percent Open Vegetation	.004	-.025	.000	.003	.001	-.030
Percent Shrub	.000	-.007	.001	.011	.000	-.006
Percent Stream	.000	.040	.001	.012	.000	.008
Percent Road	.001	.019	.001	.011	.000	-.021

Table 3. 12. Numbers of trap sites, total abundance, and average abundance (number of individuals per trap site per night) of common moth species by vegetation type. Numbers followed by the same letter are not significantly different from one another at $p < 0.05$ according to a post-hoc Tukey test).

Groups	Count	Sum	Average
High elevation unregenerated clearcut	2	703	351.5c
Low elevation young conifer forest plantation	2	7365	3683.5a
Low elevation mature/old growth conifer forest	4	14266	3567.5a
Ridgetop meadow	2	1259	629.5b
Low elevation riparian hardwood vegetation	5	11395	2279.0a,b
High elevation mature/old-growth conifer forest	5	6901	1380.2b,c

Table 3. 13. Numbers of trap sites, total abundance (number of captured common individuals associated with a given foodplant group), and average abundance of common moth species by foodplant group per trap site. Numbers followed by the same letter are not significantly different from one another at $p < 0.05$ according to a post-hoc Tukey test).

Groups	Count	Sum	Average
Conifer	20	23694	1184.7a
Hardwood	20	14176	708.8b
Herb/grass	20	1354	67.7c
Mix	20	0	0c

Table 3. 14. Numbers of trap sites, total abundance, and average abundance of rare moth species (number of individuals per trap site per night) by structural vegetation type. Numbers followed by the same letter are not significantly different from one another at $p < 0.05$ according to a post-hoc Tukey test.

Groups	Count	Abundance	Average
High elevation unregenerated clearcut	2	54	27.0a
Low elevation young conifer forest plantation	2	33	17.5a
Low elevation mature/old growth conifer forest	4	52	13.0a
Ridgetop meadow	2	95	48.5b
Low elevation riparian hardwood vegetation	5	111	22.2a
High elevation mature/old-growth conifer forest	5	122	24.4a

Table 3. 15. Numbers of trap sites, total abundance (number of captured moth individuals of rare species that are associated with a given foodplant group), and average abundance of rare moth species (number of individuals by foodplant group per trap site). Numbers followed by the same letter are not significantly different from one another at $p < 0.05$ according to a post-hoc Tukey test).

Foodplant Groups	Count	Abundance	Average
Conifer	20	15	0.8b
Hardwood	20	207	10.4a
Herb/grass	20	152	7.6a
Mix	20	6	0.3b

Table 3. 16. Mean calendar dates of first capture of 26 common moth species, by year. Numbers followed by the same letter are not significantly different from one another at $p < 0.05$ according to a post-hoc Tukey test.

Calendar day					
Groups	Count	Sum	Average	Variance	Day
2004	26	4322	166.2a	354.0	June 14
2005	26	4301	165.4a	719.3	June 15
2006	26	4154	159.7 a,b	605.5	June 9
2007	26	4278	164.5a	550.7	June 13
2008	26	4561	175.4b	515.9	June 23

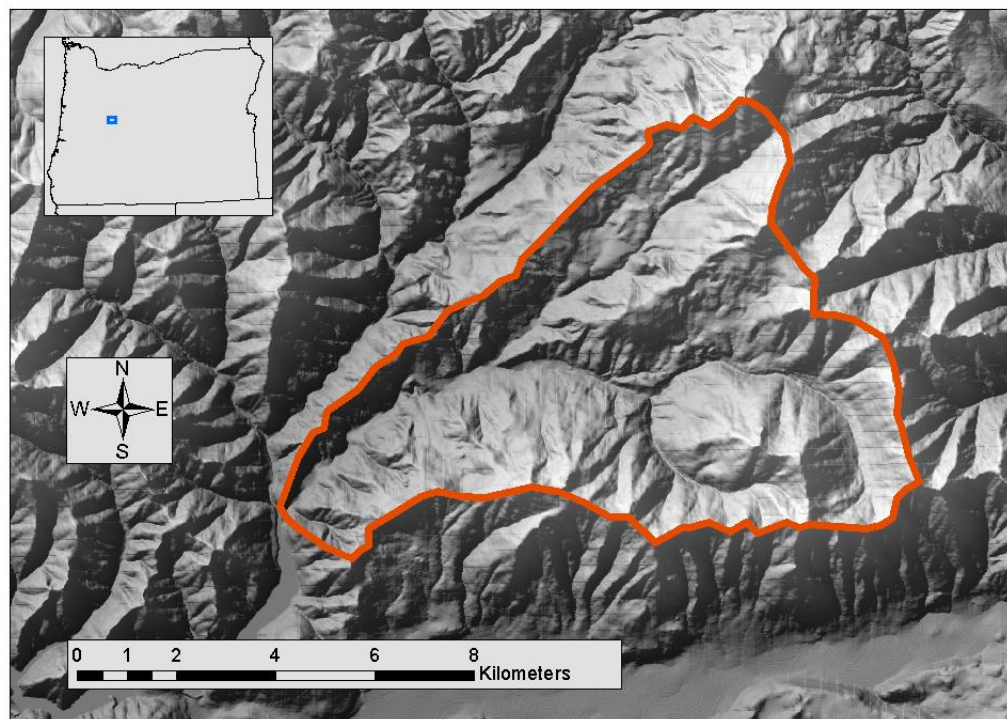


Figure 3. 2. Map showing the location of the Andrews Forest in the central western Cascades, Oregon.

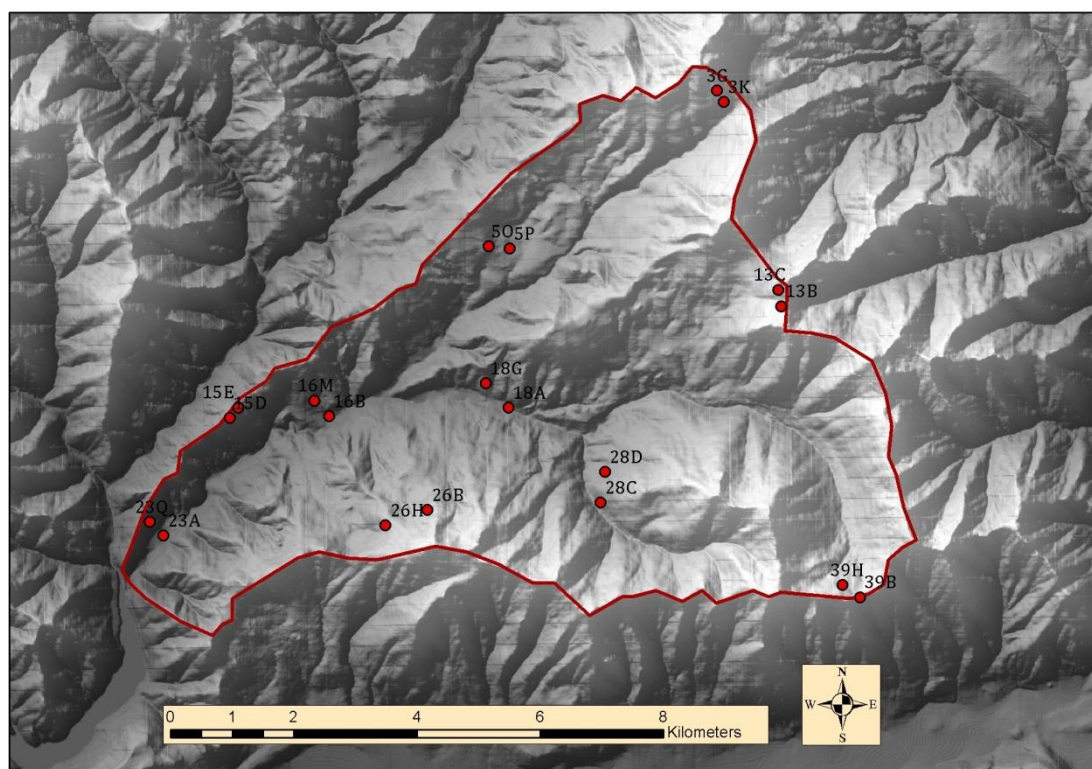


Figure 3. 3. Locations of the twenty moth trap sites (red dots) sampled from 2004 to 2008 in the Andrews Forest. The red line is the boundary of the HJ Andrews Experimental Forest.

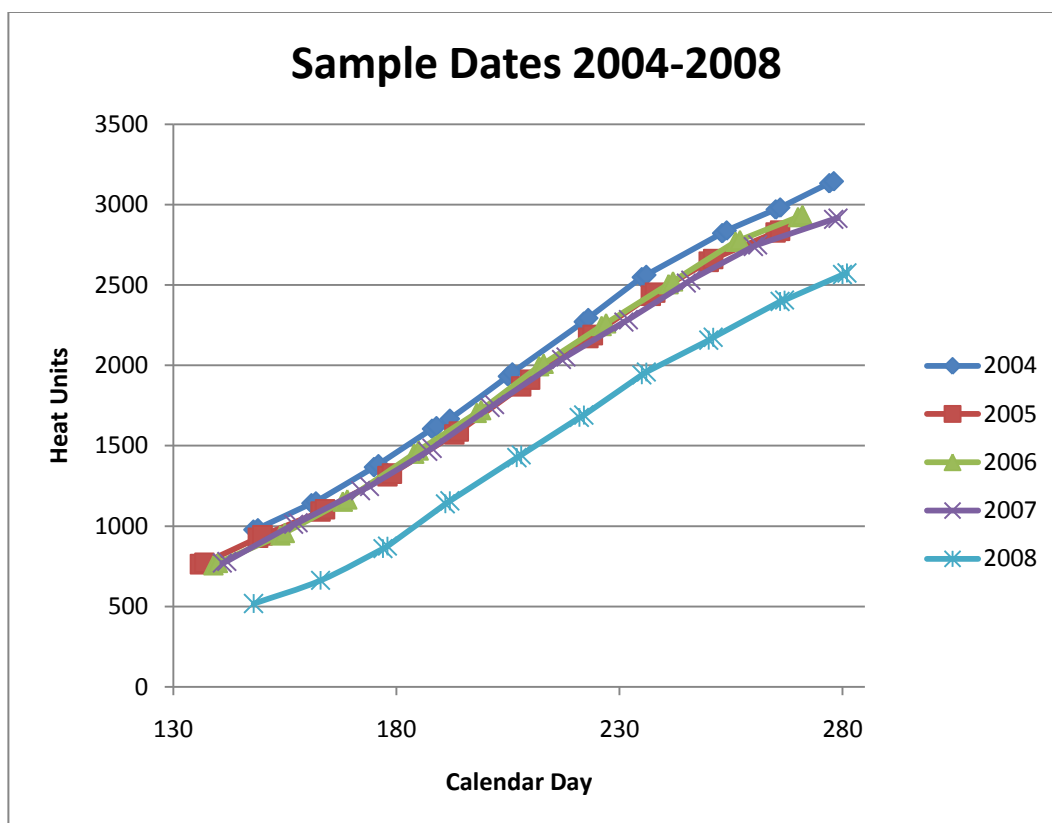


Figure 3.3. Graph showing the accumulation of degree days over the course of the sampling periods, 2004-2008.

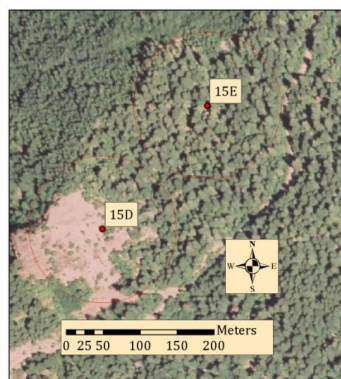
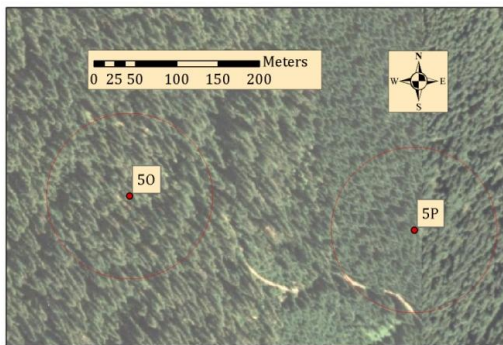
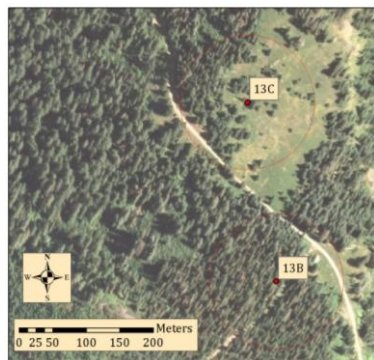
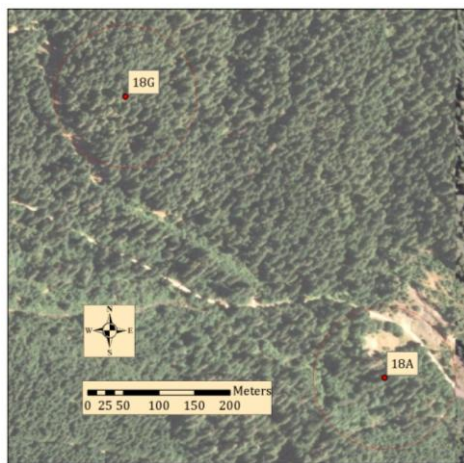
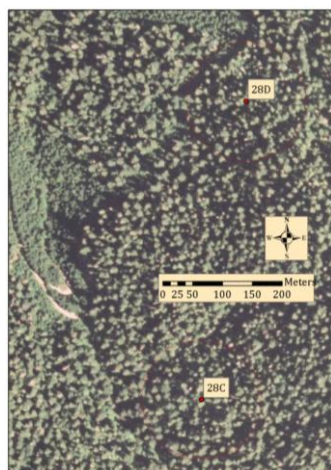




Figure 3. 4 -3.13. Aerial photographs showing the localities of the 20 moth traps utilized in this study. Red circles show 100-m radii around trap site localities, used for determining percent cover and coarse vegetation description.

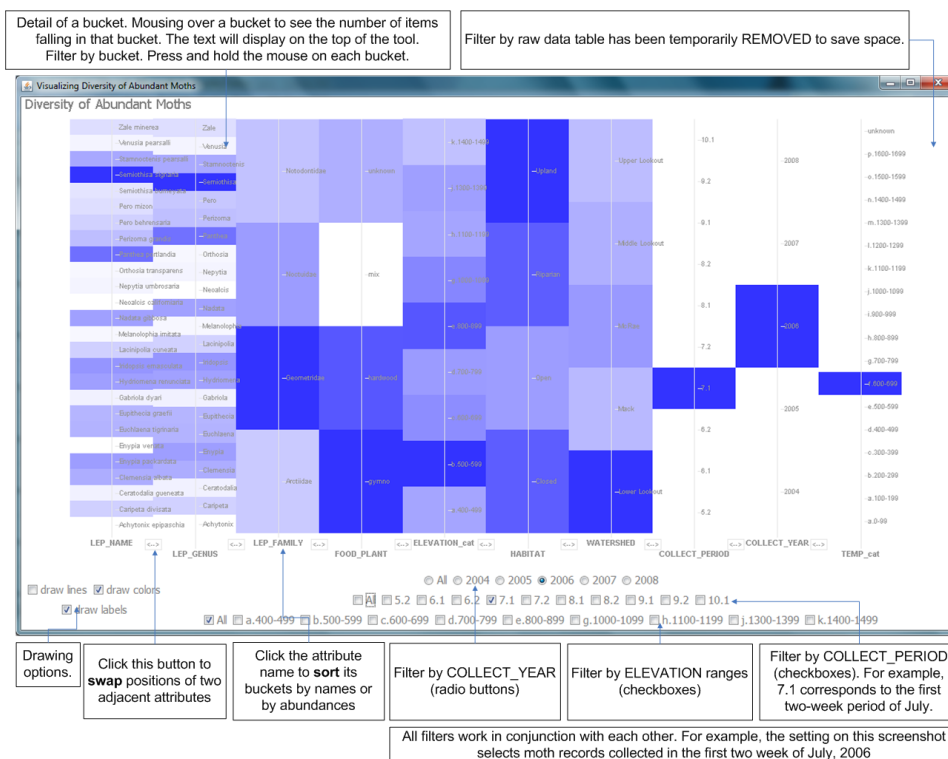


Figure 3. 5. Screenshot showing the layout of the moth visualization tool. The visualizations can be explored at the following weblinks: Visualization of Common Moths (2004-2008, Abundance ≥ 500): <http://web.engr.oregonstate.edu/~pham/moth/flash/CommonMoth.html>; Visualization of Rare Moths (2004-2008, $5 \leq$ Abundance ≤ 10): <http://web.engr.oregonstate.edu/~pham/moth/flash/RareMoth.html>

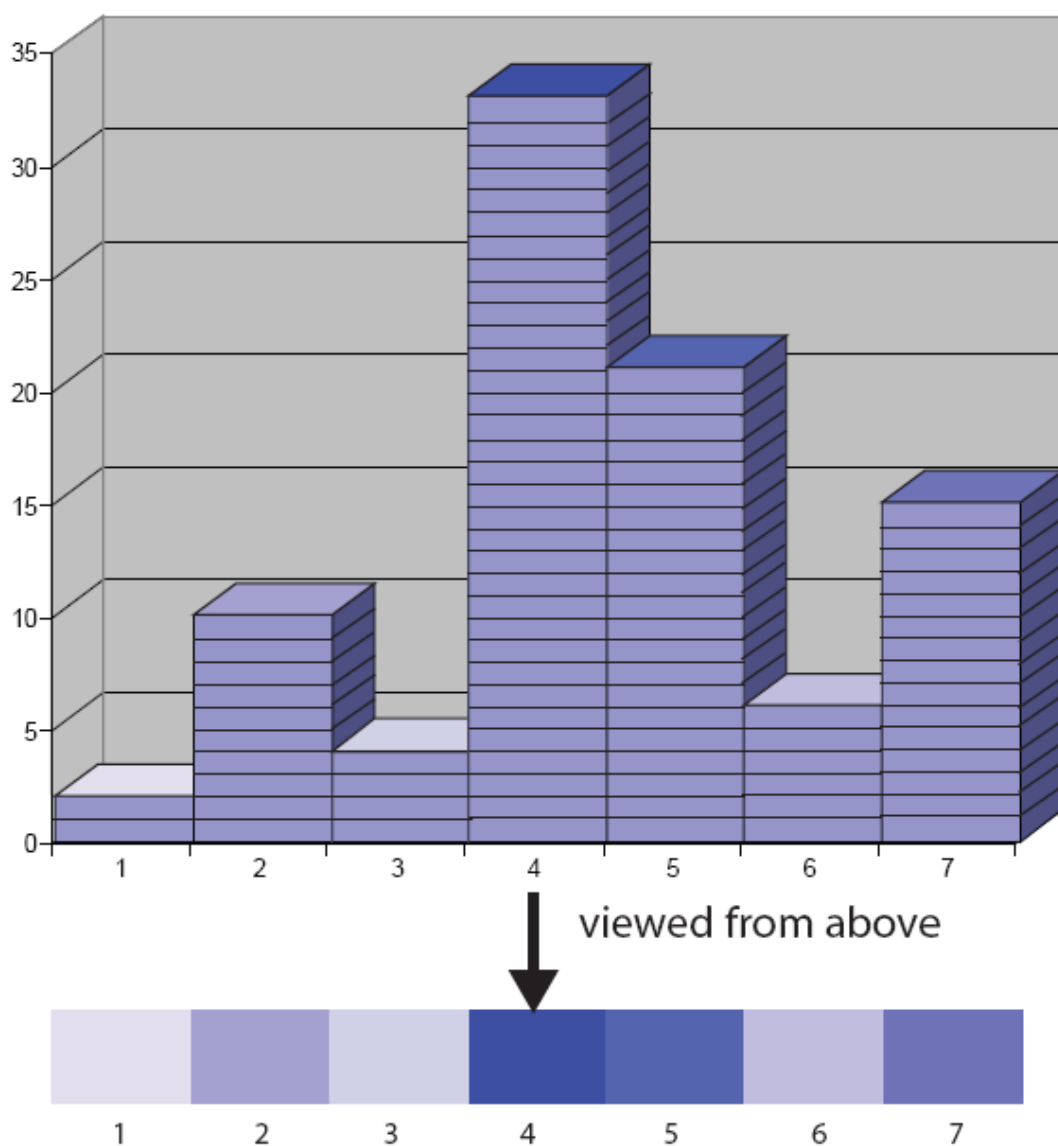


Figure 3. 16. Image of the diversity map showing that when viewed from above, the taller stacks of tiles appear darker, while the shorter stacks appear lighter, according to the total combined contribution of the tiles in each stack to that stack's opacity

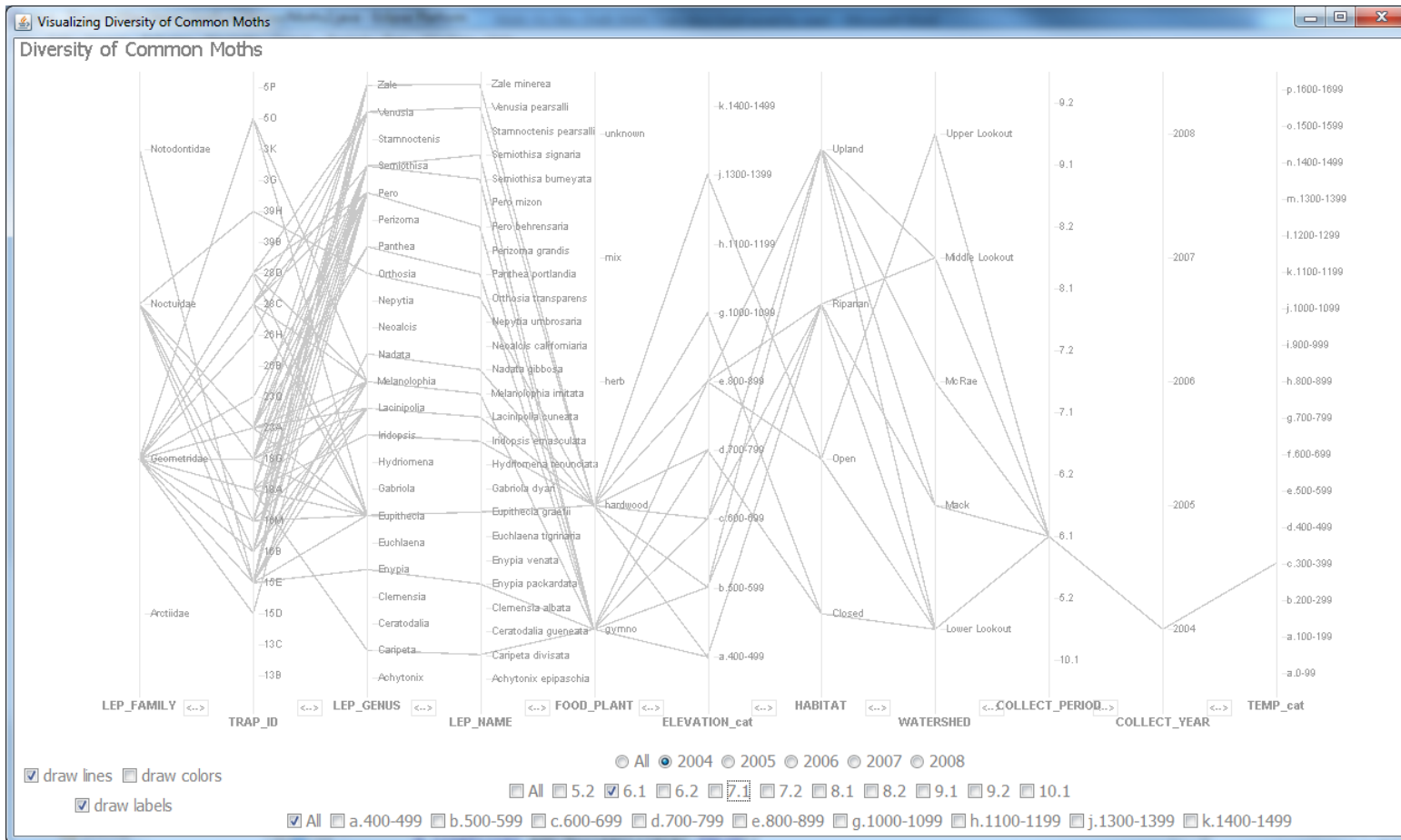


Figure 3. 17. The diversity map viewed in the traditional poly-line representation used in parallel coordinates visualizations; this view is particularly useful in comparing the relationships between samples in two adjacent attributes.

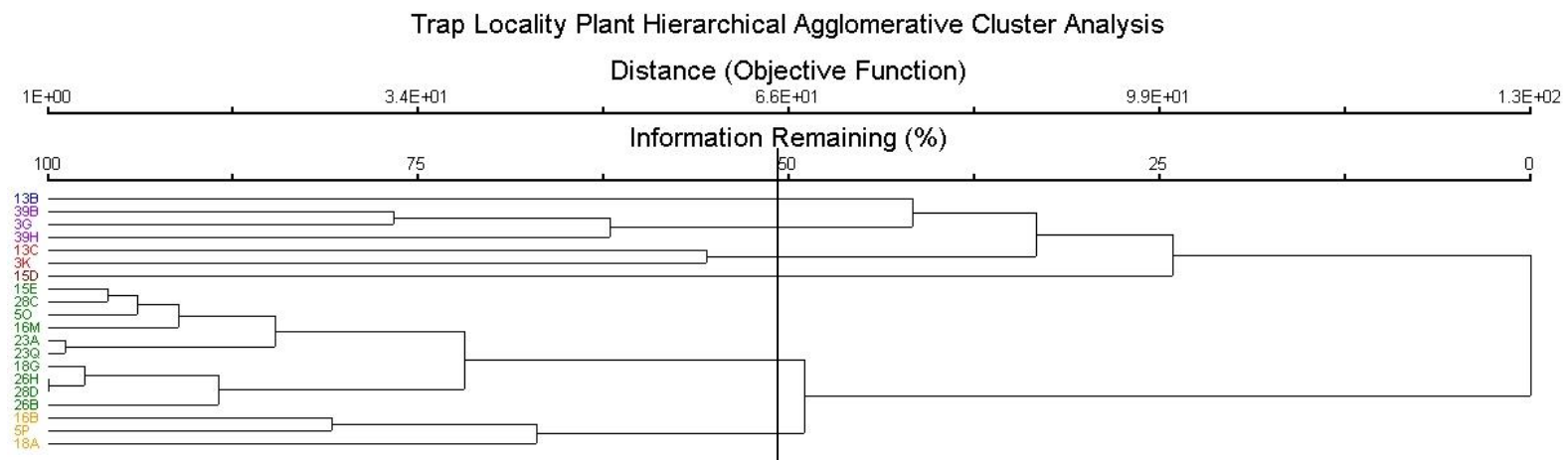


Figure 3. 18. Hierarchical agglomerative cluster analysis dendrogram showing the clustering of trap sites. The vertical bar marks the six taxonomic vegetation categories defined and utilized in this study.

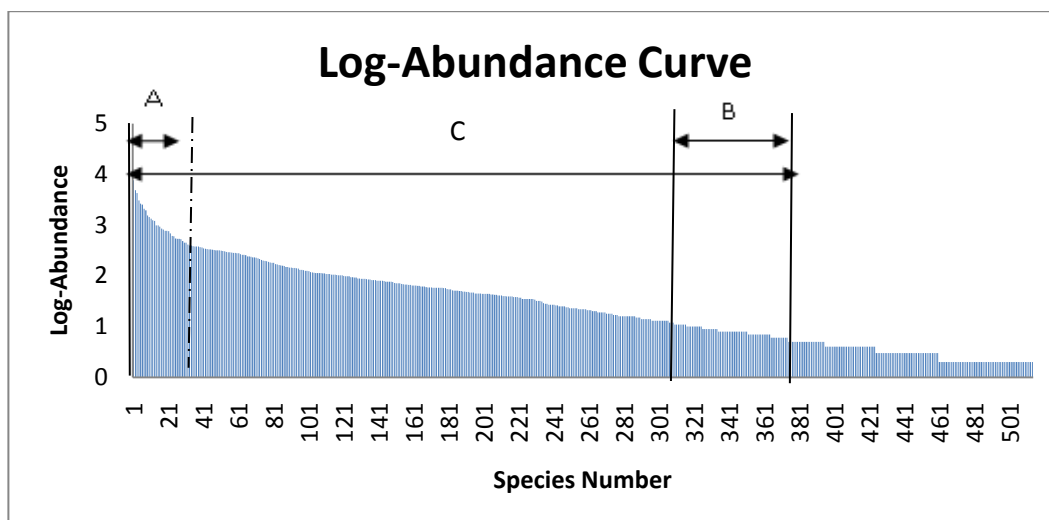


Figure 3. 19. Log Abundance curve showing the distribution of moth species in this dataset. A shows the common moths, B shows the rare moths, and C shows the common through rare moths.

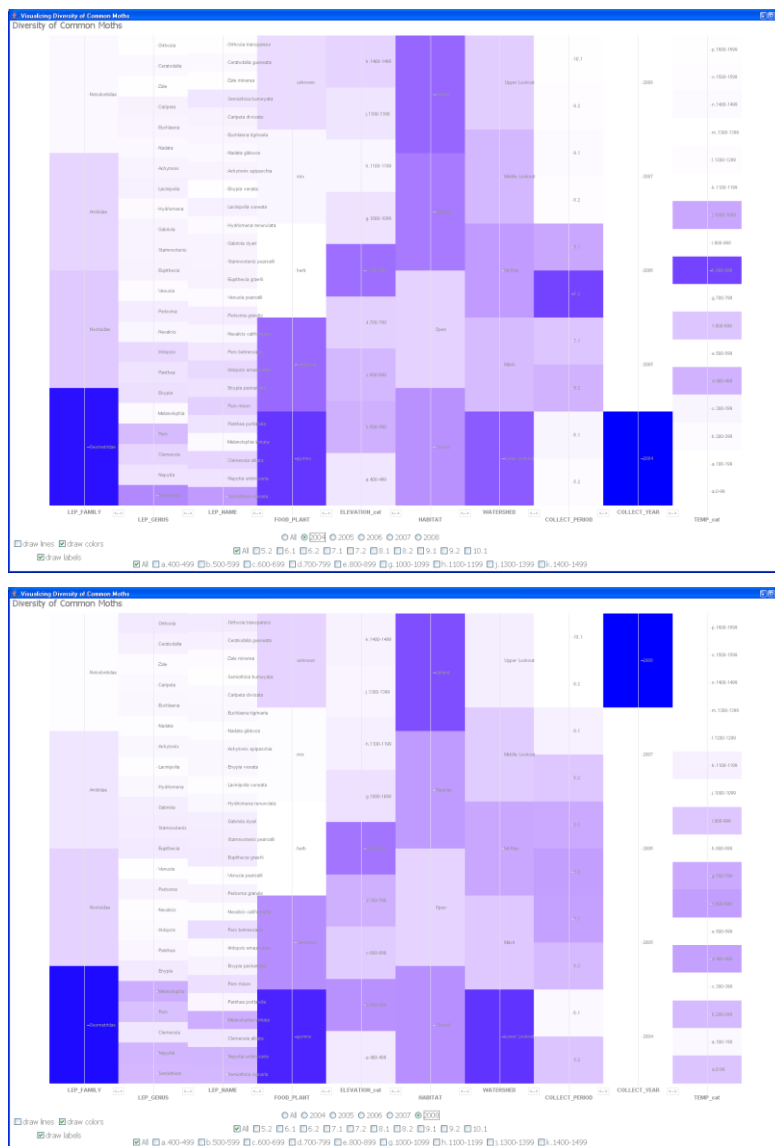


Figure 3.110. Timing of emergence of adults of common moth species in 2004 (left) and 2008 (right), shown by the diversity mapping visualization. The visualizations can be explored at the following weblinks: Visualization of Common Moths (2004-2008, Abundance ≥ 500):

<http://web.engr.oregonstate.edu/~pham/moth/flash/CommonMoth.html>; Visualization of Rare Moths (2004-2008, $5 \leq$ Abundance ≤ 10):

<http://web.engr.oregonstate.edu/~pham/moth/flash/RareMoth.html>

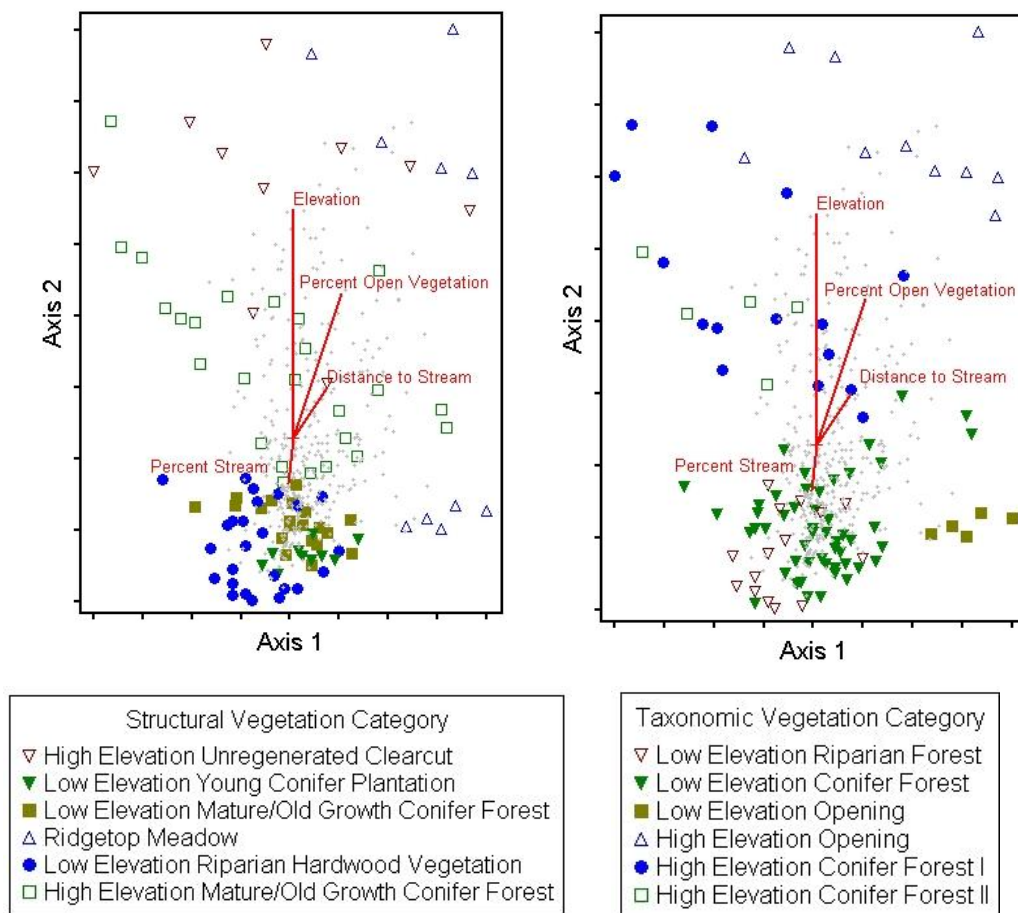


Figure 3. 11. 2-D NMS ordination graphs of yearly aggregated moth traps using structural and taxonomic vegetation categories as grouping variables. The high elevation trap sites exhibit higher inter-annual variation as shown by the larger distances separating the samples.

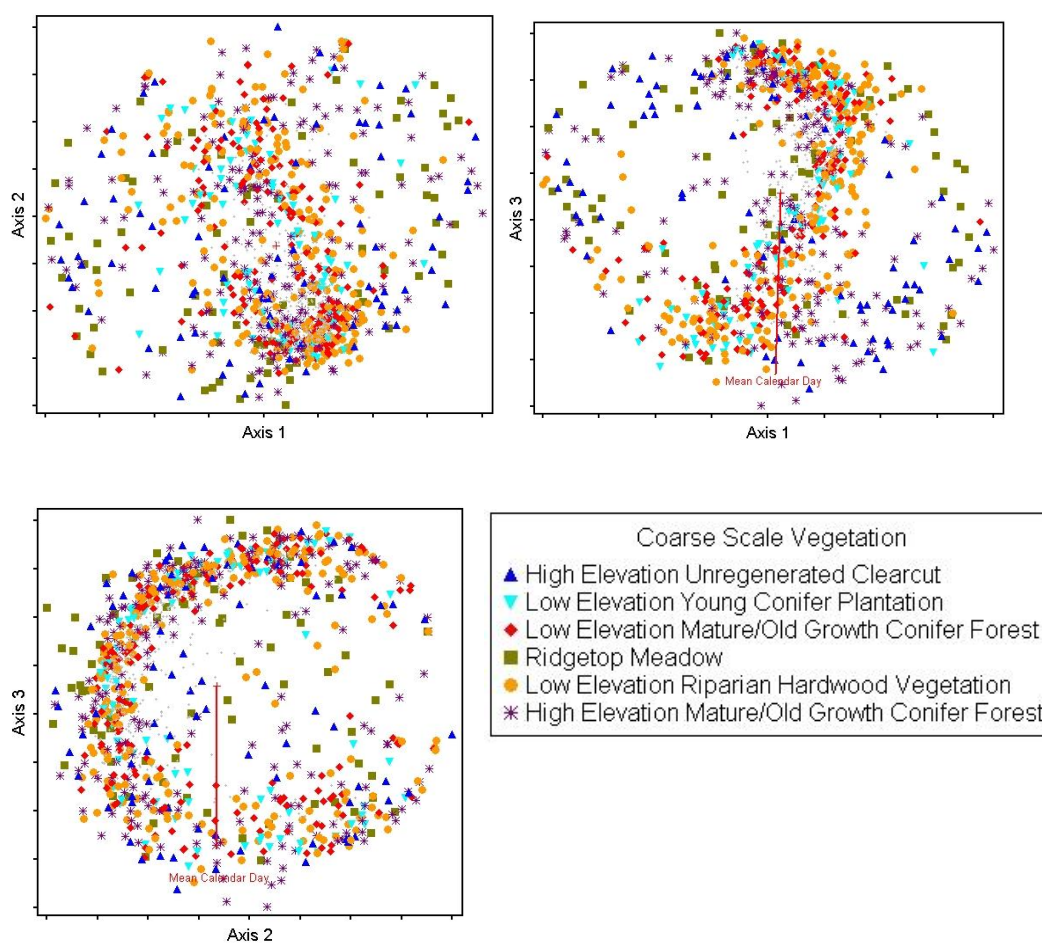


Figure 3. 12. 3-D NMS ordination graphs of unaggregated moth traps using structural vegetation categories as the grouping variable. No identifiable pattern of vegetation based groupings are evident in the ordination graph.

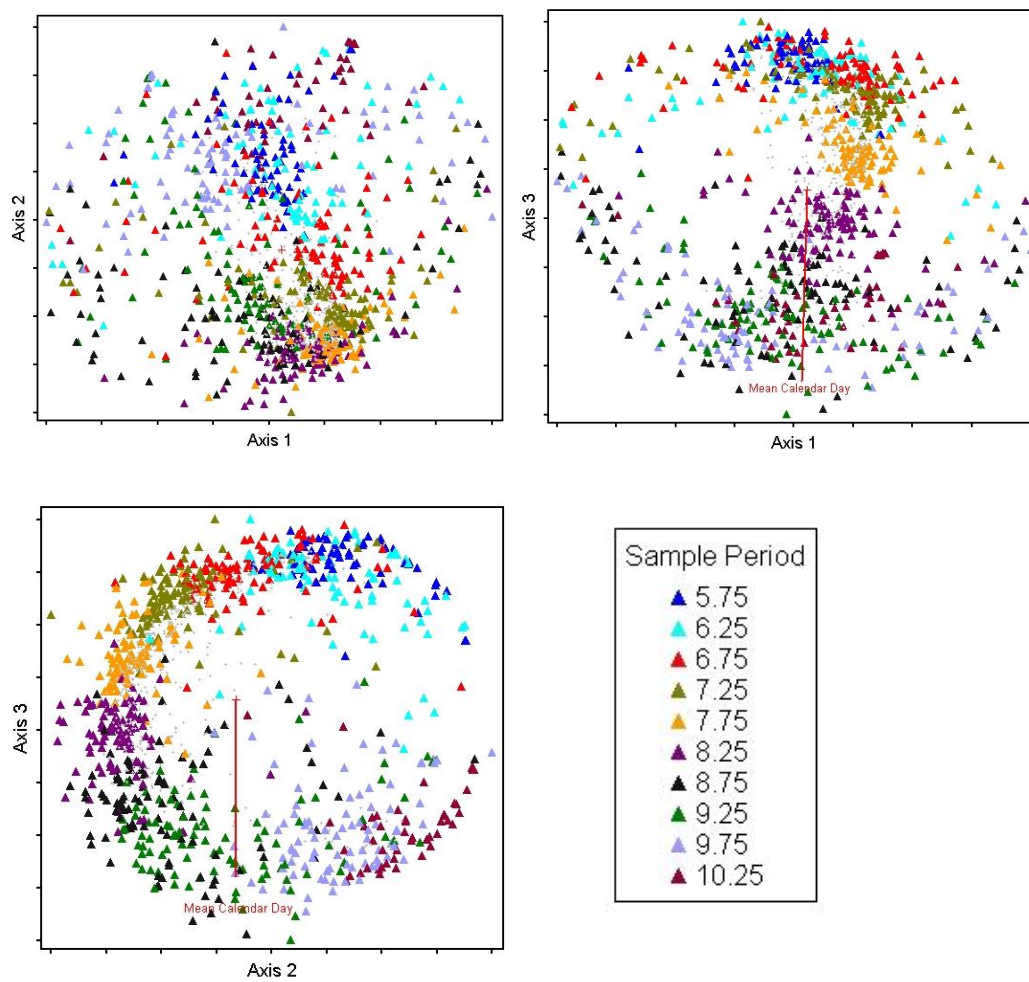


Figure 3. 13. 3-D NMS ordination graphs of unaggregated moth traps using sample period as the grouping variable. Groups defined by sample periods are evident in the ordination graph.

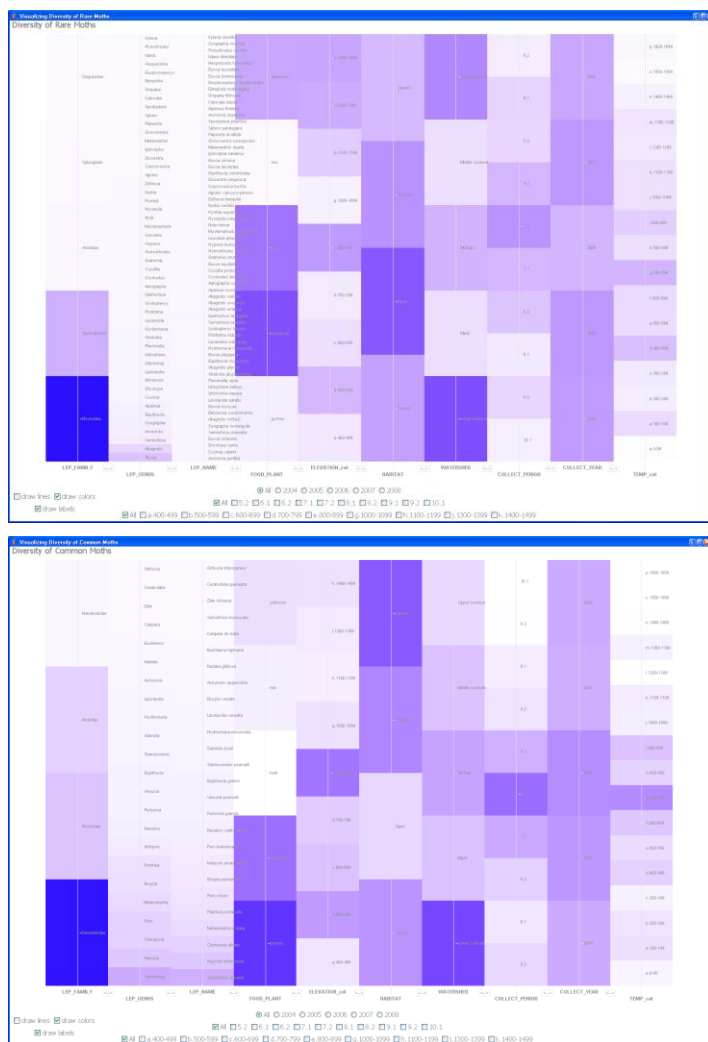


Figure 3. 14. Vegetation type and food plant preferences of moth species vary between common and rare moths, shown by the diversity mapping visualization of rare (left) and common (right) moths. The visualizations can be explored at the following weblinks: Visualization of Common Moths (2004-2008, Abundance ≥ 500): <http://web.engr.oregonstate.edu/~pham/moth/flash/CommonMoth.html>; Visualization of Rare Moths (2004-2008, $5 \leq$ Abundance ≤ 10): <http://web.engr.oregonstate.edu/~pham/moth/flash/RareMoth.html>

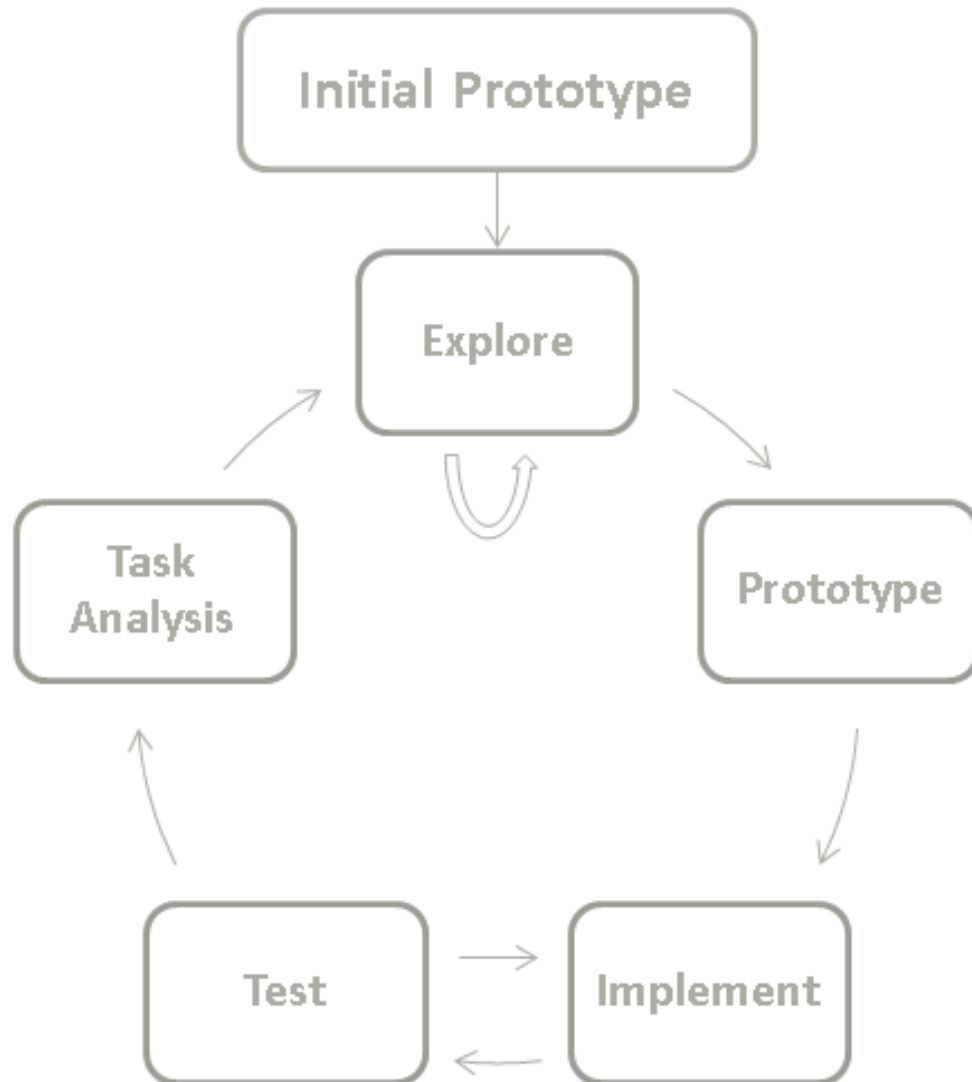


Figure 3. 15. The collaboration between ecologists and computer scientists has taken a user-centered, participatory design approach.

CHAPTER 4: DETERMINANTS OF HERBACEOUS PLANT AND MOTH FEEDING-GUILD RICHNESS, ABUNDANCE, AND COMMUNITY STRUCTURE IN MONTANE MEADOWS IN THE CENTRAL WESTERN CASCADES, OREGON

ABSTRACT

The biodiversity and community structure of moths and plants on the high ridges of the western Cascades is poorly understood. The meadows that occupy prominent localities on these ridges are contracting due to conifer invasion. Aerial photographs of the HJ Andrews Experimental Forest from 1949 and 2005 were analyzed to identify the rate and pattern of meadow contraction. Seventeen meadows of varying sizes and configurations were sampled for herbaceous plant diversity, and 98 meadows and adjacent forest localities were sampled for moths. Meadows have contracted by nearly 50% between 1949 and 2005. Herbaceous plant diversity and community structure is largely related to the size and configuration of the meadows in 1949, as is the diversity and community structure of herb-feeding moths. Hardwood and conifer feeding moth diversity and community structure is better explained by the present-day configuration of the landscape. The plants and insects on the ridges of the west Cascades are rare in the overall landscape and contribute greatly to biodiversity of the region. Managing this landscape for biodiversity requires an understanding of the varying relationships between the contemporary and historic landscape with the distribution of plants and insects present today.

INTRODUCTION

Land use, climate, and changes to both are the most influential variables affecting the current and changing distribution of species and biological communities today (Parmesan and Yohe 2003). In many temperate parts of the world, including the western United States, montane meadows located within otherwise forested mountain ranges have experienced severe contraction and biological alteration (Miller and Halpern 1998; Debinski et al. 2000; Lepofsky et al. 2003; Norman and Taylor 2005; Baur et al. 2006; Zier and Baker 2006; Takaoka and Swanson 2008; Zald 2009;). Although the contraction of montane meadows is well documented, the effects of such contraction on plant and invertebrate distributions are less documented (but see Baur et al. 2006). Nevertheless, studies in lowland grassland and semi-grassland habitats indicate that contraction has a negative effect on plants and invertebrates (Erhardt and Thomas 1991; Schwartz et al. 1997; Helm et al. 2006; Lindborg 2007). This is consistent with island biogeography theory, which predicts that reduction of habitat size and increases in distance between habitat patches lowers the diversity of the organisms that rely on those habitats (Wilson and MacArthur 1967). Overall habitat loss appears to be the dominant driver

of biodiversity loss (Fahrig 2003), but fragmentation and patch connectivity or separation is also important (Helm et al. 2006; Lindborg 2007; Pardini et al. 2010).

As habitat patches contract and become more isolated, species and communities are predicted to become disrupted and species may be extirpated or go extinct (Andren 1994, 1996; Pardini et al. 2010). The rate at which species will disappear from the landscape is dependent upon the type and degree of landscape change as well as characteristics of the species themselves, such as longevity and dispersal ability (Helm et al. 2006; Lindborg 2007; Pardini et al. 2010). Grassland vascular plant diversity in contracting semi-natural grasslands in northern Europe is best explained by the area and connectivity of the grasslands 70 years prior to the study, rather than the current configuration (Helm et al. 2006). Plants responded differently to contractions of semi-natural grasslands in northern Europe depending upon their longevity and dispersal ability, with short-lived species being far more associated with contemporary landscape configurations than long-lived species (Lindborg 2007). Small patches of grassland can maintain higher levels of plant diversity than anticipated (Schwartz et al. 1997). The concept of "extinction debt" has been developed to explain such patterns, with a lack of clear area-species richness relationship attributable to metapopulation disequilibrium (Tilman et al. 1994; Hanski and Ovaskainen 2000, 2002).

Many insects and Lepidoptera, in particular, should be good indicators of environmental change and sensitive indicators of landscape dynamics due to their limited mobility and phytophagy (Holloway 1985; Luff and Woiwood 1995; Smith and Remington 1996; Niemela 1997; Kitching et al. 2000; Ricketts et al. 2001). Lepidoptera, including macromoths, are highly specialized, often utilizing a single species or genus as a host-plant. Moth species abundance is tightly coupled to that of their host-plants, and extirpation of host plants may drive moth species to extinction (Nieminen 1996). Many studies have related moth species distribution and communities to vegetation factors, including amount of rare habitat (Miller et al. 2003), vegetation disturbance (Kitching et al. 2000; Beck et al. 2002; Summerville and Crist 2004; Kuussaari et al. 2007), and habitat size and distribution (Usher and Keiller 1998; Summerville and Crist 2004; Ober and Hayes 2010).

Moths pass through multiple morphological stages during their lifetimes: egg, caterpillar, pupa, and adult. A fertile female will lay fertilized eggs on or near a host-plant. Depending on the species, a female may lay less than 100 to over 1000 eggs either singly or in batches (Miller and Hammond 2000). Caterpillars emerging from the eggs will feed on the host plant and may pass through multiple instars (typically five) as it grows. Once the final instar has matured, it will pupate. Many pupae in the Pacific Northwest pupate over the winter, but some species pupate for only a few weeks (Miller and Hammond 2000). Once the pupal stage ends, the adult moth emerges. Most moths

fly, though some (typically females), do not. Adult moths typically disperse and mate, after which the female will lay fertilized eggs on or near a host-plant.

Spatial and temporal partitioning of habitat use can produce high diversity and abundance of moths. Spatial partitioning occurs as a result of host-plant preferences of moth larvae. Moth species can be grouped into multiple feeding-guilds, including moths whose larvae feed on conifers (“gymnosperm-feeders”), hardwood trees and shrubs (“hardwood-feeders”), and herbs and grasses (“herb-feeders”) (Miller and Hammond 1998). Temporal partitioning is a consequence of the coupling of larval feeding (caterpillar stage) to particular phenological stages of plants, and short adult life spans. Temporal turnover of moth species exceeded spatial turnover in eastern deciduous woodlands of North America (Summerville and Crist 2004) and in the forests of northern Japan (Hirao et al. 2007).

It is debated whether plant and insect species and communities respond similarly to changes in landscape configuration, habitat size, or other drivers, such as climate change. At the community level, this debate concerns whether population sizes are driven primarily by changes in the abundances of co-occurring competitors (i.e., compensatory dynamics), or whether most species have a common response to environmental factors. An analysis of species abundance data from many natural communities showed that the primary driver of community dynamics is abiotic environmental forcing, not competition (Houlihan et al 2007). On the other hand, the abundance and diversity of species specialized to rare habitats would be expected to decline, and those specialized to common habitats would be expected to increase, as a result of a relative loss of rare habitat.

In addition, it has been suggested that species may persist for some time in habitat networks where they are expected to go extinct even without further landscape change. This concept, called “extinction debt” (Tilman et al. 1994) has been examined for butterflies using metapopulation models (Bulman et al 2007). Few field studies have examined insect species and plant communities in terms of extinction debt. However, butterfly and moth species abundances were related to both previous and present-day areas of declining calcareous grasslands in Estonia (Sang et al. 2010); these authors noted that butterflies had responded more rapidly to habitat loss than plants. Cumulative declines in the area of montane meadows provide an opportunity to test the relationships between present-day abundance and diversity and past meadow size and configuration.

This study examined the relationship between plants, moths, and the changing distribution and configuration of a rare habitat – montane meadow in the western Cascades of Oregon. We documented the changes that have occurred in meadow size and configuration between 1949 and 2005 and examined herbaceous plant diversity and distribution in meadows for evidence of extinction debt and legacy effects. We also investigated the relationship between the diversity and community

structure of the three main macromoth feeding guilds and declining meadow habitat. A more accurate understanding of the dynamics of these rare habitats and their plant and moth inhabitants will hopefully facilitate in the development of management strategies to conserve these rare habitats and communities.

METHODS

Study Site

This study is based on vegetation data and moths collected during the summer and fall of 2008 and 2009, and the summer of 2010 on the high eastern ridge of the HJ Andrews Forest (hereafter referred to as Andrews Forest) within the Willamette National Forest, Lane County, OR (Figure 4.1). The Andrews Forest is located on the west slope of the Oregon Cascade Range approximately 80 km east of Eugene, OR. The Andrews Forest consists of 64,000 ha, representing the entire Lookout Creek watershed. Lookout Creek drains west from a high elevation (1,620 m) north-south trending ridge that defines the eastern border of the Andrews Forest and joins Blue River at an elevation of 425 m. High elevation ridges (1,000 – 1,500 m) also define the northern and southern boundaries of the Andrews Forest. Annual precipitation averages 230 cm/yr with most of the rain or snow falling between December and March.

Approximately 95% of the Andrews Forest is forested, with slightly less than 5% consisting of meadows along ridgetops. Plant communities below 1,000 m elevation are dominated by an overstory of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) that create a canopy 60-80 m high. The understory of these low-elevation forests consists of a wide diversity of hardwood trees and shrubs, including maples (*Acer* spp.), willow (*Salix* spp.), and alders (*Alnus* spp.). Steep south-facing slopes occur throughout the watershed, with distinct vegetation including evergreen trees and shrubs such as Manzanita (*Arctostaphylos* spp.), rhododendron (*Rhododendron macrophyllum*), and chinquapin (*Castanopsis chrysophylla*).

Plant communities above 1,000 m on the eastern ridge consist of a mix of subalpine forests, shrub fields, and montane meadows. Suubalpine forests are dominated by an overstory of 50-70 m Pacific Silver fir (*Abies amabilis*) and noble fir (*Abies procera*) with an understory of various hardwood trees and shrubs such as huckleberry (*Vaccinium* spp.) and ocean spray (*Holodiscus discolor*). Shrub fields are dominated by Sitka alder, (*Alnus viridis* ssp. *sinuata*). Open montane ridgetop meadows are dominated by herbaceous plants and grasses, such as lupines (*Lupinus* spp.) and fescues (*Festuca* spp.).

Questions and Hypotheses

This study examined the relationships among meadow size, change, distance, and abundance, distribution, and species composition of plant and moth communities in montane meadows of Andrews Forest. We asked the following questions:

- 1) What are the effects of meadow size, shape, and fragmentation on herbaceous and moth communities?
- 2) How does the historical size and shape of a meadow affect the modern herbaceous and moth communities?
- 3) How are herbaceous and moth communities related?
- 4) How do different moth feeding guilds respond to the configuration of the landscape?

The study was structured around several hypotheses:

H1. Abundance and richness of plant and moth communities are positively related to the size of individual meadows.

H2. Abundance and richness of plant and moth communities are negatively related to meadow isolation.

H3. Abundance and richness of plant and moth communities are more closely related to recent meadow sizes (2005) than past meadow size (1949).

H4. Different feeding guilds of moths (herb-feeders, hardwood-feeders, and gymnosperm-feeders) respond differently to the size, arrangement, and change in montane meadows.

Meadow Identification and Rate of Change

Meadows larger than 0.1 ha were mapped and classified into three meadow classes according to the interpretation of aerial photographs obtained in 1949 and 2005. A 2005 one-meter resolution image of Lane County, OR from the National Agricultural Imagery Program (NAIP) was used as the basis for digitizing the 2005 meadow layer. Separate aerial photographs of the area in 1949 (black and white, 1:20,000) were acquired and scanned at the U.S. Forest Service Pacific Northwest Research Station, then georectified, using permanent or semi-permanent landscape markers, such as rock outcrops and large, easily identifiable individual old growth trees. The outline and extent of meadows were mapped in ArcGIS 9.3, excluding all identifiable trees and tree clusters in meadows.

Meadows were classified as xeric, mesic, and wet using tone and field visits, with darker tones signifying mesic meadows and lighter tones signifying xeric meadows. Texture was used to distinguish between meadows and shrub fields, which were not examined in this study. Field visits indicated that mesic meadows are dominated by Bracken fern (*Pteridium aquilinum*) and herbs, such

as *Lupinus* spp. and thick loamy soil, and xeric meadows are dominated by a grasses and herbs and thinner, gravelly soil. The few wet meadows (all on Lookout Mountain) were identified by field visits. Wet meadows are dominated by dense herbs interspersed with *Salix* spp. shrubs.

The perimeter and area of each meadow were calculated using ArcGIS 9.3. Elevation, aspect, and slope were calculated for the centroid of each meadow using a 10-m digital elevation model (DEM). Meadow area and perimeter in 1949 were subtracted from those of 2005 to provide metrics of area and perimeter change. The area and perimeter change values were converted to percent changes relative to the area or perimeter of the meadow in 1949. A meadow was considered to have fragmented into multiple meadows if a single meadow in 1949 had been divided by one or more lines of trees in 2005. Area and perimeter in 2005 was based on all fragments of continuous meadows apparent in 1949 air photos. Figures 4.2- 4.6 show the distributions of meadow in 1949 and 2005 for the five complexes, as visible on aerial photographs from 2005.

Meadow Descriptors and Environmental Covariates

Twenty-seven continuous and six categorical environmental variables were included as covariates in statistical analyses. Categorical variables were month, year, complex, matrix, vegetation category 1, 1949 and 2005 meadow area groups, and aspect. Month and year refers to the month or year in which a sample was taken. Matrix is a qualitative classification of vegetation structure surrounding the sample, and includes forest, shrub, and road. The matrix value was assigned by interpretation of the Stohlgren-Whittaker plot or moth sample location on a 2005 aerial photograph.

Each meadow was assigned to one of five meadow complexes, designated as Carpenter Mountain, BCM, Meadow 2, Meadow 1, and Lookout Mountain complexes (Figure 4.1). Meadow complexes were defined as groups of meadows were separated by forested or semi-forested areas, based on examination of 1949 aerial photographs. Since 1949, roads and clearcuts have potentially obscured the original meadow complexes. One Stohlgren-Whittaker plot and multiple moth samples also were taken at Frissel Ridge a sixth smaller meadow complex along a wooded ridge between Meadow1 and Lookout Mountain.

Vegetation categories are structural descriptors of the vegetation community at a given sample location. Each sample was classified as one of the following based on field inspection and interpretation of 2005 air photos: xeric meadow >3.5 ha, xeric meadow 3.5-0.5 ha, xeric meadow <0.5 ha, mesic meadow, wet meadow, mature/old growth conifer forest, young conifer forest, clearcut, forest road, and edge. Each meadow also was classified according to its area in 1949 and 2005: >3.5 ha, 0.5-3.5 ha, <0.5 ha, and non-meadow. Each meadow was classified according to one of eight

categories of aspect as follows: NNE (1-45°), ENE (45-90°), ESE (91-135°), SSE (136-180°), SSW (181-225°), WSW (226-270°), WNW (271-315°), NNW (315-360°).

Continuous variables were calendar day; elevation; slope; distances to road, stream, forest, and nearest meadow; percent cover of mature/old growth forest, young forest, open vegetation, shrubs, streams, and roads; meadow area, meadow perimeter, meadow perimeter-area ratio, and meadow complex area in 1949 and 2005; change in meadow area and perimeter from 1949-2005; fragmentation; and the aggregated area of meadow fragments in 2005. Calendar day refers to the number of the day on which sampling was conducted. Elevation and slope were calculated from a 10-m digital elevation model (DEM) using ArcGIS 9.3. The percent cover of mature/old growth forest, young forest, open vegetation, shrubs, roads, and streams were calculated within a 100-m radius circle surrounding each moth trap site on 2005 aerial photographs. Distances to roads, streams, forests, and openings were defined as the shortest distance from a trap site to the nearest road or stream as identified on 2005 aerial photographs, calculated using the measuring tool in ArcGIS 9.3. Meadow area and perimeter were photointerpreted from 1949 and 2005 aerial photographs georectified in ArcGIS 9.3. Meadow perimeter-area ratio was calculated by dividing the area (m²) by the perimeter (m). Fragmentation was calculated as the number of individual meadows in 2005 that occupied the area of a single meadow in 1949, divided by the total area of the intact meadow in 1949. Aggregated 2005 meadow area was calculated as the sum of the areas of 2005 meadow fragments that comprised a single meadow in 1949. Area and perimeter change were the difference in area or perimeter of a meadow in 1949 versus 2005, calculated by subtracting the 1949 value from the 2005 value. Meadow complex area (1949 and 2005) was the sum of the area of all meadows within a given complex.

Field Sampling: Moths

Moths were collected over the summers of 2008, 2009, and 2010 using UV light traps. The trap consists of a 5-gallon bucket on which is mounted a circular ultraviolet blacklight and containing an insecticide impregnated strip (Bioquip model #2851 trap, 22-watt circle light bulbs, 12-volt batteries, and "HotShot" strips). Moth traps are placed in a given location for a single night (excluding periods of near full moon) and collected the following day. Moths are attracted to the light and overcome by the insecticide, falling into the bottom of the bucket. A total of 98 moth traps were placed in 63 locations from July to September in 2008 (44 traps), 2009 (43 traps), and 2010 (11 traps). Moth traps were placed in meadows of varying sizes (0.5-4.7 ha), as well as forests, clearcuts, and roads at high-elevation sites along the eastern bounding ridge of the Andrews Forest. Moths were collected, transported to Corvallis, identified, counted, and recorded according to date and location of

collection. Moth abundance refers to the number of individuals caught in a single trap in a single night, or the total number of individuals in any aggregated assemblage of trapping events. All moths were identified to species level when possible and genus level otherwise by Dana Ross and the author. Host plants for moths, if known, were based on Miller and Hammond (2000, 2003), who captured caterpillars in the field and successfully reared them to adulthood using the vegetation on which they were found.

Field Sampling: plants

Vegetation was sampled in seventeen localities, including 15 meadows and two non-meadows adjacent to meadows, using Stohlgren-Whittaker plots. The 17 plot locations were the largest meadows in each complex (n=5), medium-sized and small fragments of meadows in multiple complexes that had been connected and much larger in 1949 (n=5); isolated medium and small meadows (n=5), and semi-open forested non-meadows (n=2). Stohlgren-Whittaker plots consist of a 20x50 m plot within which are nested one central 5x20 m subplot, two corner 2x5 m subplots, and ten 0.5x2 m subplots distributed around the inside edge of the large plot (Stohlgren et al 1995). Percent cover of all plant species was recorded in each nested subplot. The remaining portion of the full plot is examined for plant species not identified in the subplots. This nested vegetation plot design is appropriate for studies of biological diversity because it captures more species of plants in a smaller amount of time than many other techniques (Stohlgren et al 1995). This study utilized the total abundance and diversity in all subplots.

Statistical Analysis

Data were analyzed using five statistical techniques: (1) hierarchical agglomerative cluster analysis (CLA), (2) rank-transformed Multi-Response Permutation Procedure (MRPP), (3) Indicator Species Analysis, (4) Non-Metric Multidimensional Scaling Ordination (NMS), and (5) Generalized Additive Models (GAM) (Table 4.1). PC-ORD version 5.31 was used for the CLA, MRPP, and NMS analyses (McCune and Mefford 2006). Simpson's diversity index, Shannon's diversity index, Pielou's evenness index, and overall beta-diversity ("half-changes") were calculated using PC-ORD version 5.31 (McCune and Mefford 2006). Simpson's diversity index values were utilized in statistical tests because of problems noted with the use of Shannon's diversity index and Pielou's evenness index (Magurran 2004), but all diversity index values are presented. "Half-changes" beta-diversity measures the number of species that would have to change for samples to achieve 50% similarity. The R statistical package, including the mgvc package, was used for the GAM analysis.

Hierarchical agglomerative cluster analysis (CLA) was used to infer vegetation groups defined by their species similarities from the Stohlgren plot species data, with the Sorensen distance and

Flexible Beta (-0.25) linkage method (McCune and Grace, 2002). The Sorensen distance measure is a proportion coefficient calculated by dividing the shared abundance of species by the total abundance of species. The Flexible Beta (-0.25) is a space-conserving method of linkage recommended for CLA (McCune and Grace 2002). The dendrogram was pruned with approximately 60% information remaining, producing four categories (see results).

Multi-Response Permutation Procedure (MRPP) is a nonparametric procedure for testing the hypothesis of no difference between two or more groups (McCune and Grace 2002; Mielke 1984; Mielke and Berry 2001). Results of MRPP are evaluated based on a p-value and an A-statistic (Table 4.1). The A-value is a chance-corrected within-group agreement that measures the effect size, with a value of 0.1 indicating moderate effect and a value of over 0.2 indicating a moderate to high effect (McCune and Grace 2002). MRPP was used to test differences among the vegetation categories identified in the cluster analysis (CLA). Before conducting the MRPP, the environmental matrix was relativized by the standard deviation of each variable and the species and environmental matrix was switched so as to not test species clusters for significance in species space (McCune and Grace, 2002). For plants, MRPP was also used to test other, a-priori defined vegetation groups including one based on 1949 meadow area and another based on 2005 meadow area. For moths, MRPP was also used to analyze the high elevation moth community using a-priori defined groups including one based on 2005 structural vegetation categories, one based on 1949 structural vegetation categories, and one based on sample period. Vegetation categories were considered significantly different if the MRPP analysis was significant ($p < 0.05$), and effect size was moderate-high ($A > 0.2$). Moth categories were considered significant if the MRPP was significant ($p < 0.05$) and effect size was small-moderate ($A > 1$).

An Indicator Species Analysis (ISA) was conducted to create descriptions for vegetation and moth categories from the cluster analysis (CLA) and a-priori vegetation groups (Dufrene and Legendre 1998). Plants and moths were adopted as indicator species if they were shown to be significant ($p < 0.05$) indicators for a group and had an indicator value (IV) exceeding 50%.

Non-Metric Multidimensional Scaling Ordination (NMS) was used to describe the organization of plant and moth communities in montane meadows and identify the environmental variables correlated to this organization. Only species that were present in more than 5% of all sample units were used in the NMS analysis. Plant abundance data were transformed by adding 1 to each abundance value before log transforming the value; this procedure accounts for zeros in the data. An Outlier Analysis was conducted on the species and sample units, to identify species or sample units whose distance measure is more than two standard deviations from the grand mean. No plant species or samples were found to be outliers. The NMS was conducted using a Sorensen/Bray-Curtis similarity

matrix with a flexible beta linkage (-0.25). For the NMS analysis, the following procedure was employed: (1) a random starting configuration was chosen, (2) 250 runs were made for the Monte Carlo test, (3) dimensionality was selected based on a better than random solution as determined by the results of the Monte Carlo test and reduction in stress, (4) up to 250 iterations were allowed to calculate a stress stability of $<.000001$ over the last 15 iterations, and (5) the NMS plots were overlaid with the environmental variables (Kruskal 1964, McCune and Grace 2002). NMS was also used to assess patterns in high elevation moth communities and their relationships to the environmental variables described in the previous section. The NMS procedure for moth data was identical to the procedure for plant data, except that the moth abundance data were transformed using Beal's Smoothing (McCune 1996, McCune and Grace 2002). Beal's Smoothing was used in the NMS analysis to reduce the high degree of heterogeneity and noise in the data and clarify the underlying patterns (McCune 1996, McCune and Grace 2002). Herb, hardwood, and gymnosperm feeders were analyzed separately with NMS, following the same procedures. In all NMS moth analyses, outliers (species and samples that were more than 2.3 standard deviations away from the grand mean) were omitted.

Generalized Additive Models (GAM) were used to relate patterns of vegetation richness and moth richness and abundance to environmental variables. In particular, models tested the relationship between contemporary vegetation and moth richness and abundance and the distribution of meadows, forest, and roads in 1949 and 2005. All environmental variables were included as predictors, and response variables included plant species richness, species richnesses of the three moth feeding guilds, and species abundances of the three moth feeding guilds. GAM models were run for every combination of predictor and response variable using Un-Biased Risk Estimator criterion (UBRE) scores to assess variable inclusion in the larger models. The three predictor variables with the lowest UBRE scores were combined for the initial larger model. Then other variables were added and subtracted until the lowest overall UBRE score was identified, so long as all predictor variables were significant ($p < 0.05$). This was designated as the best-fit model.

RESULTS

Meadow Size, Distribution, and Change 1949-2005

Five meadow complexes were identified in the high elevation of the HJ Andrews Forest (Figures 4.1-4.6): Carpenter Mountain, BCM, Meadow 2, Meadow 1, and Lookout Mountain. In 1949, these five meadow complexes occupied 145.8 ha, but by 2005, they occupied only 79.8 ha (54.8% of the total area in 1949) (Table 4.2).

In 1949, Carpenter Mountain had 132 meadows totaling 40.8 ha and Lookout Mountain had 136 meadows totaling 51.5 ha, while BCM, Meadow 1, and Meadow 2 had 151 meadows (54, 53, and 44, respectively) totaling 53.5 ha (13.9, 21.8, and 17.8, respectively). In 1949, average meadow size was 0.31 ha (Carpenter Mountain), 0.37 ha (Lookout Mountain), 0.25 ha (BCM), 0.41 ha (Meadow 1), and 0.43 ha (Meadow 2). Xeric meadows were most frequent and occupied the largest portion of total meadow area in 1949.

In 2005, Carpenter Mountain had 63 meadows totaling 13.7 ha and Lookout Mountain had 82 meadows totaling 22.8 ha. BCM, Meadow 1, and Meadow 2 had 40, 44, and 32 meadows, respectively, covering 43.3 ha (10.2, 15.8, and 17.3 ha, respectively). In 2005, average meadow size was 0.21 ha (Carpenter Mountain), 0.28 ha (Lookout Mountain), 0.26 ha (BCM), 0.36 ha (Meadow 1), and 0.54 ha (Meadow 2). Xeric meadows were most frequent and occupied the largest portion of total meadow area in 2005 (Table 4.2).

Carpenter Mountain and Lookout Mountain lost more meadows and meadow area than the other three meadow complexes. Carpenter Mountain lost 96 meadows (27.1 ha), while Lookout Mountain lost 91 meadows (28.7 ha). BCM, Meadow 1, and Meadow 2 lost a total of 90 meadows (29, 25, and 36, respectively), losing 10.2 ha (3.7, 6.0, and 0.5 ha, respectively). Carpenter Mountain and Lookout Mountain both lost over half of their total meadow area, while BCM, Meadow 1, and Meadow 2 only lost 26.6, 27.5, and 2.8 percent of their total area. Xeric meadows lost more meadows and meadow area than mesic meadows (Table 4.2).

Meadows in all five complexes were fragmented from 1949 to 2005. "Fragmented" meadows were present in 1949 and are still present in some form, but they have been broken into multiple parts. In all five complexes xeric meadows that persisted from 1949 to 2005 have been divided into multiple meadows. Only 31 of the 127 xeric meadows present in the Carpenter Mountain complex in 1949 persisted to 2005, and those 31 remaining meadows had been broken into 58 separate fragments. Similarly, in 2005, Lookout Mountain had only 35 of the 108 xeric meadows present in the Lookout Mountain complex in 1949 persisted to 2005, and those 35 original meadows had been broken into 70 fragments. Mesic meadows contracted in size but did not undergo fragmentation.

Overall meadow area in the five complexes also decreased from 1949 to 2005. The perimeter-area ratio of a meadow, an edge metric calculated by dividing the area (m^2) by the perimeter (m), varied from 0.05 to 0.20 m^2/m 1949 and 0.17-0.06 in 2005. Smaller perimeter-area ratios reflect higher amounts of edge in a given meadow. There was no uniform trend in perimeter-area ratio change from 1949 to 2005. In some meadows, this ratio increased while in others it decreased.

Vegetation - Plant abundance and diversity

A total of 148 plant species was recorded in the 17 0.1-ha sample plots (1.7 ha) distributed throughout the five meadow complexes (Appendix A, Figures 4.2-4.6). Overall species richness varied from 49 to 21, with an average of 35 species per plot. Overall beta-diversity (average half changes) is 1.5, indicating a moderate level of change in composition from one plot to another (Table 4.3). Cover in most plots was dominated by a few species, and most species were rare and had low cover.

Plant sampling locations ranged from 1331-1557 m in elevation (Table 4.4). Slope varied between 9 and 70 degrees. The percent bare ground in a sample varied between 5 and 30 percent. Most samples were relatively close to a forest (0 to 50 m), but varied widely in their proximity to roads (0 to 920 m). Non-meadow samples were relatively close to meadows (10 and 80 m). The distance from a sample to the next nearest meadow varied from 0 to 288 m. Most aspect categories were represented, except for SSE (45-90 degrees). The sampled meadows ranged from 0.05 to 10.7 ha in 1949 and 0.04 to 4.7 ha in 2005 (Table 4.5). In most instances, meadow area decreased from 1949 to 2005. Most meadows also experienced fragmentation, and the combined area of all fragments in 2005 was smaller than the area of that meadow in 1949.

Richness and diversity were positively related to meadow size, but the largest meadows were not the most species-rich or diverse (Table 4.3). M1-x1a, one of the largest meadows in the study area, had the highest richness (49 species) and Simpson's diversity value (0.92). This meadow (M1-x1a) and three others (LOM-x1a, M2-21a, and CM-41a) are the largest meadows in their complexes (LOM=Lookout Mt., M1-Meadow 1, M2=Meadow 2, CM=Carpenter Mt.), but they are not always the richest or most diverse in their complexes. LOM-x1a (43 species, Lookout Mountain) and CM-x41a (43 species, Carpenter Mountain) have the highest richness in their complexes, but lower richness than other, smaller meadows in different complexes. M2-x21a (49 species) is the largest meadow in the Meadow 2 complex, but M2-x23a, a small meadow that was part of a much larger meadow in 1949 also has very high richness (47 species) (Table 4.3). The two sample units located in non-meadows in close proximity to meadows (M1-pt and FR-gs) have relatively low richness (30 and 24 species) and moderate diversity values.

Covariates predicting plant richness were investigated using bivariate plots and GAM models. Variables included in the model were elevation, slope, distance to road, distance to forest, 1949 meadow area, 1949 meadow perimeter, 1949 meadow perimeter-area ratio, 2005 meadow area, 2005 meadow perimeter, 2005 meadow perimeter-area ratio, 1949-2005 meadow area change, 1949-

2005 meadow perimeter change, fragmentation, 1949 complex area, 2005 complex meadow area, 2005 aggregated meadow fragments area, complex, aspect, and matrix. Plant species richness, diversity (Simpson's D and Shannon's H), and evenness (Simpson's E and Pielou's J) were plotted against 1949 meadow area, distance to road, distance to nearest meadow, and meadow complex area (Figures 4.7-4.10). Richness and diversity increase with 1949 meadow area in bivariate scatterplots (Figure 4.7). Evenness appears to be negatively related to 1949 area (Simpson's E) or not related to 1949 area (Pielou's J) (Figure 4.7). Richness is weakly negatively related, diversity is not related, and evenness is slightly positively related to distance from road, but relationships are weak (Figure 4.8). Richness is weakly negatively related to distance to nearest meadow, but diversity and evenness measures are weakly positively related to distance to nearest meadow (Figure 4.9). Richness, diversity, and evenness (Pielou's J) are weakly positively related to meadow complex area in 2005, but Simpson's E is weakly negatively related to meadow complex area (Figure 4.10).

Plant species richness in the 17 sample plots was best explained by meadow area in 1949, but distance to road (m) was also important in the best fit GAM model (GAM $R^2=0.76$), with meadow area in 1949 more significant ($p=0.0003$) than distance to road ($p=0.005$) (Figure 4.11). Plant species richness increased rapidly for meadows from 0 to 4 ha, and from 8 to 11 ha, but there was little change in richness between 4 and 8-ha meadows (Figure 4.11a). Richness also was negatively related to distance to road, with samples closer to roads having higher plant richness (Figure 4.11b). The influence of 1949 meadow area is much greater than distance to roads as shown by the GAM interactive plot in Figure 4.11c.

Vegetation was grouped into four taxonomically derived categories identified using hierarchical agglomerative cluster analysis (CLA) (Figure 4.12), as well as grouped according to complex, matrix, and area (Table 4.6). The four vegetation categories were significantly different based on MRPP analysis ($p=0.00000031$) with a high effect size ($A=0.693$) (Table 4.7). The grouping of the meadows in the CLA analysis is due to associations of major plants and appears related to meadow size, slope, and richness of plants, with some small but rich meadows included in cluster groups with larger meadows. Vegetation groups differed significantly according to the cluster analysis grouping, as well as area in 1949 area, area in 2005, and aspect, but not by complex or matrix (Table 4.7). The 1949 grouping is more significant with a higher effect than the 2005 area grouping, and both are more significant and effective groupings than aspect. Some indicator species are common regardless which grouping variable is used, such as *Vicia americana*, *Eriophyllum lanatum*, *Potentilla arguta*, and *Rumex acetosella*. *Vicia americana*, an indicator species for vegetation categories based on meadow area in 1949 and 2005, as well as categories based on aspect, is a good indicator of large meadows that

generally face west-southwest. *Eriophyllum lanatum*, *Potentilla arguta*, and *Rumex acetosella* are all indicators for large meadows (1949 and 2005 area groups) and cluster analysis group 1.

Plant abundance and diversity also were explained by meadow area in 1949 in the three-dimensional NMS ordination (Figure 4.13). Plant abundance and diversity also were related to slope, distance to forest, distance to nearest meadow, 2005 complex area, and 2005 aggregated fragment area (NMS final stress 7.15262, final instability 0.00000). NMS axes 1, 2, and 3 explained 58.0%, 12.4%, and 21.0% of the variance, respectively, for a total r^2 of 91.4%. Measures of the areas of the sampled meadows were the most strongly correlated with ordination axes but distance to road and slope also were important explanatory variables (Table 8). Meadow area in 1949, meadow area in 2005, aggregated fragment area, and 2005 complex area were all highly to moderately correlated with Axis 1, the dominant axis. Meadow area in 2005 was moderately correlated with Axis 3. Meadow area in 1949 was the most strongly correlated variable with vegetation community structure ($r^2=0.626$ with Axis 1, the dominant axis). Distance to forest and distance to the nearest meadow also were correlated with Axis 1 ($r^2=0.429$ and 0.255 , respectively). Slope was correlated with Axis 2 ($r^2=0.434$) (Table 4.8).

Samples that were grouped into the same clusters by the hierarchical agglomerative analysis plotted very close to one another in the NMS (Figure 4.13). Cluster 4 is very distinct and separated from the other three clusters in ordination space, but it is not associated with any indicator species (Table 4.7). Cluster 1, defined by indicator species *Festuca idahoensis*, *Eriophyllum lanatum*, *Castilleja sp.*, *Gilia capitata*, *Lathyrus torreyi*, *Lupinus caudatus*, *Potentilla arguta*, and *Rumex acetosella*, is moderately distinct. Plots belonging to clusters 2 and 3 are somewhat intermixed in the ordination (Figure 4.13), although Cluster 2 is defined by indicator species *Cirsium undulatum*, *Orthocarpus imbricatus*, and *Vaccinium membranaceum*, whereas Cluster 3 is defined by indicator species *Arctostaphylos nevadensis*, *Penstemon procerus*, and *Xerophyllum tenax*.

Although meadow area in 1949 explained much of the variation in the GAM model, the NMS ordination based on these groups did not produce well-defined clusters (Figure 4.14). Samples from meadows that were >3.5 ha in 1949 are all grouped together on the right third of the ordination. Samples from meadows that were 0.5-3.5 ha in 1949 grouped together, except one sample (CM-43x) that overlaps with the large meadow group. Samples from meadows that were <0.5 ha in 1949 mostly group together with the exception of BCM-x44, which groups more with the non-meadow group. *Eriophyllum lanatum*, *Potentilla arguta*, and *Rumex acetosella*, indicator species for CLA 1 and 1949 Group 1, are all positively correlated with Axis 1 of the NMR.

Moths

Overall Moth Abundance, Richness, and Diversity

A total of 4955 individuals from 248 moth species and 16 unidentified groups were recorded in the 98 samples from 63 locations over three years. Overall abundance, richness, Simpson's diversity index, Shannon's diversity index, and Pielou's evenness index for the 98 moth samples were calculated for all moths (Appendix C), hardwood-feeders (Appendix D), herb-feeders (Appendix E), and gymnosperm feeders (Appendix F). The number of individuals caught in a single sample varied from 2 to 185, with an average of 51 individuals. Overall species richness varied from 2 to 44 per sample, with an average of 19. Beta-diversity (average half-changes) was 3.3, indicating a high level of change in composition from one plot to another.

Moth Abundance

Most species were rare, with only a few hyper-abundant species dominating most assemblages (Figure 4.15). The 15 most abundant species account for 2450 individuals (49.4% of total abundance). Of the 264 species and unidentified groups, 62 species were represented by only one individual (singletons) and 30 species were represented by only two individuals (doubletons) (34.8% of total richness). Singletons and doubletons were predominantly hardwood, unknown guild, or herb feeders (Table 4.9). Most of the singletons and doubletons were captured in meadows of varying sizes, and very few were captured in forests, roads, or clearcuts (Table 4.10). Herb-feeder common moth species were the most abundant, followed closely by gymnosperm-feeders, and hardwood feeders (Table 4.11). Overall, hardwood-feeders were the most abundant ($n=1413$), followed closely by herb-feeders ($n=1488$), gymnosperm-feeders ($n=966$), unknown-feeders ($n=943$), and mixed-feeders ($n=45$).

Moth abundance peaked at approximately calendar day 210 for gymnosperm-, herb-, and hardwood-feeders (Figure 4.16). Abundances of herb-feeder moths was positively related, abundances of gymnosperm-feeder moths was negatively related, and abundances of hardwood-feeders were not related to meadow area in 1949 (Figure 4.17). Abundances of moths in all three guilds are negatively related to the perimeter-area ratio in 2005 (Figure 4.18). Abundances of gymnosperm- and hardwood-feeder moths are positively related to the decline in meadow area from 1949 to 2005 (Figure 4.19).

The relationships between abundance of moths and the two measures of isolation (distance to road and distance to nearest meadow) differ by guild. Abundance of herb-feeder moths is negatively related, but abundances of hardwood-feeder and gymnosperm-feeder moths are not related to distance to the nearest meadow (Figure 4.20). Abundance of moths of all three feeding

guilds is negatively related to distance from the road (Figure 4.21). Each guild also shows a different response to elevation; abundance of herb- and hardwood-feeder moths peaks at approximately 5000 m and abundance of gymnosperm feeder moths peaks around 4800 m (Figure 4.22). The three guilds also showed different responses to the percent cover of young conifer forest, with gymnosperm feeder abundance peaking at a higher percentage than hardwood-feeders, which peaked at a higher percentage than herb-feeders (Figure 4.23).

Samples with the highest abundance of moths, m2x21ae1 (185 individuals) and m221afF2 (159 individuals), were obtained in semi-wooded or forested locations (Figures 4.16-4.23). Samples with the highest abundance of hardwood-feeder moths also were semi-wooded edge environments. These samples were frsa1 (51 individuals), frsgs1 (44 individuals), m1asa2 (43 individuals), bsa1 (42 individuals), and m2x21ae1 (42 individuals). Three of these sample locations occur on relatively flat saddles between large meadows (frsa1, m1asa1, bsa1); one is the forest/meadow edge of a large meadow (m2x21ae1); and one is a semi-open, rocky location (frgs1). The sample with the highest abundance of herb-feeder moths is a semi-wooded saddle locality (bsa1, 72 individuals). The samples with the next highest abundance of herb-feeder moths (cx41a1, m2x21a1, m1x1au1, and m2x23c1 with 62, 58, 54, and 48 individuals, respectively) are all meadows, and two of these (m1-x1a and m2-x21a) are the largest meadows in Meadow 1 and Meadow 2 complexes. The five most abundant samples for gymnosperm-feeders (m2x21ae1, bx35a1, cx282, m221afF2, and bx311 with 75, 71, 61, 52, and 46 individuals, respectively) are also located in forested, semi-wooded edge, or small meadow environments (Figures 4.15-4.23).

Moth Richness

A total of 248 moth species and 16 unidentified groups were recorded in the 98 samples from 63 locations over three years. Overall species richness varied from 2 to 44 per sample, with an average of 19 species (Appendix C). Richness was highest for hardwood-feeder moth species (113 species), then herb-feeder moths (67 species), then unknown-feeder moths (53 species), then gymnosperm-feeder moths (24 species), then mixed-feeder moths (7 species).

In bivariate plots, relationships of richness of moth species to environmental covariates differed among feeding guilds. Bivariate relationships existed for at least one of the three guilds with calendar day, meadow area, perimeter-area ratio, distance from roads or nearest meadow, elevation, and shrub cover (Figures 4.24-4.31). Richness of gymnosperm- and hardwood-feeder moths peaks at around calendar day 210, but herb-feeders peak at around 195, nearly two weeks earlier (Figure 4.24). The relationship of richness to measures of meadow area (1949 meadow area, 2005 meadow perimeter-area ratio, and 1949-2005 meadow area change) is similar for all three guilds. Moth

richness and diversity is not consistently related to 1949 meadow area (Figure 4.25), negatively related to perimeter-area ratio in 2005 (Figure 4.26), and negatively related to change in meadow area from 1949 to 2005. The three feeding guilds of moths respond differently to the two isolation measurements (distance to road and distance to nearest meadow). Richness was weakly negatively related to distance from roads all three guilds (Figure 4.29). In contrast, richness of gymnosperm-feeder moths and hardwood-feeder moths were not related, but richness of herb-feeder moths was negatively related to distance to nearest meadow (Figure 4.28). Richness of hardwood and herb-feeder moths was positively related, but richness of gymnosperm-feeder moths was negatively related to elevation (Figure 30). Richness of gymnosperm-feeder moths was negatively related, richness of hardwood-feeder moths was positively related, and richness of herb-feeder moths was not related to percent cover of shrubs (Figure 4.31).

Richness of all moth species, and hardwood species, was highest in semi-wooded or forest sites, which also tend to have high plant richness. The sample with the highest richness of moth species (m1asa2, 46 species) was obtained in a semi-wooded saddle near meadow m1-x1a, which had the highest richness of plant species. Samples with the next highest values of moth species richness, m221afF2 (44 species) and frgs1 (42 species), also were in semi-wooded locations or forests near meadows or semi-open areas. Of the moth samples obtained in meadows, the sample with the highest richness (lx1a4, 40 species) was obtained in the largest meadow on Lookout Mountain. Patterns of richness of hardwood-feeder moths may be responsible for these trends; three samples with the highest richness of hardwood-feeder moths are in semi-wooded or forested locations (frgs1 (23 hardwood-feeder species), miasa2 (19 species), and b44x43f1 (16 species)).

Richness of herb-feeder moth species are highest in large to medium sized meadows. Of the samples in meadows, lx1a4 (19 hardwood-feeder species) has the highest richness of hardwood-feeder moths, as well as the highest moth species richness overall. In contrast, patterns of richness of herb-feeder moth species are not related to patterns of richness of all moth species. Samples with the highest richness of herb-feeder moths are all located in meadows [(m2x21a1 (18 herb-feeder species), bx311 (15 species), m2x21ae1 (14 species), lx1a4 (13 species), and lx1b1 (12 species)]. However, one sample with high herb-feeder moth species richness is located on a meadow edge (m2x21ae1, 14 herb-feeder species), and two samples [m221afF2 (12 herb-feeder moth species) and bsa1 (11 species)], are in forested or semi-wooded saddle locations.

Richness of gymnosperm feeder moth species is highest in forest, semi-wooded areas, and small meadows. The samples with the highest richness of gymnosperm-feeder moth species [cx28e1 (10 gymnosperm-feeder species), cx28f1 (9 species), cx282 (8 species), cx41c1 (8 species), and

m2x21ae1 (8 species)] are located in forested, semi-wooded edge, and small meadows environments. Four of these samples with highest richness of gymnosperm-feeder moth species are located in the Carpenter Mt. complex.

Models Explaining Feeding Guild Abundance and Richness

Overall abundance and richness patterns revealed that, depending upon the feeding guild, different environmental variables were important factors in determining richness and abundance. In the GAM models, calendar day is the only variable included in all of the best-fit models (Table 4.12). All best-fit models also include some measure of meadow area. Best-fit models for richness and abundance of herb feeder moth species include meadow area in 1949 meadow (Table 4.12, Figure 4.32). Best-fit models for richness and abundance of hardwood feeder moth species include 2005 meadow perimeter-area ratios. Best-fit models for richness and abundance of gymnosperm feeder moth species include the change in meadow area from 1949 to 2005.

Moth Community Structure

Although moth community structure was explained by several grouping variables, tests did not reveal consistent groups of moth species. Moth community structure was explained by several grouping variables (meadow area in 1949 and 2005; meadow complex area; matrix; calendar date/sample period; and two sets of vegetation variables) (Table 4.13). Although moth community structure was significantly explained by all eight of the grouping variables ($p < 0.05$), most have little biological relevance ($A < 0.1$). Sample period (two-week groups of calendar dates) has largest effect size ($A = 0.252$). Vegetation group and 2005 area group are the only two other variables that have moderate biological relevance, based on the A-value. This lack of consistent explanatory power also is evident in the indicator species analysis. Although both sample period and vegetation group 1 have multiple indicator species with moderate to high indicator values, the indicator species are different in the two analyses.

The community structure of all moth species was strongly related to calendar day based on two-dimensional NMS ordination (Figure 4.33) (NMS final stress 10.75507, final instability 0.00000). NMS axes 1 and 2 explained 31.6% and 62.9% of the variance, for a total r^2 of 94.5%. Table 4.14 lists the Pearson correlations of the environmental variables with the ordination axes. Of the 24 environmental variables assessed for correlations with axes 1 and 2, Calendar day ($R^2 = 0.667$ with Axis 1) was most highly correlated with moth richness and abundance of the 24 environmental variables tested.

The community structure of herb-feeder moth species also was strongly related to calendar day, as well as distance to forest, and percent road, based on two-dimensional NMS ordination (NMS

final stress 9.87649, final instability 0.00000) (Figure 4.34). NMS axes 1, 2, and 3 explained 35.0%, 39.8%, and 19.5% of the variance, for a total r^2 of 94.4%. Table 4.15 lists the Pearson correlations of the environmental variables with the ordination axes. Calendar day was most highly correlated (with Axis 1), and distance to forest was next (with Axis 2) (Table 15).

Community structure of hardwood-feeder moth species also was strongly related to calendar day, based on two-dimensional NMS ordination (NMS final stress 11.87963, final instability 0.00000) (Figure 4.35). NMS axes 1 and 2 explained 40.5% and 51.7% of the variance, for a total r^2 of 92.2%. Table 4.16 lists the Pearson correlations of the environmental variables with the ordination axes. Calendar day was the most correlated (with Axis 2); no other environmental variable had an r^2 above 10% (Table 4.20).

The community structure of gymnosperm-feeder moth species also was strongly related to calendar day, based on two-dimensional NMS ordination (NMS final stress 14.74124, final instability 0.02741) (Figure 4.36). NMS axes 1 and 2 explained 54.0% and 38.1% of the variance, for a total r^2 of 92.1%. Table 4.17 lists Pearson correlations of the environmental variables with the ordination axes. Calendar day was the most correlated (with Axis 1), and slope is also correlated with Axis 1.

DISCUSSION

Previous research has demonstrated that meadows in the Oregon Cascades have been contracting for approximately 200 years (Miller and Halpern 1998, Takaoka and Swanson 2008, Rice 2009). In the HJA, meadows have contracted in size by nearly half (45.3%) between 1949-2005.

Meadows are not contracting at equivalent rates in all parts of the landscape; it is unclear why different meadows and meadow complexes are contracting at different rates. The largest meadow complexes in the HJA in 1949, Lookout Mt. and Carpenter Mt., had contracted the most by 2005 (55.7 and 66.4%, respectively). In contrast, the complex with the largest single meadow (m1-x1a in Meadow 1 complex), only contracted by 27.5%, and the Meadow 2 complex contracted by only 2.8%. Possible causes of meadow contraction include cessation of grazing, changes in climate, and fire suppression (Vale 1981; Miller and Halpern 1998; Takaoka and Swanson 2008). Once trees have started colonizing a meadow, biotic interactions between trees and herbs appear to become the dominant pathway for further colonization (Haugo and Halpern 2007; Lang and Halpern 2007; Halpern et al. 2010). Many of these studies, though, have taken place in relatively flat subalpine meadows which are potentially quite different than the meadows in this study.

The meadows in this study and perhaps in most of the western Cascades probably were burned regularly by Native Americans prior to approximately 1800 (Chapter 2, this dissertation). The

cessation of burning therefore could be a major factor explaining the contraction of meadows in the HJ Andrews. Moreover, if some meadows, such as Carpenter and Lookout Mountains, had experienced more intensive use of fire by pre-historic peoples, the cessation of regular burning could explain differential rates of meadow contraction. The differential rates of meadow contraction could have major implications for management strategies designed to conserve these rare habitats, as some would require more immediate attention than others.

The meadow plant communities described in this study are similar but not identical to some previously defined montane meadow communities. The meadows analyzed here generally fall into four categories of meadow plant communities defined by Hickman (1976): *Rubus parviflorus*/*Pteridium aquilinum*, *Bromus carinatus*/*Rudbeckia occidentalis*, *Gilia aggregate*/*Polygonum douglasii*/*Eriogonum nudum*, and *Eriophyllum lanatum*/*Castilleja hispida*/*Sedum oregonense*, with some mixing. Hickman (1976) separated community types based on landscape features including soils, slope, and aspect, whereas this analysis derived communities from species co-occurrences and community distance. The community groups identified in this study also appear to roughly correspond to communities described by Halpern et al. (1984) for the *Festuca idahoensis*/*Agrostis diogoensis*, *Eriophyllum lanatum*/*Giliacapitata*, and *Penstemon procerus*/*Sanicula graveolens* communities found on upper ridges in the western portion of the Three Sisters Wilderness Area and surrounding area. Halpern et al. (1984) noted that the *Festuca idahoensis*/*Agrostis diogoensis* community was very common on the eastern ridges of the HJA but not in the High Cascades. Halpern et al. (1984) distinguished communities on the basis of present-day environmental conditions such as soil depth, slope, and moisture, whereas communities in this analysis were distinguished on the basis of present-day and past meadow size. *Eriophyllum lanatum* and *Festuca idahoensis* were considered as dominants of two different communities by Halpern et al. (1984), but these two species are indicator species for a single vegetation category (CLA category 1) in this analysis, *Penstemon procerus*, an indicator for CLA group 3, is considered a dominant of a third Halpern et al. (1984) community. Because there is a moderate degree of mixing among some meadow plant communities (Halpern et al. 1984), differences in indicator species are probably not significant.

Generally, larger meadows have higher herb and grass richness. The richness of herbaceous plants and grasses in meadows in the western Cascades is most predicted by the area of the meadow in 1949, and less correlated with meadow area in 2005. Lindborg (2006) and Helm et al. (2006) also found that semi-natural agricultural grasslands in northern Europe had a legacy effect, with grassland richness largely explained by the size of the grassland decades prior to the date of the study. In

contrast, Adrians et al. (2006), found no evidence of an extinction debt in calcareous grassland remnants in Belgium.

This study also found that meadow plant richness is secondarily predicted by the distance from the meadow to a road and by the total area of meadows in a given complex in 1949. Proximity to a road may assist in seed dispersal along roadways. On the other hand, higher diversity near roads may be a legacy of past high diversity along trails formerly used by pre-historic peoples that then were utilized by Europeans and became roads (see Chapter 2, this dissertation).

Meadow community structure also is correlated with distance to the nearest neighboring meadow. Near neighbors are better able to exchange dispersing seed, and they also may be fragments of previously connected larger meadows, leading to high similarity. In contrast, Adrians et al. (2006) concluded that isolation did not affect meadow plant communities. In this study, meadow area in 1949 was negatively related to distance to nearest meadow, so the effect of meadow size and distance to nearest neighbor meadow may be somewhat confounded.

Excluding investigations of forest pests (gypsy moth, Douglas-fir tussock moth, western spruce budworm moth), very little research has been conducted on moth communities in western Oregon, including the Cascade Range. Hammond and Miller (1998) described the overall distribution of moths in the western Cascades, grouped moth species by feeding-guilds, and compared moth species of the western Cascades to those in two other forested regions – eastern Oregon and West Virginia. Miller et al. (2003) discuss the distribution and functional role of rare and uncommon moths in the HJA. Ober and Hayes (2010) investigated moth community structure and richness in riparian areas in the Oregon Coast Range; they showed that elevation influenced richness more than any other variable, and forest canopy cover controlled species dominance and diversity. Miller (unpublished data) has also sampled multiple localities in western Oregon, including the HJA, the Umpqua River watershed, and the Rogue River watershed.

In the western Cascades, hardwood-feeder moth species have the highest richness, but conifer-feeders are the most abundant in the landscape (Hammond and Miller 1998; Ch 3, this dissertation). However, this study found that herb feeder and hardwood feeder moth species also were very abundant in montane meadows. In this study, a non-native herb feeder, *Noctua pronuba*, was the most abundant species. After *Noctua pronuba*, the most abundant species include hardwood-feeders (*Eurois astricta*, *Polia purpurissata*, and *Synedoida adumbrata*), gymnosperm (*Enypia packardata*, *Pero occidentalis/behrensaria*, *Semiothisa signaria*, and *Enypia venata*), herb-feeders (*Euxoa divergens*, *Parabagrotis exertistigma*, and *Leucania insueta*), and one moth whose feeding

guild is unknown (*Perizoma grandis*). *Perizoma grandis* was the most common moth found by Ober and Hayes (2010) in the Oregon Coast Range.

In this study, calendar day (a fine scale measure of seasonality) explained most variation in moth abundance, richness, and community structure, regardless of feeding-guild. Temporal species turnover in moths in this study is so high that the beta-diversity between early summer and late autumn is higher than the beta-diversity between two very different habitats, such as large meadow and old growth conifer forest, sampled at the same time. Temporal turnover of moth species exceeded spatial turnover in eastern deciduous woodlands of North America (Summerville and Crist 2004) and in the forests of northern Japan (Hirao et al. 2007). Because moth adults are so short-lived (approximately two weeks on average) and adapted to a specific temperature threshold (Ch 3, this dissertation; Miller and Highland, unpublished), multiple species may utilize the same habitat and avoid competition for resources by temporal partitioning.

Although richness, abundance, and community structure varied primarily by calendar day for all three moth feeding guilds, the three guilds responded differently to meadow size and habitat type variables. Some studies have investigated the role of feeding guild in distributions of moth pests (e.g. Fraser and Lawton 2008). However, few studies have investigated ecological relationships among multiple moth feeding guilds and habitat characteristics (but see Summerville and Crist 2004). The richness of woody-plant feeder moths species was related to the size of relict forest patches in eastern deciduous forests (Summerville and Crist 2004), and a subfamily of mostly herb-feeder moths was associated with rare meadow habitats in the Andrews Forest (Miller et al. 2003). Hammond and Miller (1998) investigated the relationship of different feeding guilds in three forested landscapes, and found that the richnesses and abundances of moths of the different feeding guilds varied from landscape to landscape and that moths could be useful for assessing land management strategies.

This study provides evidence for extinction debt affecting the diversity of herb-feeder, but not hardwood-feeder or gymnosperm-feeder moth species in montane meadows of the Oregon Cascades. In our study, meadow area in 1949 and elevation explain herb-feeder moth species richness more than any other variables, aside from calendar day. Meadow area in 2005 was also included in these models, but it explained much less variation. Herb-feeding moths account for most of the common moth species of the upper elevation ridges in the Andrews Forest. These common herb-feeders include *Noctua pronuba*, *Euxoa divergens*, *Parabagrotis exertistigma*, and *Leucania insueta*. *Noctua pronuba*, the most common moth of the upper elevations, is a non-native moth from Eurasia. The samples with the highest herb-feeding moth richness are mostly large meadows, which were larger in 1949, including the largest meadows in the Lookout Mt., Meadow 1, and Meadow 2

complexes. Richness of butterflies and moths was related to the past as well as the present-day area of declining calcareous grasslands in Estonia, but in these models current and past grassland area were nearly equally important in explaining current species richness of habitat specialists (Sang et al 2010).

Connectivity of meadow habitat as well as meadow size influences abundance and diversity of herb-feeder moth species in the high-elevation meadows of the Andrews Forest. The richness of herb-feeder moth species decreased with distance from roads. Roads in the study area are semi-open habitats within otherwise forested environments with herbaceous plants growing on roadsides, and they connect otherwise fragmented or isolated meadows. In seasonally dry sites, roadside plants may exploit increased moisture availability from roadside runoff (Donaldson and Bennett 2004). Thus, roads provide both habitat and patch connectivity for herb-feeding moths. After calendar day, herb-feeder community structure is most related to distance to forest. However, some forested and semi-wooded samples had high herb-feeder richness, indicating that herb-feeder moth species will fly through partially wooded areas. These results suggest that tree invasion and fragmentation of meadows is responsible for the decline in herb-feeder moth species in montane meadows of the Andrews Forest.

In contrast to herb-feeder moth species, richness and abundance of hardwood-feeder moth species are influenced by meadow perimeter-area ratio in 2005 in addition to calendar day. Hardwood feeding moths are the most species-rich moth feeding guild in the study area. Hardwood-feeding moth species include three of common species (*Eurois astricta*, *Polia purpurissata*, and *Synedoida adumbrata*), but many of hardwood-feeder moth species are very rare represented by only one or two individuals. Unlike herb-feeders, hardwood feeders are responding to contemporary, not previous landscape configuration. Perimeter-area ratio of meadows is an indication of edges, with a higher ratio an indication of less edge. Edges are more likely to contain hardwood shrubs than other habitats, thus providing probably host plant habitat for hardwood-feeder moth species.

In contrast to both herb- and hardwood-feeder moth species, richness, abundance, and community structure of gymnosperm-feeder moths, was most influenced by the change in meadow area from 1949-2005 (in addition to calendar day). Meadow area decreased from 1949-2005 as conifer trees invaded the study area (see Chapter 2, this dissertation), providing expanded host plant habitat for gymnosperm-feeding moths.

Richness and abundance of hardwood- and gymnosperm-feeder moth species also is positively related to proximity to roads. Other studies have noted a positive association between moth and butterfly communities and roads with semi-natural grassland edges (Saarinen et al. 2005, Kuussaari et al. 2007). Where roads pass through conifer forest they create edges, and they may

increase the abundance of hardwood shrubs and associated host plants for hardwood-feeder moth species. It is unclear why gymnosperm-feeders would respond positively to the presence of roads, unless roads allow for the movement of species from one forested area to another more easily than forested environments allow. Alternatively, roads were placed in saddle locations, which are typically high in diversity. The positive influence of roads on moth richness and abundance could potentially be a result of the placement of roads.

Patterns of moth communities, richness, and abundance in the high elevation ridges of the HJA are less well defined than those of plants, because of high temporal turnover of moth species, differential responses among moth feeder guilds, and the fact that adult moths, not caterpillars, were sampled. Overall, moths are highly structured by season: calendar day explains far more variation than any other variable in moth community structure, richness, and abundance of all three moth feeder guilds. Moreover, the three moth feeding guilds respond very differently to past and current landscape configuration, so changes in moth community structure are obscured when guilds are combined in an analysis. Moreover, the analysis was based on sampling of adult moths, which are highly vagile, and may be captured flying through an area that would not support them during their caterpillar phase.

CONCLUSIONS

This study showed that species and groups of species respond to changes in landscape configurations in different ways and at different rates. Richness and abundance of herbaceous plants, grasses, and herb-feeding moths associated with contracting meadows in the HJ Andrews Forest was more closely related to the configuration of the landscape in 1949 than to the contemporary landscape. In contrast, richness and abundance of moths that are reliant on non-meadow host plants, such as hardwood shrubs and conifer (gymnosperm) trees, were more closely related to characteristics of the present-day landscape.

Plants and insects reliant on contracting meadow habitats in the Andrews Forest appear to be subject to extinction debt. Over the past half-century, as meadow habitats have decreased in size and become more isolated, the richness, abundance, and community structure of plants and moths in that habitat did not respond immediately, but rather have persisted for multiple decades. Moth communities appeared to have responded more rapidly than plant communities, but moth community response to changing meadow habitat may be obscured by complexities of moth community diversity, including high turnover of moths within the spring to autumn, differences in responses among feeding

guilds, and the fact that the study was based on sampling of adult moths, which are less likely to be found near host plants than caterpillars.

This study provides evidence for compensatory dynamics among groups of moth species associated with meadow, hardwood shrub, and conifer forest habitats in high-elevation areas of the Andrews Forest. Although meadow-dependent (herb-feeder) moth species appear to have declined with meadow contraction over the past 60 years, richness and abundances of hardwood and gymnosperm feeders, whose habitats expand with the contraction of meadows, appear to have increased. In contrast, Houlahan et al (2007) found evidence for synchronous changes in populations in response to external drivers such as temperature and moisture, rather than compensatory dynamics. In this study, the reciprocal relationships among groups of moth species were only evident in conjunction with a detailed study of changes in various habitat types and their relationships with moth host plant feeding guilds.

Paradoxically, the construction of roads in the high-elevation ridges of the Andrews Forest appears to have helped preserve habitat connectivity and counteract the loss of meadow plant and moth species as a result of meadow contraction. Roads apparently had a positive effect on herbaceous plants and herb-feeder moth species because they created and connected open meadow habitats, or because they were constructed in, and therefore maintained, highly diverse open habitats, or both. Moreover, meadow contraction rates, and implied rates of decline of associated moth and plant species, differed between the meadow complexes. The differential rates of meadow decline may be related to patterns of prehistoric vegetation management, which may have been more intensive in some portions of the high ridges of the Andrews Forest than in others (see Chapter 2, this dissertation). Thus, moth and plant species response to recent meadow contraction is not a simple function of meadow area, but also depends on many other factors including moth-plant interactions, historical legacies, and counteracting factors, such as connectivity provided by roads.

Meadows account for a very small part of the landscape of the western Cascades, but contribute a great deal of biodiversity. Herb and hardwood feeding moths are positively influenced by the presence of meadows, whether through the plants in the interior or edge of the meadows. These two feeding guilds account for the majority of rare moth species in the western Cascades (Ch 2, this dissertation). If managers wish to preserve rare species and landscape biodiversity, it will be necessary to actively manage meadows to increase their sizes and connectivities. Active conservation measures should be undertaken soon, because some rare moths and plants have persisted despite recent declines in meadow area, but these species are likely to go extinct in the future unless meadow area increases.

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Table 4. 1. Description of the statistical techniques utilized in this study, including their purpose, form of output, and measure of significance.

Technique	Abbreviation	Purpose	Form of Output	Measure of Significance
Hierarchical Agglomerative Cluster Analysis	CLA	Clustering	Dendrogram	Analyze with MRPP for significance
Multi-Response Permutation Procedure	MRPP	Group Comparison	Significance of difference between groups	A statistic (effect size); p-value
Indicator Species Analysis	ISA	Identifies species that are representative of groups	Species list with values	Indicator value (percent); p-value
Nonmetric Multidimensional Scaling	NMS	Ordination	Ordination plot; correlation tables	Correlation (R^2)
Generalized Additive Model	GAM	Describe nonlinear and linear relationships	Model; plot	p-value

Table 4. 2. Summary of the area of meadows lost between 1949 and 2005, in the five meadow complexes at the HJ Andrews Forest, Oregon.

<i>Complex</i> Meadow Type	1949 Number	1949 Area (ha)	2005 Number	2005 Area (ha)	Total Loss (Number)	Total Area Change (ha)	Total Change (Percent)	Original Remaining	Number of Fragments
<i>Carpenter Mt</i>									
Mesic	5	3.8	5	2.2	0	-1.6	-42.1	5	5
Xeric	127	37.1	58	11.6	69	-25.5	-68.7	31	58
Wet	0	0.0	0	0.0	0	0.0	0.0	0	0
Total	132	40.8	63	13.7	96	-27.1	-66.4	36	63
<i>BCM</i>									
Mesic	0	0.0	1	0.2	0	0.2	100.0	0	0
Xeric	54	13.9	39	10.0	29	-3.9	-28.1	25	39
Wet	0	0.0	0	0.0	0	0.0	0.0	0	0
Total	54	13.9	40	10.2	29	-3.7	-26.6	25	39
<i>Meadow 1</i>									
Mesic	9	3.8	5	2.3	4	-1.5	-39.5	5	5
Xeric	44	18.0	39	13.5	21	-4.5	-25.0	23	39
Wet	0	0.0	0	0.0	0	0.0	0.0	0	0
Total	53	21.8	44	15.8	25	-6.0	-27.5	28	44
<i>Meadow 2</i>									
Mesic	1	0.3	2	0.4	0	0.1	-33.3	1	1
Xeric	43	17.6	30	16.9	36	-0.7	-4.0	7	32
Wet	0	0.0	0	0.0	0	0.0	0.0	0	0
Total	44	17.8	32	17.3	36	-0.5	-2.8	8	33
<i>Lookout Mt</i>									
Mesic	25	4.6	10	1.5	17	-3.1	-67.4	10	10
Xeric	108	45.7	70	20.9	73	-24.8	-54.3	35	70
Wet	3	1.2	2	0.4	1	-0.8	-66.7	2	2
Total	136	51.5	82	22.8	91	-28.7	-55.7	45	80
<i>Total (All Complexes)</i>									
Mesic	40	12.5	23	6.6	21	-5.9	-47.2	21	21
Xeric	376	132.3	236	72.9	255	-59.4	-44.9	121	243
Wet	3	1.2	2	0.4	1	-0.8	-66.7	2	2
Total	419	145.8	261	79.8	277	-66.0	-45.3	144	266

Table 4. 3. Meadow area, richness (148 total species), Simpson's Diversity Index, Shannon's Diversity Index, and Pielou's Evenness Index for the 17 vegetation sample plots. For the sample names, CM=Carpenter Mountain, BCM=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, LOM=Lookout Mountain.

Vegetation Sample	2005 Meadow Area (ha)	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
BCM-x32b	0.974	41	0.89	2.71	0.71
BCM-x44	0.049	21	0.81	2.05	0.67
BCM-x45a	0.597	26	0.89	2.55	0.78
CM-x28	0.387	32	0.88	2.41	0.69
CM-X41a	2.521	43	0.85	2.54	0.68
CM-x43	0.725	36	0.89	2.75	0.77
CM-x44c	0.259	23	0.85	2.28	0.73
FR-gs	0	24	0.88	2.35	0.74
LOM-x1a	3.863	43	0.91	2.85	0.76
LOM-x4a	1.679	33	0.89	2.52	0.72
LOM-x4c	0.094	32	0.78	2.04	0.59
M1-pt	0	30	0.88	2.55	0.75
M1-x1a	4.742	49	0.92	2.97	0.76
M2-x21a	4.440	38	0.89	2.74	0.75
M2-x21f	0.276	40	0.86	2.41	0.65
M2-x23a	0.095	47	0.91	2.79	0.73
M2-x23c	0.626	41	0.87	2.54	0.68

Table 4. 4. Environmental variables associated with the vegetation sample units. For the sample names, CM=Carpenter Mountain, BCM=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, LOM=Lookout Mountain.

Sample Name	Elevation (m)	Aspect ¹	Slope (degrees)	Percent Bare Ground	Distance to Road (m)	Distance to Forest (m)	Distance to Opening (m)	Distance to Nearest Meadow (m)
BCM-x32b	1557	4	64	20.00	325	20	0	5
BCM-x44	1433	3	57	18.00	175	10	0	60
BCM-x45a	1402	3	62	20.36	125	20	0	60
CM-x28	1341	6	39	22.94	10	15	0	288
CM-X41a	1538	5	60	29.00	180	25	0	9
CM-x43	1331	8	40	28.00	530	30	0	94
CM-x44c	1353	1	39	13.00	660	10	0	16
FR-gs	1526	3	28	5.67	0	0	80	256
LOM-x1a	1474	6	70	17.67	920	30	0	18
LOM-x4a	1516	1	9	16.67	775	28	0	20
LOM-x4c	1510	6	31	19.30	735	10	0	15
M1-pt	1450	6	29	30.33	0	10	10	30
M1-x1a	1505	5	57	20.00	135	35	0	9
M2-x21a	1492	5	56	27.14	100	50	0	6
M2-x21f	1448	6	9	24.00	20	0	30	2
M2-x23a	1489	5	44	13.33	120	10	0	46
M2-x23c	1450	5	67	24.64	200	10	0	12

¹ Aspect Categories: 1=1-45 degrees, 2=46-90 degrees, 3=91-135 degrees, 4=136-180 degrees, 5=181-225 degrees, 6=226-270 degrees, 7=271-315 degrees, 8=316-360 degrees.

Table 4. 5. Size and shape metrics of the meadows in which S-W plots were placed. For the sample names, CM=Carpenter Mountain, BCM=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, LOM=Lookout Mountain.

Sample Name	2005 Meadow Area (ha)	2005 Meadow Perimeter-Area Ratio	1949 Meadow Area (ha)	1949 Meadow Perimeter-Area Ratio	Fragmentation	Aggregated Fragment Area (ha)	1949 Complex Area (ha)	2005 Complex Area (ha)
BCM-x32b	1.0	0.10	2.0	0.07	1.00	1.3	13.9	10.1
BCM-x44	0.0	0.17	0.1	0.19	0.00	0.0	13.9	10.1
BCM-x45a	0.6	0.07	0.6	0.11	3.24	0.6	13.9	10.1
CM-x28	0.4	0.15	0.1	0.20	0.00	0.4	40.8	13.7
CM-X41a	2.5	0.06	7.9	0.08	0.38	3.9	40.8	13.7
CM-x43	0.7	0.07	2.2	0.05	0.00	0.0	40.8	13.7
CM-x44c	0.3	0.08	1.4	0.06	2.10	0.4	40.8	13.7
FR-gs	0.0	0.00	0.0	0.00	0.00	0.0	0.0	0.0
LOM-x1a	3.9	0.06	10.7	0.08	1.21	6.7	51.5	22.8
LOM-x4a	1.7	0.08	3.4	0.11	1.21	6.7	51.5	22.8
LOM-x4c	0.1	0.15	3.4	0.11	0.87	2.1	51.5	22.8
M1-pt	0.0	0.00	0.0	0.00	0.00	0.0	21.8	17.3
M1-x1a	4.7	0.07	8.4	0.04	0.59	6.6	21.8	17.3
M2-x21a	4.4	0.07	8.3	0.06	0.72	6.4	17.8	17.6
M2-x21f	0.3	0.14	8.3	0.06	0.72	6.4	17.8	17.6
M2-x23a	0.1	0.15	3.1	0.09	2.27	1.9	17.8	17.6
M2-x23c	0.6	0.07	3.1	0.09	2.27	1.9	17.8	17.6

Table 4. 6. Categorical variables used in the analysis of the vegetation plots. For the sample names, CM=Carpenter Mountain, BCM=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, LOM=Lookout Mountain.

Sample Name	Complex	Matrix	2005 Group ¹	1949 Group ²	CLA Group
BCM-x32b	BCM	Forest	2	2	2
BCM-x44	BCM	Forest	1	3	4
BCM-x45a	BCM	Forest	2	3	4
CM-x28	Carpenter Mt	Forest, Road	2	3	4
CM-X41a	Carpenter Mt	Forest, Road	3	1	1
CM-x43	Carpenter Mt	Forest	2	2	1
CM-x44c	Carpenter Mt	Forest	1	3	3
FR-gs	Frissel Ridge	Forest, Road	4	4	4
LOM-x1a	Lookout Mt	Forest, Shrub	3	1	1
LOM-x4a	Lookout Mt	Forest	2	2	3
LOM-x4c	Lookout Mt	Forest	1	2	3
M1-pt	Meadow 1	Forest, Road	4	4	4
M1-x1a	Meadow 1	Forest, Road	3	1	1
M2-x21a	Meadow 2	Forest, Road	3	1	1
M2-x21f	Meadow 2	Forest, Road	1	1	3
M2-x23a	Meadow 2	Forest	1	2	2
M2-x23c	Meadow 2	Forest	2	2	3

¹ 2005 Groups: 1=Meadow <0.5 ha, 2=Meadow 3.5-0.5 ha, 3=Meadow >3.5 ha, 4=Non-Meadow

² 1949 Groups: 1=Meadow >3.5 ha, 2=Meadow 3.5-0.5 ha, 3=Meadow <0.5 ha, 4=Non-Meadow

Table 4. 7. Results of four rank-transformed MRPP analyses based on vegetation communities defined from (1) hierarchical agglomerative cluster analysis, (2) 1949 area groups, (3) 2005 area groups, (4) aspect, (5) complex, and (6) matrix. Indicator species (including IV and p-value) for the two most significant grouping variables (CLA group and 1949 area group) found to be significant ($p < 0.05$) are shown for each analysis.

Grouping Variable	MRPP A	MRPP p	ISA Species	ISA Category	ISA IV	ISA p-value
CLA Group	0.693	0.00000031	<i>Castelleja sp.</i>	1	79.3	0.0220
			<i>Eriophyllum lanatum</i>	1	66.6	0.0122
			<i>Festuca idahoensis</i>	1	100.0	0.0078
			<i>Gilia capitata</i>	1	80.0	0.0302
			<i>Lathyrus torreyi</i>	1	99.8	0.0004
			<i>Lupinus caudatus</i>	1	77.1	0.0018
			<i>Potentilla arguta</i>	1	72.7	0.0146
			<i>Rumex acetosella</i>	1	68.7	0.0012
			<i>Cirsium undulatum</i>	2	71.1	0.0122
			<i>Orthocarpus imbricatus</i>	2	68.8	0.0176
			<i>Vaccinium membranaceum</i>	2	89.9	0.0012
			<i>Arctostaphylos nevadensis</i>	3	75.9	0.0054
			<i>Penstemon procerus</i>	3	71.4	0.0310
			<i>Tenax xerophyllum</i>	3	53.9	0.0222
1949 Area Group	0.368	0.00059753	<i>Bromus carinatus</i>	1	57.9	0.0298
			<i>Epilobium minutum</i>	1	67.1	0.0418
			<i>Eriophyllum lanatum</i>	1	70.9	0.0030
			<i>Mimulus dentate</i>	1	79.0	0.0190
			<i>Pteridium aquilerium</i>	1	60.0	0.0336
			<i>Rumex acetosella</i>	1	61.3	0.0074
			<i>Viola americana</i>	1	74.1	0.0334
			<i>Navarettia sp.</i>	1	69.1	0.0464
			<i>Potentilla arguta</i>	1	65.7	0.0298
			<i>Elymus glaucus</i>	2	67.1	0.0142
			<i>Abies amabilis</i>	4	62.7	0.0478
			<i>Pseudotsuga menzeseii</i>	4	62.1	0.0480
2005 Group	0.319	0.00190392				
Aspect	0.305	0.00544453				
Complex	-0.090	0.78916820				
Matrix	-0.045	0.85484206				

^aCluster Analysis (1,2,3,4); 1949 and 2005 Area Group (1=Meadow > 3.5 ha; 2= Meadow 3.5-0.5 ha; 3= Meadow <0.5 ha; 4=Non Meadow); Aspect (1=1-45°; 3=91-135°; 5=181-225°)

Table 4. 8. Pearson correlations of environmental variables with NMS axes for plants sampled in montane meadows of the HJ Andrews Forest. Bold font shows correlations > 0.25.

Environmental Variable	Axis 1 Pearson Correlation (r^2)	Axis 2 Pearson Correlation (r^2)	Axis 3 Pearson Correlation (r^2)
Elevation	0.028	0.002	0.013
2005 Meadow Area	0.436	0.049	0.260
2005 Meadow Perimeter-Area Ratio	0.004	0.052	0.035
1949 Meadow Area	0.626	0.006	0.112
1949 Meadow Perimeter-Area Ratio	0.028	0.010	0.000
Slope	0.065	0.434	0.433
Bare Ground	0.178	0.065	0.006
Aggregated Fragment Area	0.441	0.016	0.060
1949 Complex Area	0.115	0.042	0.000
2005 Complex Area	0.298	0.123	0.000
Fragmentation	0.002	0.000	0.087
Distance to Road	0.089	0.116	0.043
Distance to Forest	0.429	0.029	0.167
Distance to Opening	0.185	0.006	0.041
Distance to Nearest Meadow	0.255	0.027	0.047

Table 4.9. Richness and abundance of moth singletons and doubletons by feeding guild.

Feeding Guild	Species Number	Individual Abundance
Gymnosperm	4	6
Herb	18	22
Hardwood	41	56
Mix	2	3
Unknown	26	34

Table 4. 10. Numbers of species and abundance of singletons and doubletons of moths by habitat type.

Vegetation Type	Count	Abundance
Large Meadow (>3.5 ha)	14	26
Medium Meadow (3.5-0.5 ha)	9	27
Small Meadow (<0.5 ha)	15	32
Clearcut	1	3
Forest	9	19
Forest/Shrub	3	14
Road/Forest	4	5
Road/Shrub	5	10

Table 4. 11. Numbers of species and abundance of common moth species by feeding guild.

Feeding Guild	Species Number	Individual Abundance
Gymnosperm	4	773
Herb	8	919
Hardwood	6	591
Mix	0	0
Unknown	2	216

Table 4.12. Summary of the results of the GAM models of moth richness and abundance by feeding guild, including the total variance explained, deviance explained (GAM) and the variables included in the best fit models.

Subject	Statistical Method	R ² (Deviance Explained)	Variables in Best Fit Models
Herb Feeder Richness	GAM	36.8 (47.8)	Calendar Day, Elevation, 1949 Meadow Area (ha), Percent Shrub, Distance to Road, Vegetation Category 2
Herb Feeder Abundance	GAM	74 (83.8)	Calendar Day, Percent Young Forest, 1949 Meadow Area (ha), Elevation, Aspect, Complex
Hardwood Feeder Richness	GAM	55.6 (64)	Calendar Day, 2005 Meadow Perimeter-Area Ratio, Distance to Nearest Meadow, Percent Young Forest
Hardwood Feeder Abundance	GAM	69.5 (80.6)	Calendar Day, 2005 Meadow Perimeter-Area Ratio, Distance to Nearest Meadow, Distance to Open Vegetation, Percent Young Forest, Fragmentation, Matrix
Gymnosperm Feeder Richness	GAM	54.4 (53.8)	Calendar Day, 1949-2005 Meadow Area Change (ha), Slope
Gymnosperm Feeder Abundance	GAM	77.5 (83.5)	Calendar Day, 1949-2005 Meadow Area Change (ha), Elevation, Distance to Road, Distance to Open Vegetation, Percent Young Forest, Complex

Table 4.13. Relationships of moth diversity and abundance to sample period, vegetation group, meadow area in 2005, year, meadow complex area, meadow area in 1949, and matrix, based on MRPP and Indicator Species Analysis of the two most significant groups in each analysis.

Grouping Variable	MRPP A	MRPP p	ISA Species	ISA Category ^{1,2}	ISA IV	ISA p-value
Sample Period	0.251973	0.00000000	<i>Lasionycta</i>			
			<i>perplexa/subfuscata</i>	7.25	30.3	0.0116
			<i>Leucania insueta</i>	7.25	28.6	0.0168
			<i>Miselia variolata</i>	7.25	33.9	0.0032
			<i>Pero</i>			
			<i>occidentalis/behrensaria</i>	7.25	57.3	0.0002
			<i>Synaxis cervinaria</i>	7.25	27.8	0.0118
			<i>Achytonix praeacuta</i>	8.25	33.8	0.0026
			<i>Enypia venata</i>	8.25	33.9	0.0050
			<i>Eurois stricta</i>	8.25	39.8	0.0002
			<i>Spaelotis bicava</i>	8.75	25.9	0.0162
			<i>Euxoa declarata</i>	9.25	33.3	0.0004
			<i>Euxoa satis</i>	9.25	46.5	0.0006
			<i>Synaxis pallulata</i>	9.75	39.6	0.0010
Vegetation Group	0.110139	0.00000546	<i>Itame confederata</i>	1	40.4	0.0218
			<i>Eulithis destinata</i>	8	44.0	0.0104
			<i>Euxoa comosa</i>	8	35.2	0.0380
			<i>Euxoa terrena</i>	10	51.0	0.0100
			<i>Achytonix epipaschia</i>	11	41.8	0.0096
			<i>Leucania anteoclara</i>	11	35.4	0.0282
			<i>Oligia indirecta</i>	11	32.2	0.0450
			<i>Sabulodes edwardsata</i>	11	34.0	0.0396
2005 Area Group	0.10367	0.00000193				
Year	0.098033	0.00000000				
Complex	0.074701	0.00018760				
1949 Area Group	0.051084	0.00026540				
Matrix	0.039865	0.00413120				

¹Sample Period Categories: 7.25=Early July, 8.25=Early August, 8.75=Late August, 9.25=Early September, 9.75=Late September.

²Vegetation Group Categories: 1=Meadow >3.5 ha, 8=Wet Meadow, 10=Clearcut, 11=Edge.

Table 4. 14. Pearson correlations of environmental variables with NMS axes for for moths (all) sampled in montane meadows of the HJ Andrews Forest. Bold font shows correlations > 0.25.all samples.

Environmental Variable	Axis 1 Pearson Correlation (r ²)	Axis 2 Pearson Correlation (r ²)
Elevation	0.001	0.005
Calendar Day	0.266	0.568
2005 Meadow Area	0.011	0.036
2005 Meadow Perimeter-Area Ratio	0.012	0.039
1949 Meadow Area	0.009	0.057
1949 Meadow Perimeter-Area Ratio	0.000	0.039
1949-2005 Area Change	0.021	0.018
Slope	0.059	0.001
Aggregated Fragment Area	0.001	0.009
1949 Complex Area	0.049	0.038
2005 Complex Area	0.105	0.008
Fragmentation	0.001	0.009
Distance to Road	0.002	0.047
Distance to Forest	0.001	0.088
Distance to Opening	0.001	0.066
Distance to Nearest Meadow	0.029	0.000
Percent Mature/Old Growth Conifer Forest	0.011	0.005
Percent Young Conifer Forest	0.025	0.001
Percent Shrub	0.000	0.021
Percent Open Vegetation	0.000	0.016
Percent Road	0.006	0.039

Table 4. 15. Pearson correlations of environmental variables with NMS axes for for moths (herb feeders) sampled in montane meadows of the HJ Andrews Forest. Bold font shows correlations > 0.25.

Environmental Variable	Axis 1 Pearson Correlation (r^2)	Axis 2 Pearson Correlation (r^2)	Axis 3 Pearson Correlation (r^2)
Elevation	0.007	0.042	0.009
Calendar Day	0.002	0.167	0.278
2005 Meadow Area	0.000	0.060	0.051
2005 Meadow Perimeter-Area Ratio	0.000	0.045	0.026
1949 Meadow Area	0.003	0.022	0.034
1949 Meadow Perimeter-Area Ratio	0.000	0.061	0.001
1949-2005 Area Change	0.001	0.030	0.025
Slope	0.007	0.006	0.010
Aggregated Fragment Area	0.002	0.032	0.022
1949 Complex Area	0.018	0.032	0.000
2005 Complex Area	0.010	0.000	0.018
Fragmentation	0.082	0.039	0.000
Distance to Road	0.009	0.071	0.002
Distance to Forest	0.005	0.106	0.032
Distance to Opening	0.019	0.063	0.013
Distance to Nearest Meadow	0.000	0.004	0.015
Percent Mature/Old Growth Conifer Forest	0.002	0.001	0.017
Percent Young Conifer Forest	0.002	0.005	0.018
Percent Shrub	0.000	0.065	0.002
Percent Open Vegetation	0.005	0.053	0.047
Percent Road	0.043	0.080	0.024

Table 4. 16. Pearson correlations of environmental variables with NMS axes for moths (hardwood feeders) sampled in montaine meadows of the HJ Andrews Forest. Bold font shows correlations > 0.25..

Environmental Variable	Axis 1 Pearson Correlation (r^2)	Axis 2 Pearson Correlation (r^2)
Elevation	0.009	0.006
Calendar Day	0.034	0.409
2005 Meadow Area	0.002	0.002
2005 Meadow Perimeter-Area Ratio	0.000	0.017
1949 Meadow Area	0.011	0.010
1949 Meadow Perimeter-Area Ratio	0.018	0.011
1949-2005 Area Change	0.022	0.001
Slope	0.004	0.009
Aggregated Fragment Area	0.003	0.019
1949 Complex Area	0.004	0.040
2005 Complex Area	0.023	0.007
Fragmentation	0.001	0.000
Distance to Road	0.031	0.019
Distance to Forest	0.029	0.001
Distance to Opening	0.020	0.011
Distance to Nearest Meadow	0.029	0.008
Percent Mature/Old Growth Conifer Forest	0.004	0.010
Percent Young Conifer Forest	0.014	0.004
Percent Shrub	0.002	0.001
Percent Open Vegetation	0.001	0.014
Percent Road	0.031	0.003

Table 4.17. Pearson correlations of environmental variables with NMS axes for moths (gymnosperm-feeders) sampled in montane meadows of the HJ Andrews Forest. Bold font shows correlations > 0.25..

Environmental Variable	Axis 1 Pearson Correlation (r^2)	Axis 2 Pearson Correlation (r^2)
Elevation	0.016	0.040
Calendar Day	0.306	0.538
2005 Meadow Area	0.015	0.014
2005 Meadow Perimeter-Area Ratio	0.005	0.000
1949 Meadow Area	0.001	0.023
1949 Meadow Perimeter-Area Ratio	0.004	0.000
1949-2005 Area Change	0.011	0.008
Slope	0.113	0.090
Aggregated Fragment Area	0.034	0.042
1949 Complex Area	0.046	0.018
2005 Complex Area	0.049	0.000
Fragmentation	0.022	0.036
Distance to Road	0.001	0.002
Distance to Forest	0.042	0.011
Distance to Opening	0.014	0.002
Distance to Nearest Meadow	0.000	0.006
Percent Mature/Old Growth Conifer Forest	0.000	0.011
Percent Young Conifer Forest	0.000	0.030
Percent Shrub	0.016	0.014
Percent Open Vegetation	0.014	0.019
Percent Road	0.049	0.015

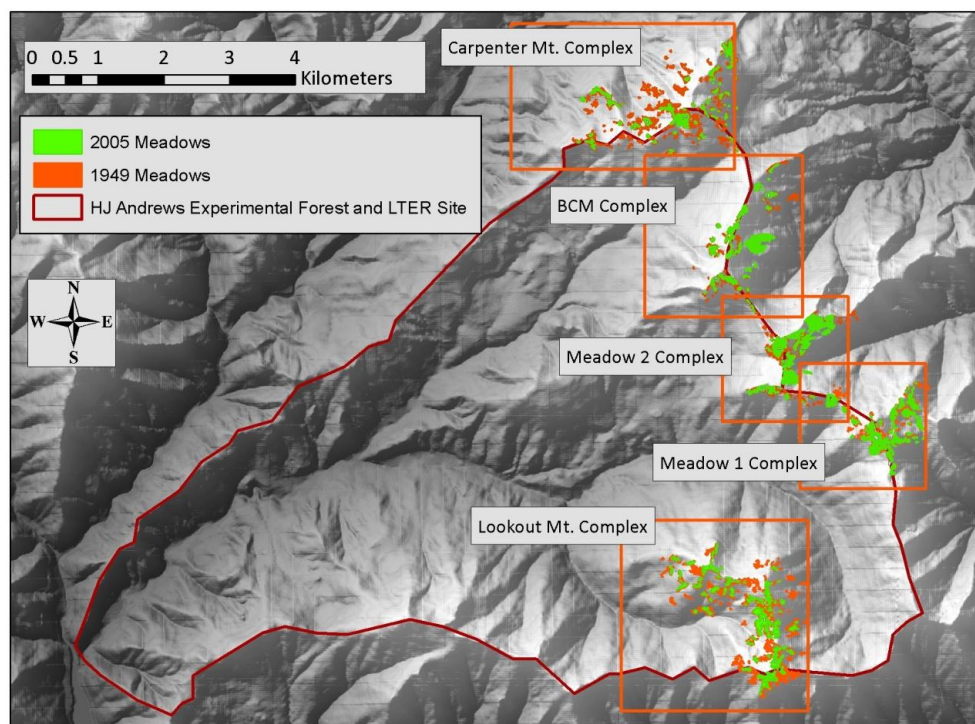


Figure 4. 1. Overview map of the HJA showing the extent of meadows in 1949 and 2005, and the five meadow complexes discussed in this study.

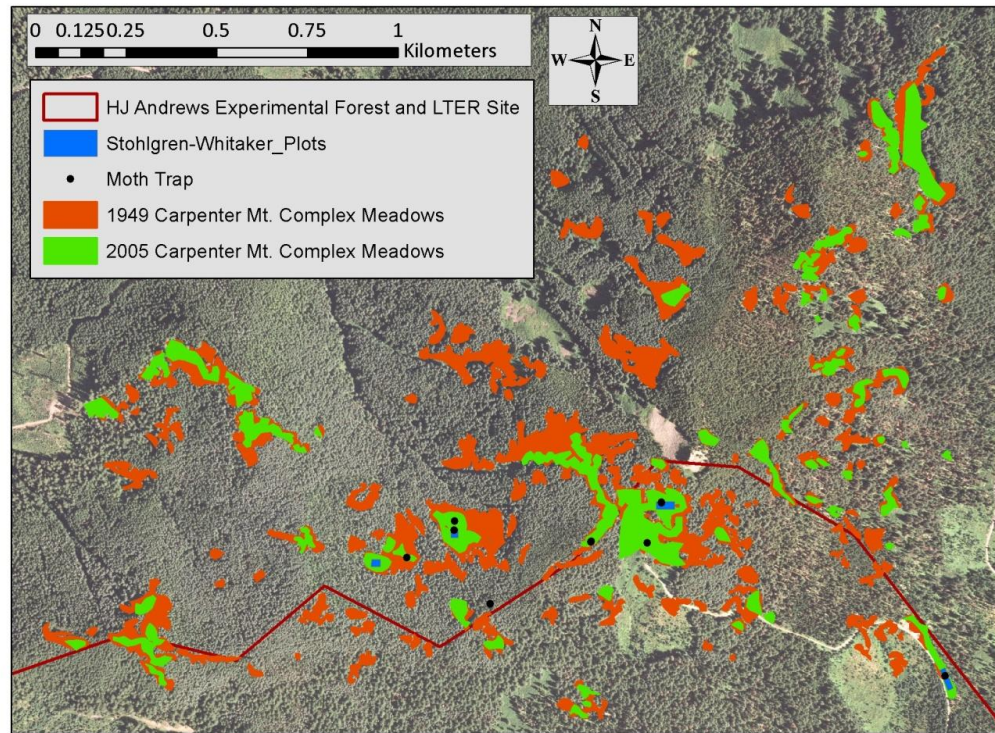


Figure 4. 2. The extent and distribution of meadows in 1949 and 2005 in the Carpenter Mt. complex. Four Stohlgren-Whittaker plots were placed in the largest meadow (CM-x41a), a small isolated saddle meadow (CM-x28), a small fragmented meadow (CM-x44c), and a medium highly contracted meadow (CM-x43).

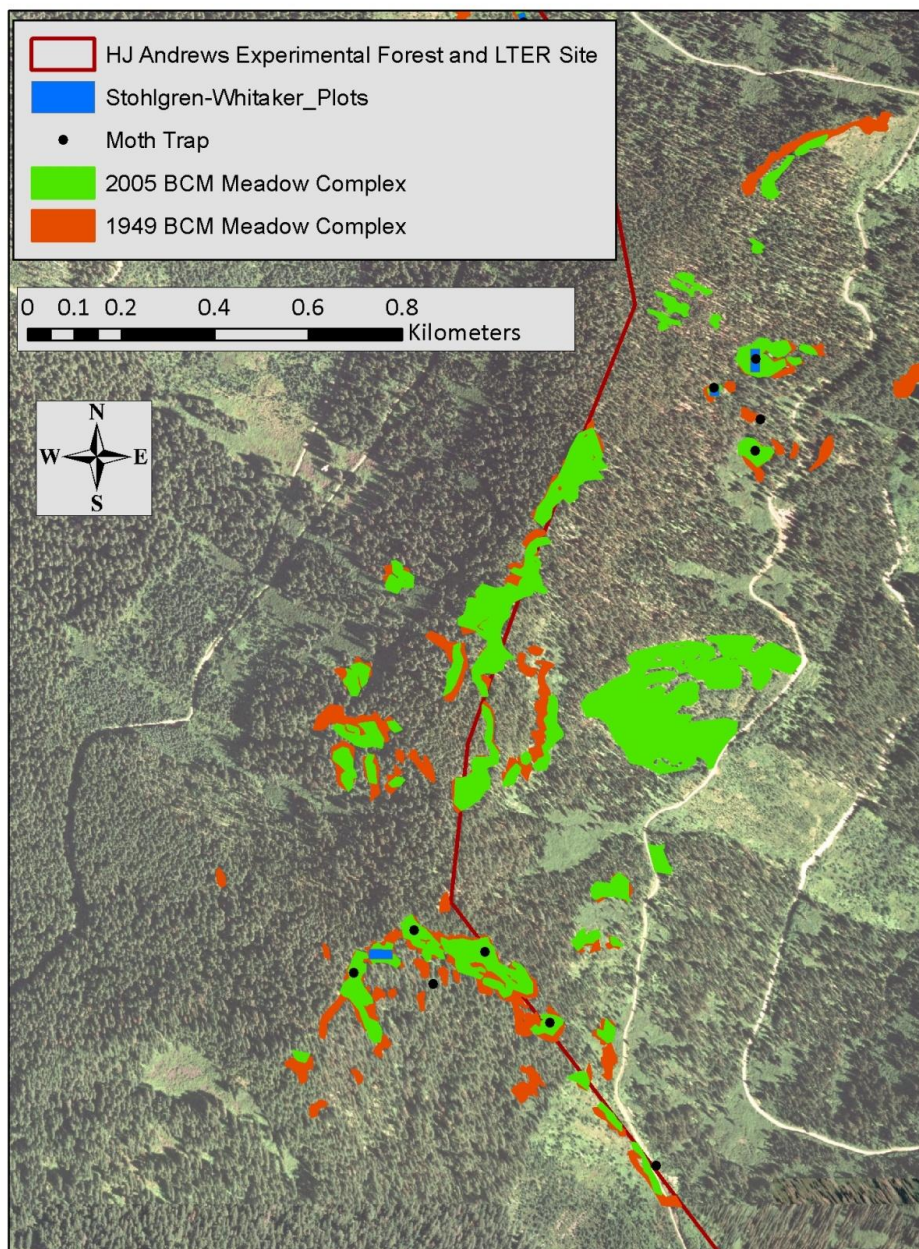


Figure 4. 3. The extent and distribution of meadows in 1949 and 2005 in the BCM complex. Three Stohlgren-Whittaker plot was placed in one very small meadow (BCM-x44), one medium fragmented meadow (BCM-x32b), and one small but previously large fragmented meadow (BCM-x45a).

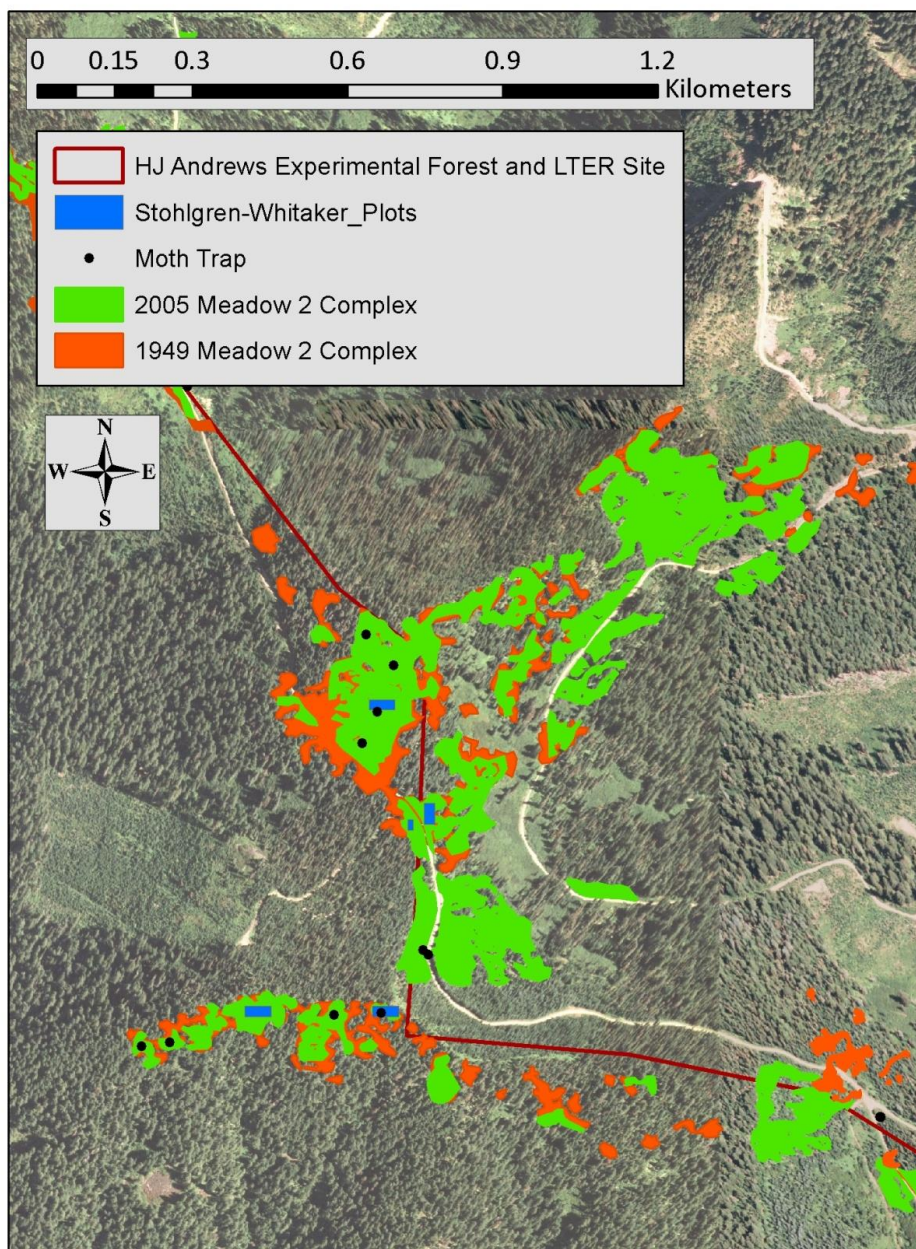


Figure 4. 4. The extent and distribution of meadows in 1949 and 2005 in the Meadow 2 complex. Four Stohlgren-Whittaker plots were placed in the largest meadow (M2-x21a), a medium saddle meadow (M2-x21f), one very small fragmented meadow (M2-x23a), and one medium fragmented meadow (M2-x23c).

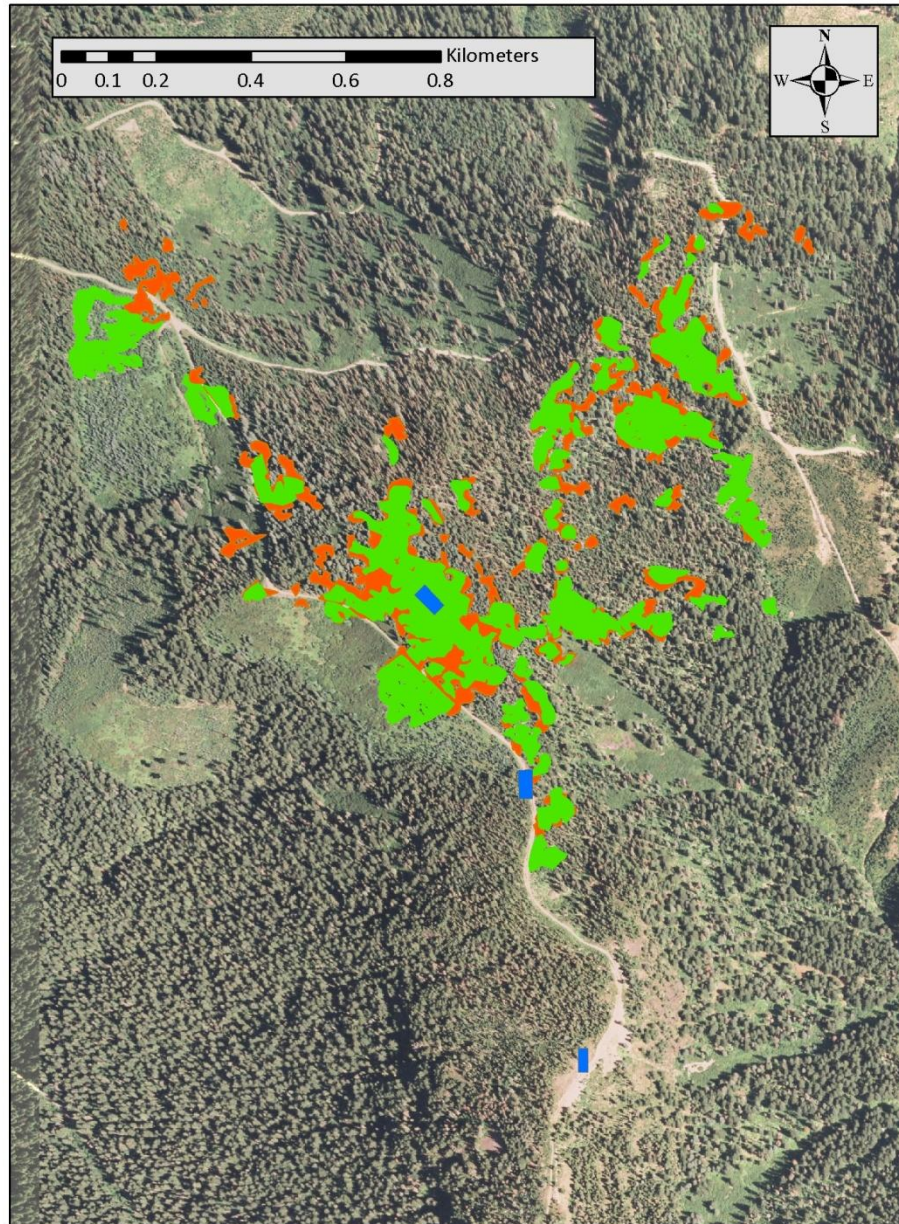


Figure 4. 5. The extent and distribution of meadows in 1949 and 2005 in the Meadow 1 complex and Frissel Ridge. Three Stohlgren-Whittaker plots were placed in the largest meadow (M1-x1a), an adjacent forested saddle (M1-pt), and area semi-forested area on Frissel Ridge (FR-gs).

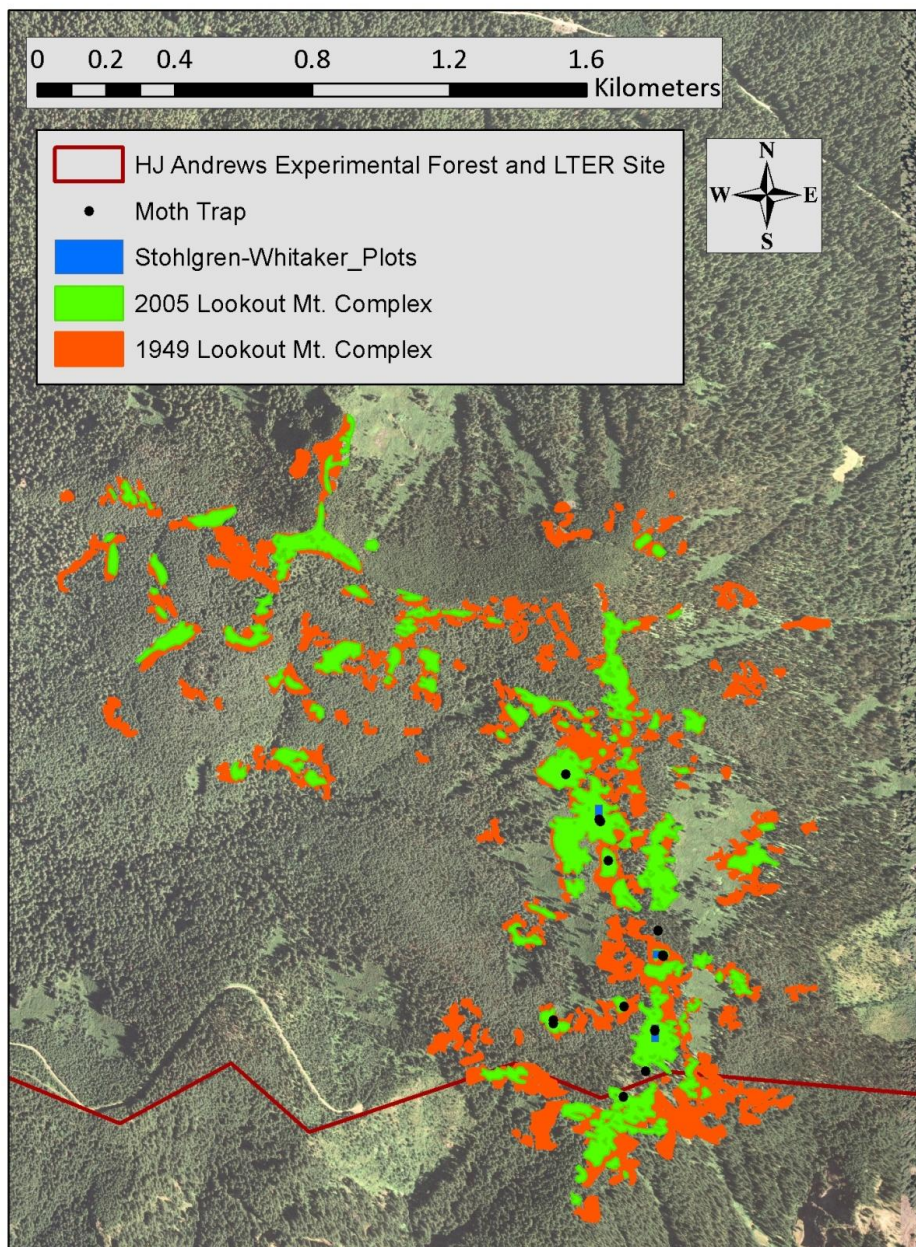


Figure 4. 6. The extent and distribution of meadows in 1949 and 2005 in the Lookout Mt. complex. Three Stohlgren-Whittaker plots were placed in the largest meadow (LOM-x1a), an expanded medium meadow (LOM-x4a), and a small fragmented meadow (LOM-x4c).

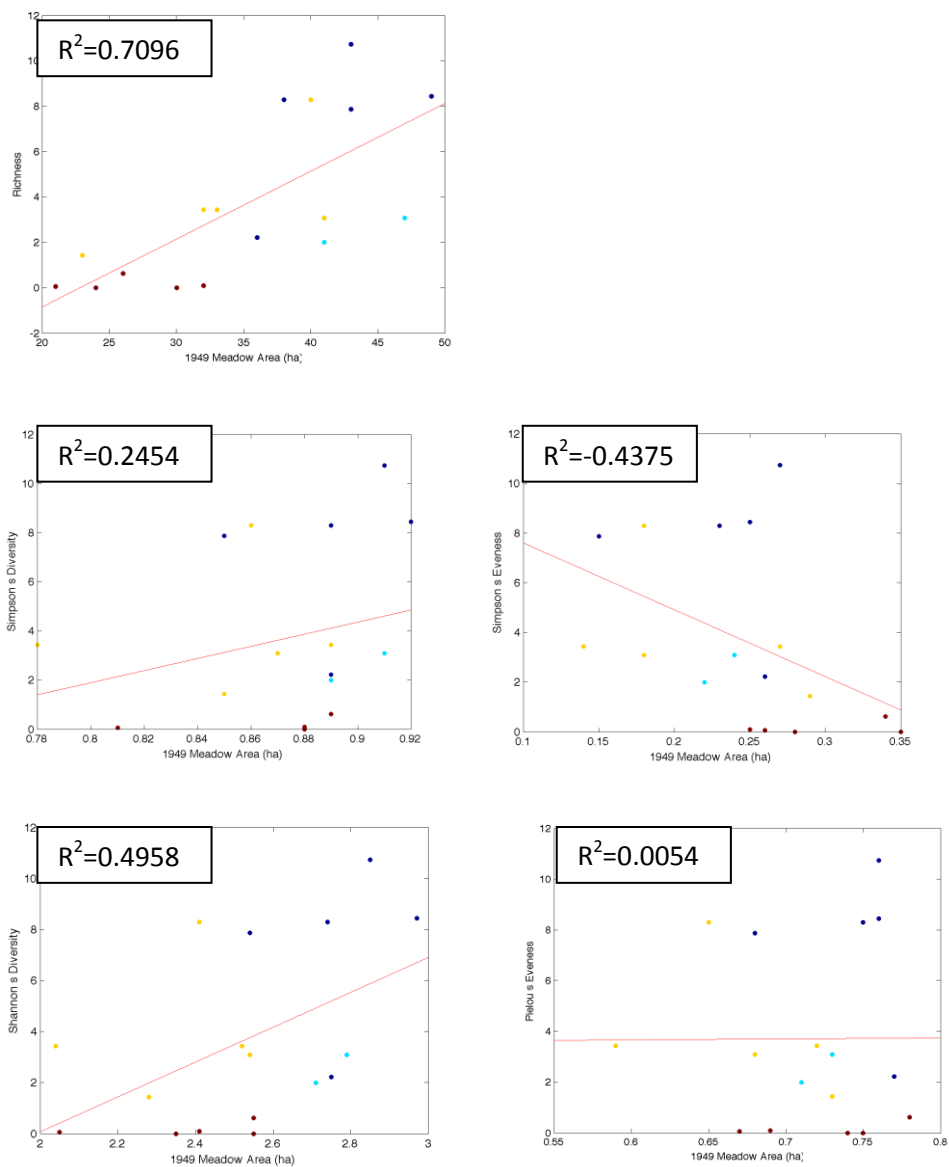


Figure 4. 7. Plant richness, Simpson's D, Simpson's E, Shannon's H, and Pielou's J as a function of meadow area in 1949 (ha).

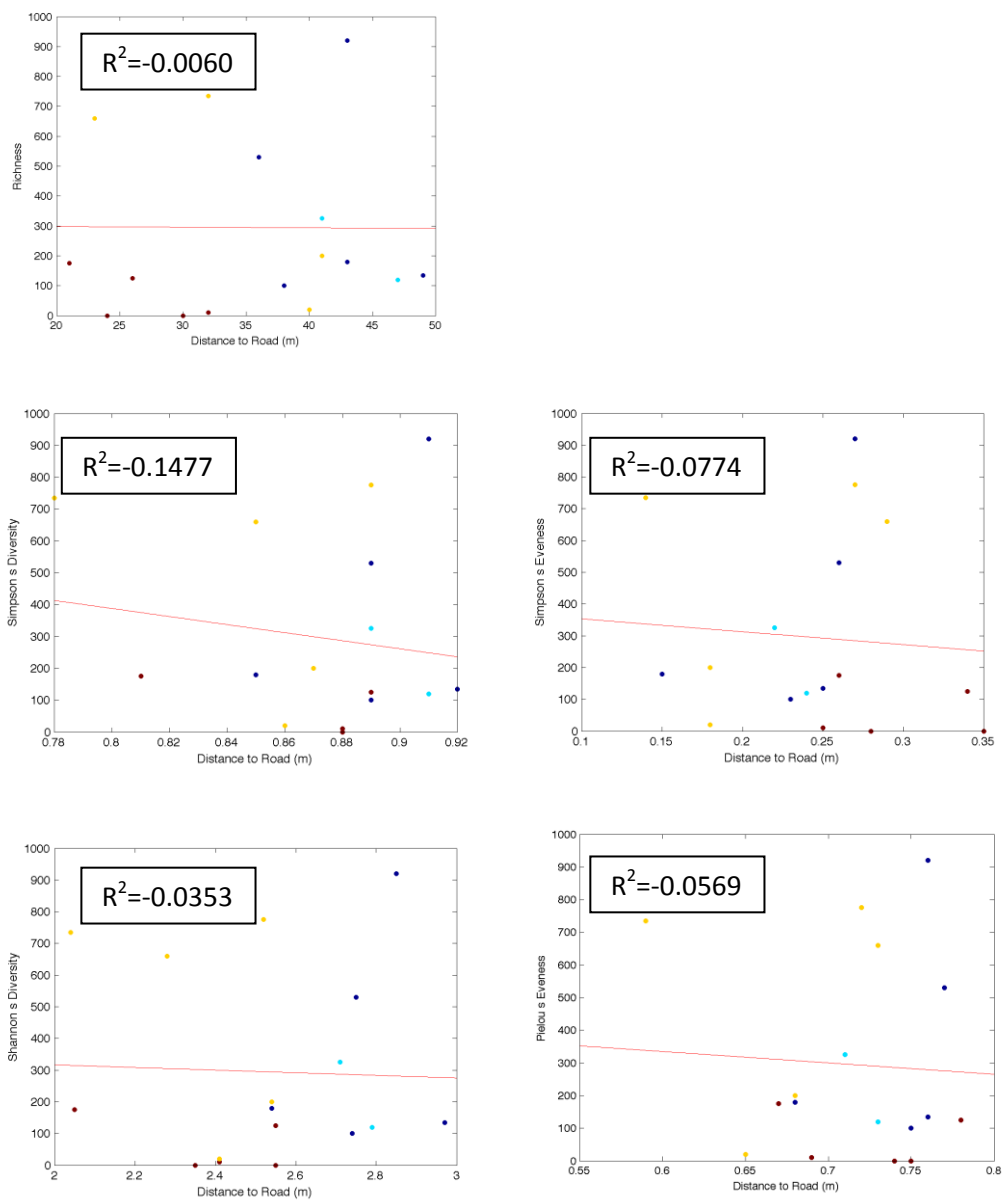


Figure 4. 8. Plant richness, Simpson's D, Simpson's E, Shannon's H, and Pielou's J as a function of distance to road (m).

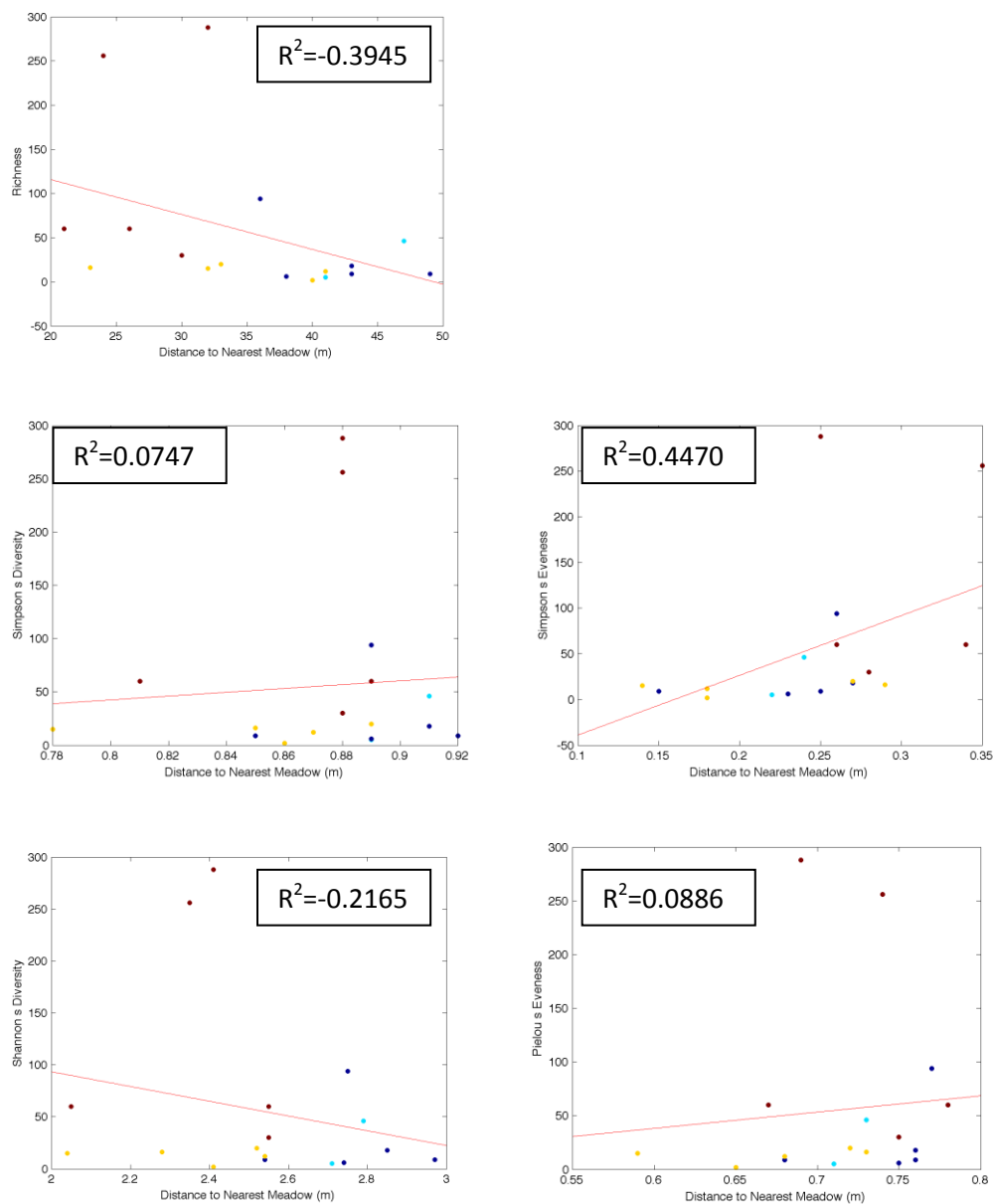


Figure 4. 9. Plant richness, Simpson's D, Simpson's E, Shannon's H, and Pielou's J as a function of distance to nearest meadow (m).

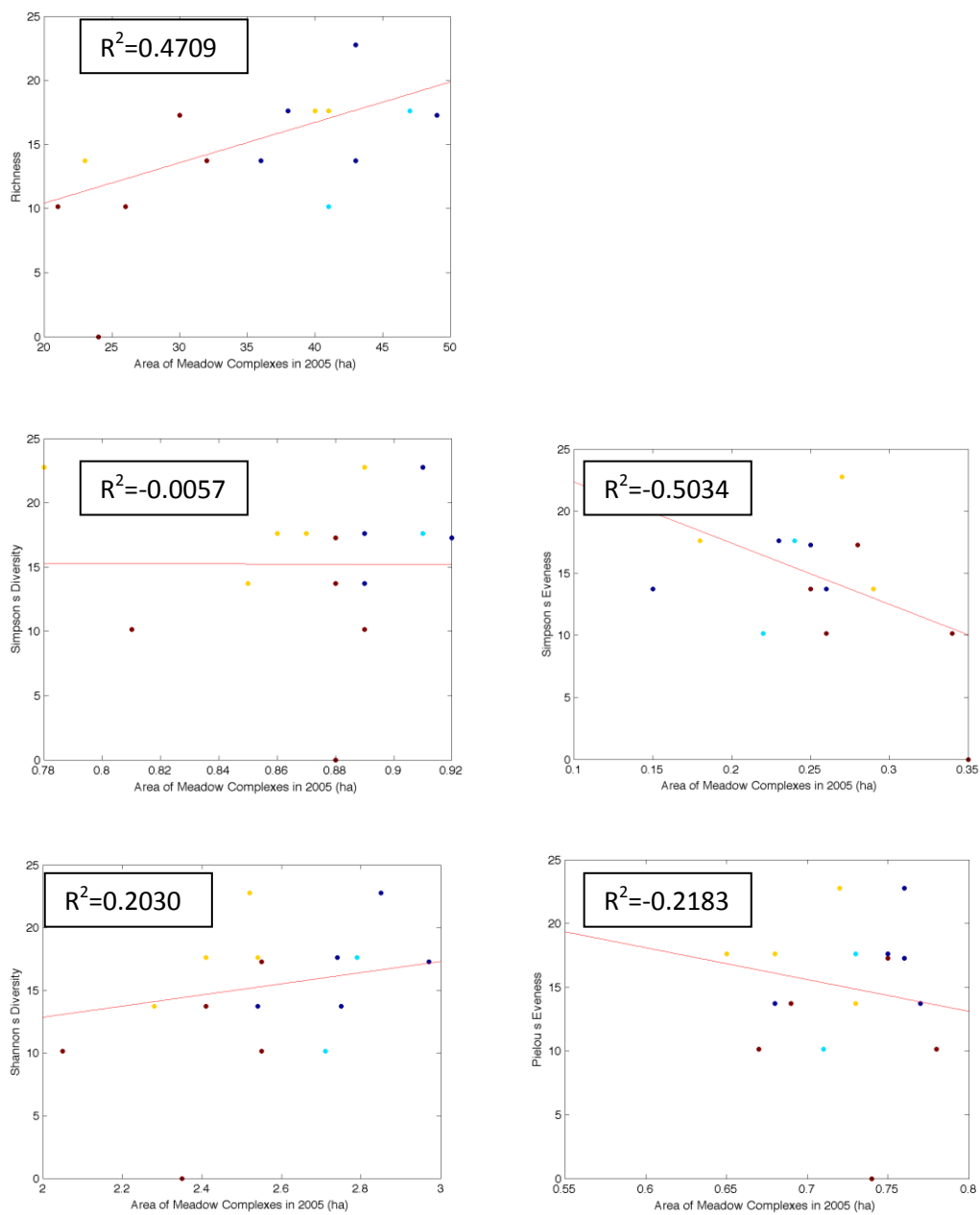


Figure 4. 10. Plant richness, Simpson's D, Simpson's E, Shannon's H, and Pielou's J as a function of the area of meadow complexes in 2005 (ha).

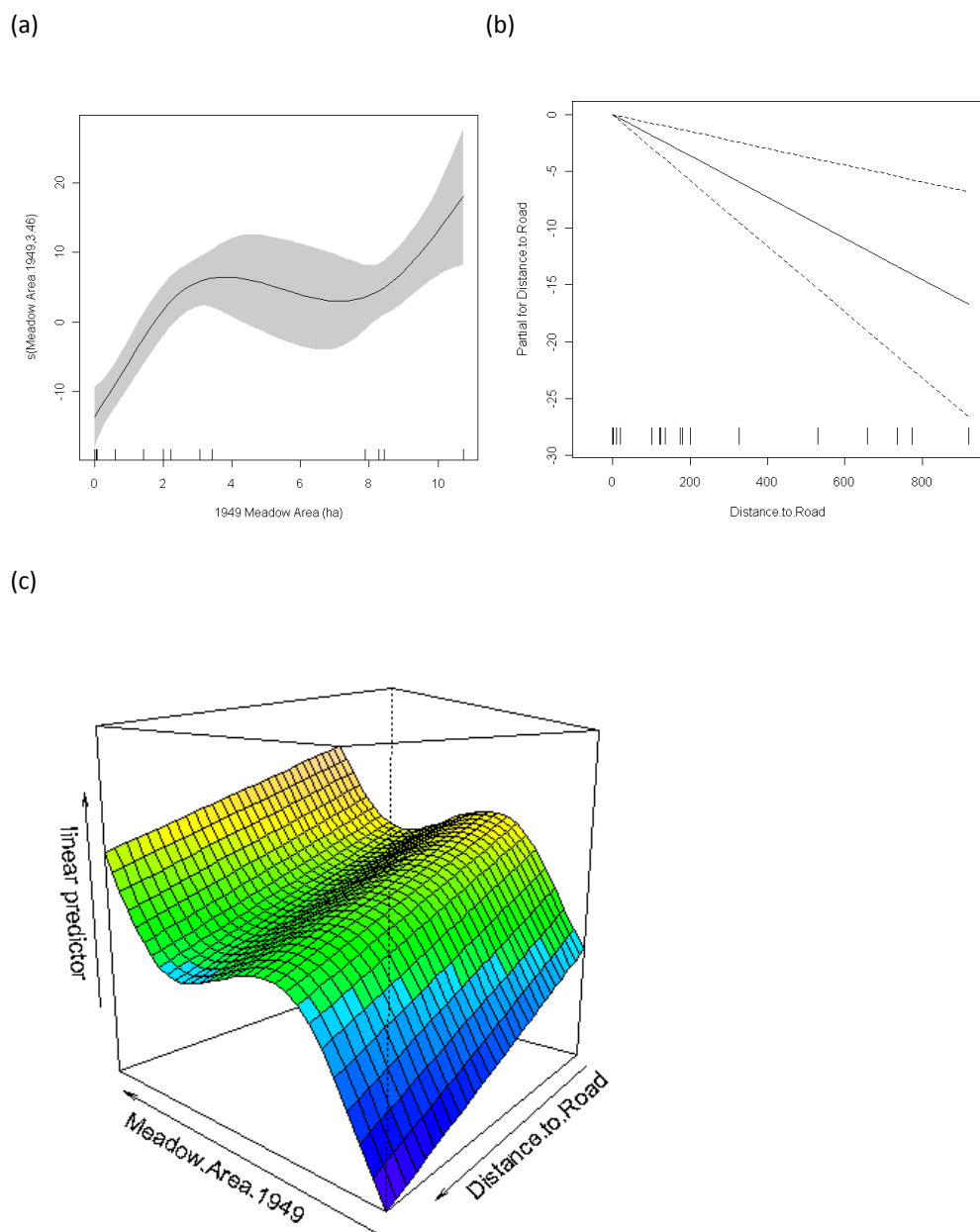


Figure 4. 11. Effect of meadow size and distance to road on plant richness in meadows of the HJ Andrews Forest. The GAM output showing the effect of 1949 meadow area on plant richness (a), the effect of distance to road on plant richness (b), and the interactive effect of 1949 meadow area and distance to road (c). Small vertical hatch marks on X-axis show sizes of meadows sampled. (a) Richness is positively related to area over the range of meadows sampled, but there is little difference in richness between 4 and 8-ha meadows. (b) Richness is negatively related to distance to road.

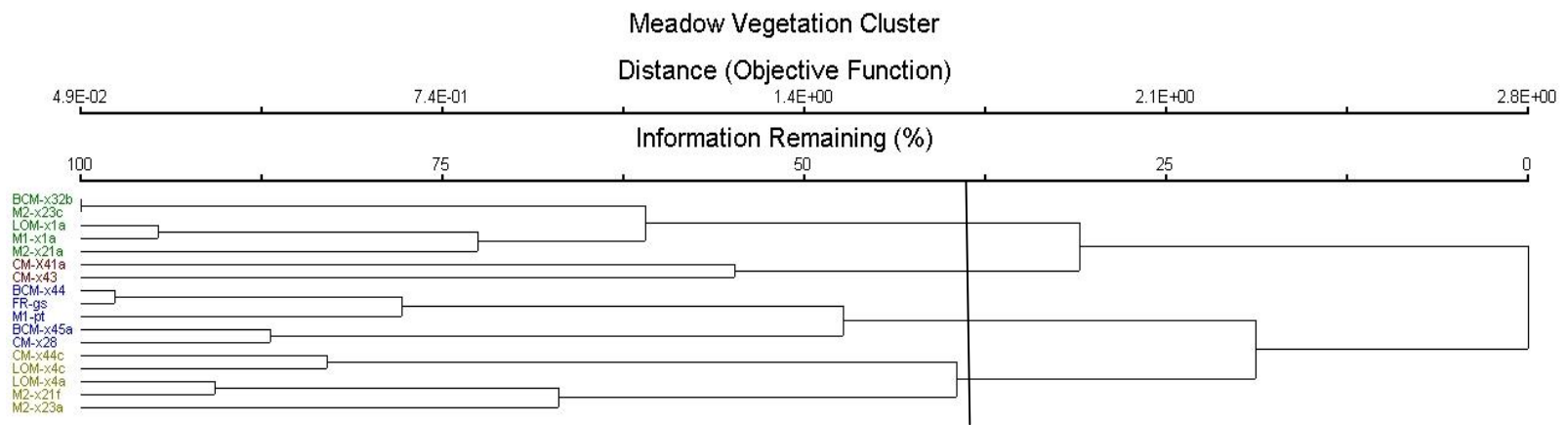


Figure 4. 12. Dendrogram showing the resulting clusters from the Hierarchical Agglomerative Cluster Analysis of the vegetation samples. The line indicates where the four classes were divided and tested for significance using MRPP.

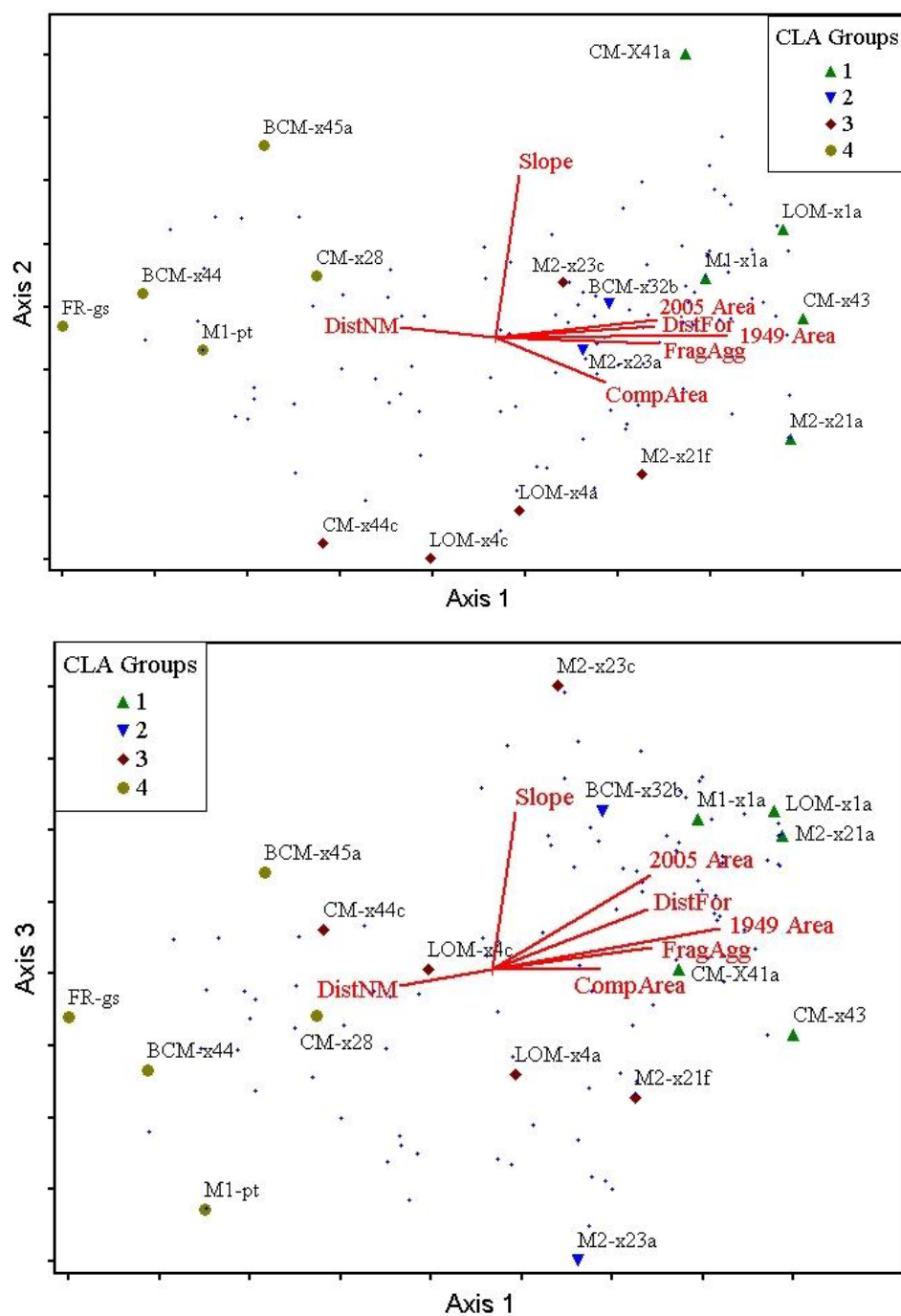


Figure 4. 13. 3-D NMS ordination graphs of vegetation plots using grouping variables derived from Hierarchical Agglomerative Cluster Analysis.

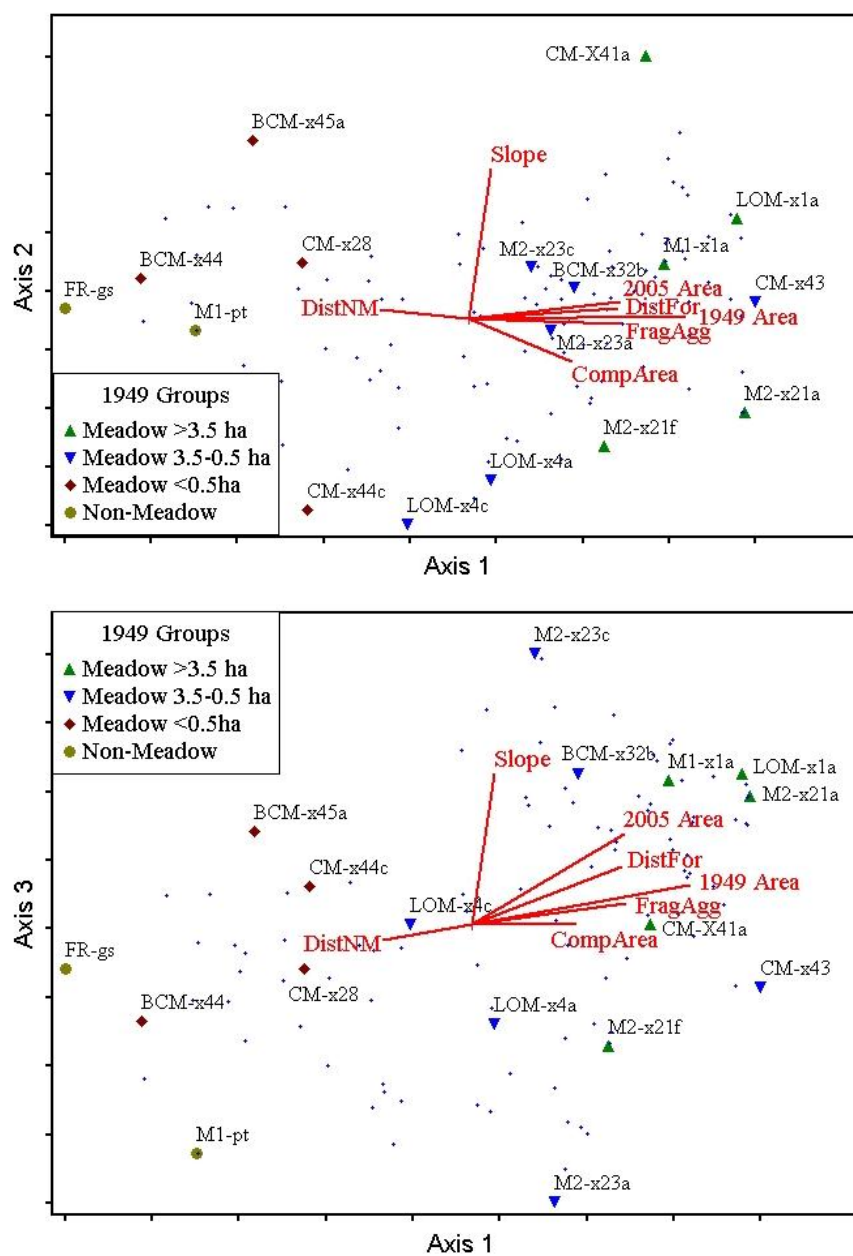


Figure 4. 14. 3-D NMS ordination graphs of vegetation plots using 1949 Area groupings.

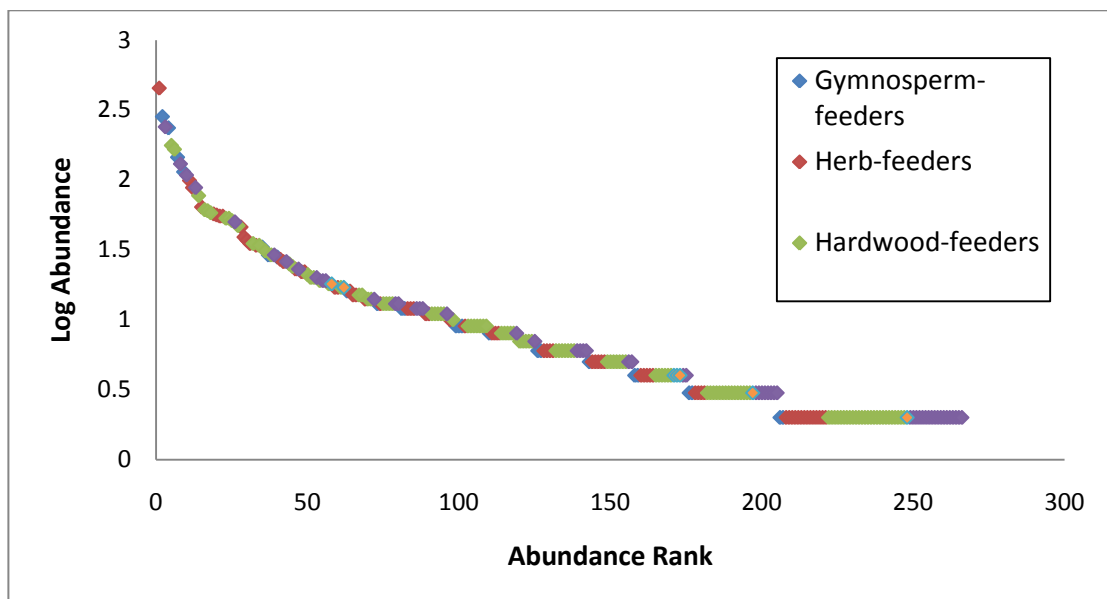


Figure 4. 15. Rank abundance curve for moth species sampled at 63 montane meadow sites in HJA in 2008-2010. The top 15 ranked species were *Noctua pronuba* (h), *Pero occidentalis/behrensaria* (g), Geometrid spp. (u), *Enypia packardata* (g), *Eurois astricta* (hw), *Polia purpurissata* (hw), *Semiothisa signaria* (g), *Eupithecia* spp. (u), *Enypia venata* (g), Noctuid spp. (u), *Euxoa divergens* (h), *Parabagrotis exertistigma* (h), *Perizoma grandis* (u), *Synedoida adumbrata* (hw), *Leucania insueta* (h).

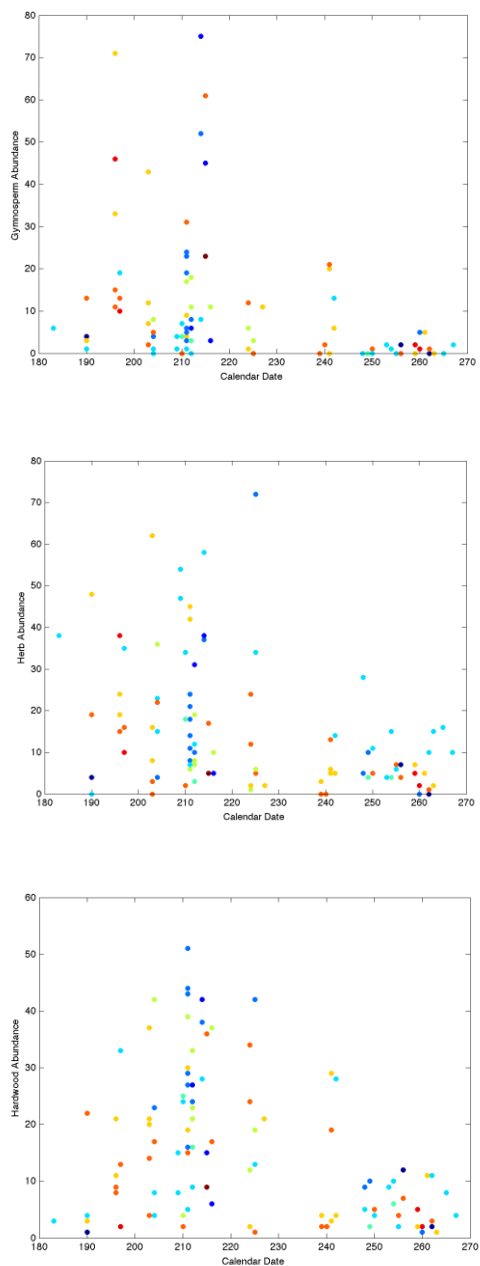


Figure 4. 16. Scatterplots showing the abundance of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths by calendar day. Color codes are as follows: dark blue=old growth conifer forest; medium blue=young conifer forest; light blue=large (>3.5 ha) meadow; sky blue=medium (0.5-3.5 ha) meadow; blue-green=small (<0.5 ha) meadow; light green=mesic meadow; light orange=wet meadow; orange=forest road; red=clearcut; dark red=edge.

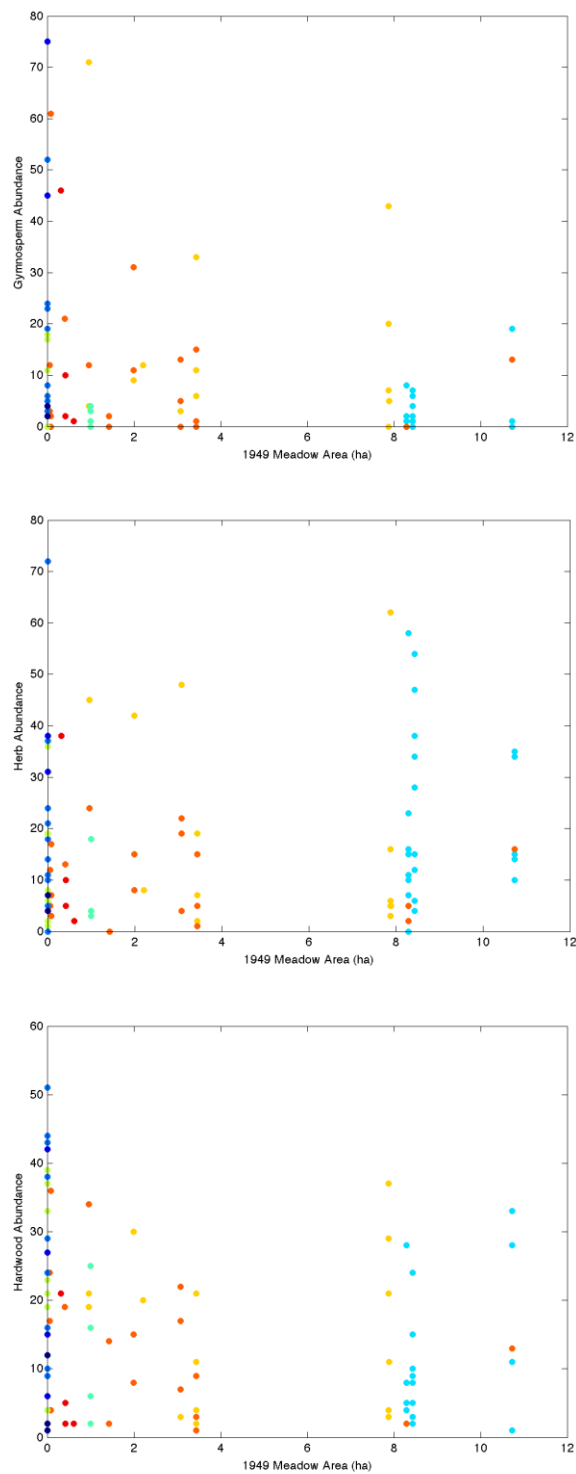


Figure 4. 17. Abundances of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of meadow area in 1949 (ha). Color codes as in Figure 4.16.

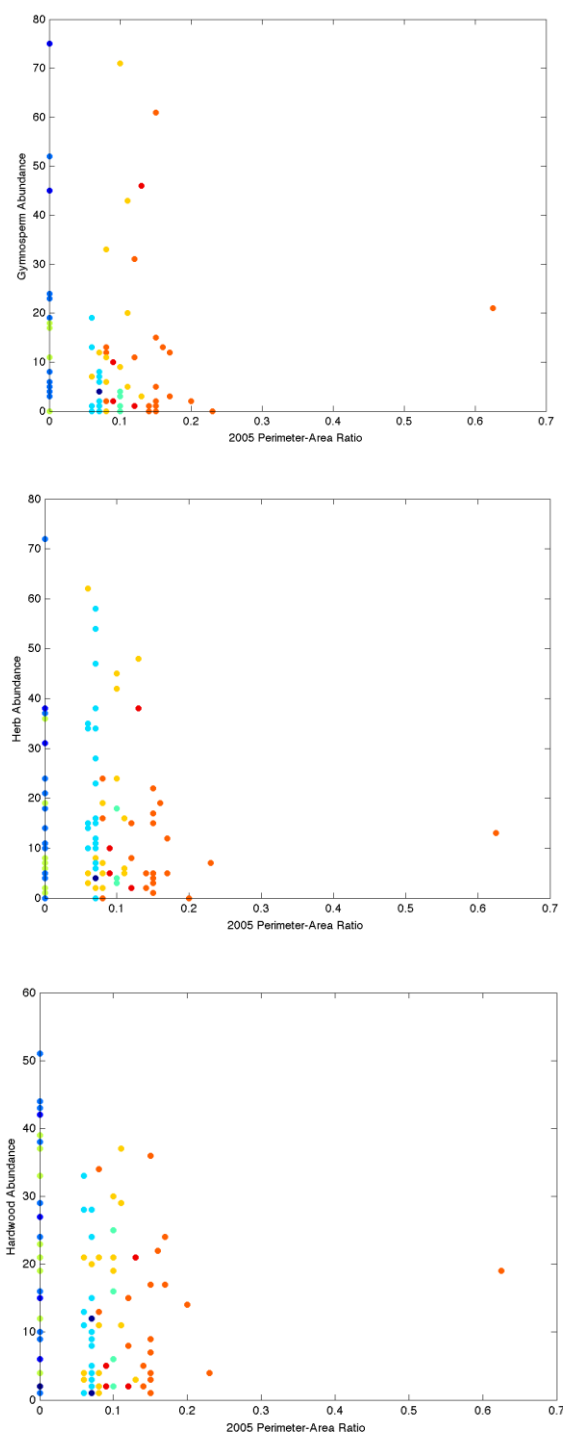


Figure 4. 18. Abundances of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of meadow perimeter-area ratio in 2005 (ha). Color codes as in Figure 4.16.

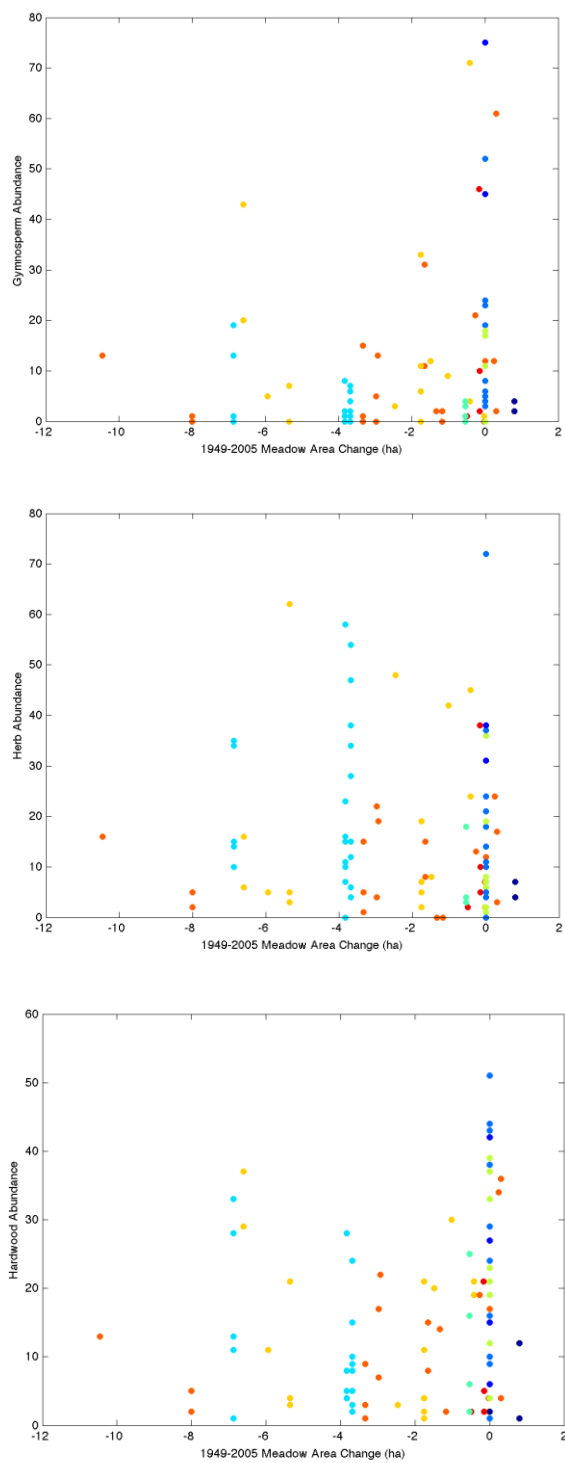


Figure 4. 19. Abundances of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of change in meadow area from 1949 to 2005 (ha). Color codes as in Figure 4.16.

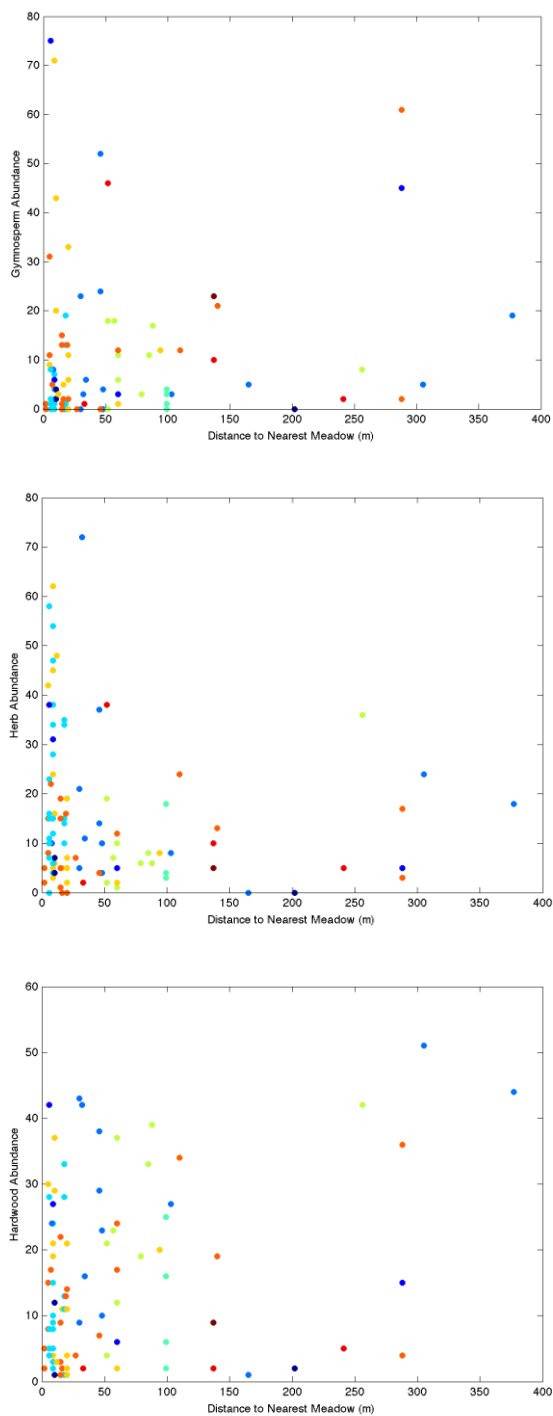


Figure 4. 20. Abundances of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of distance to nearest meadow (m). Color codes as in Figure 4.16.

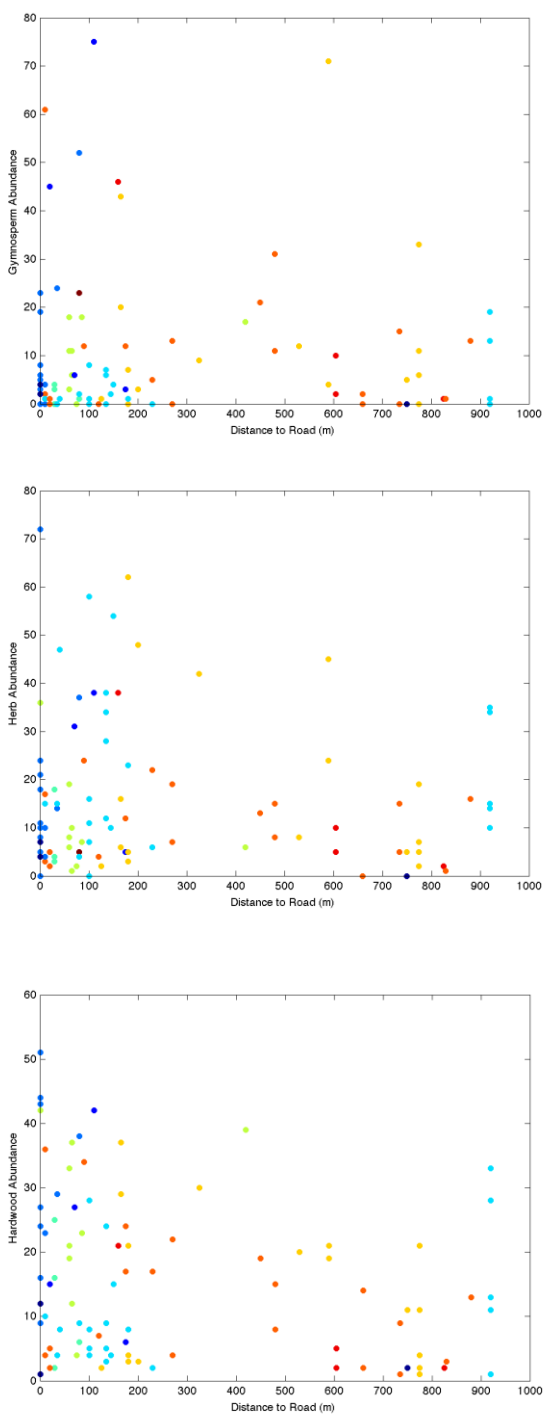


Figure 4. 21. Abundances of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of distance to road (m). Color codes as in Figure 4.16.

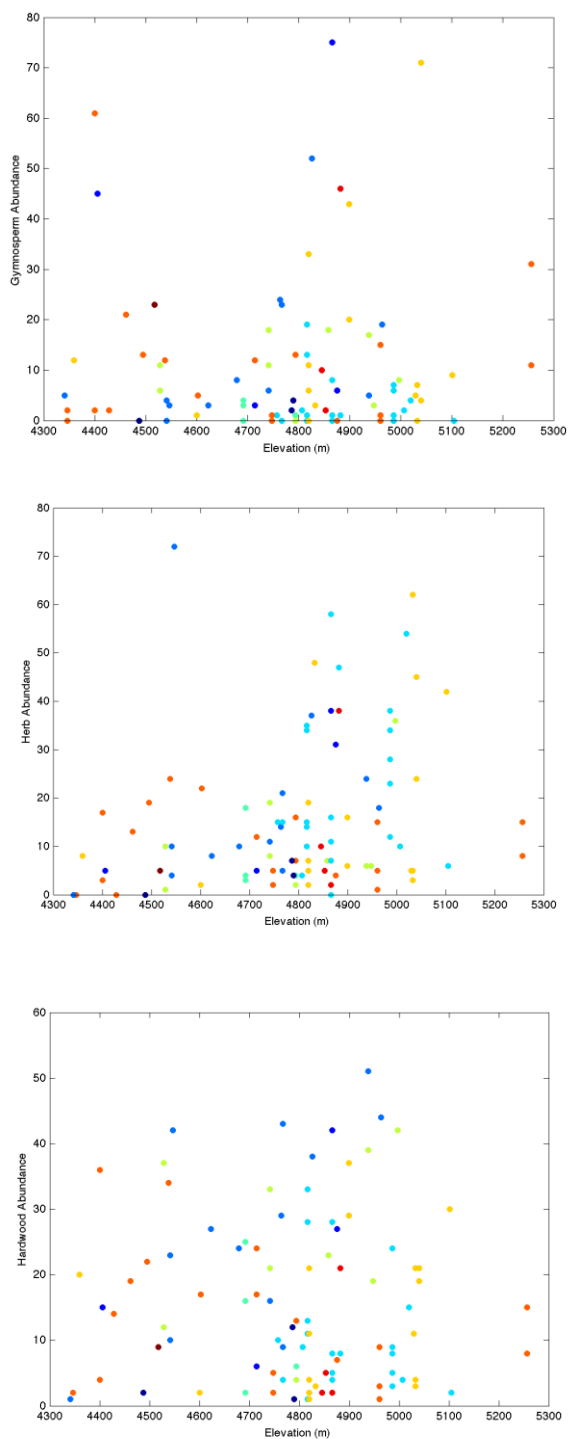


Figure 4. 22. Abundances of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of elevation (m). Color codes as in Figure 4.16.

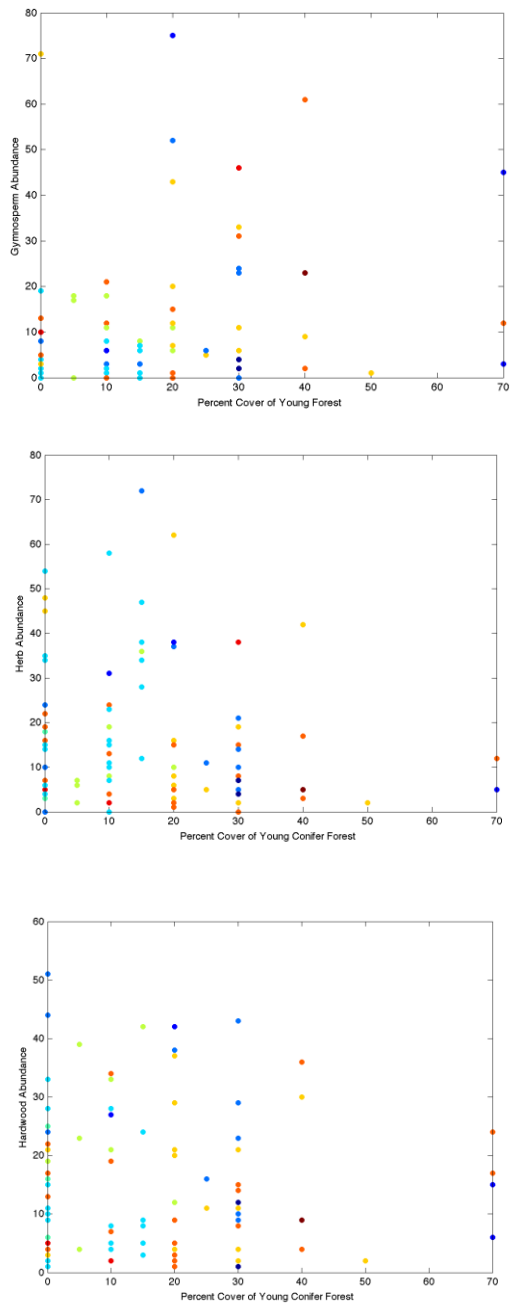


Figure 4. 23. Abundances of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of percent cover of young coniferous forest (m). Color codes as in Figure 4.16.

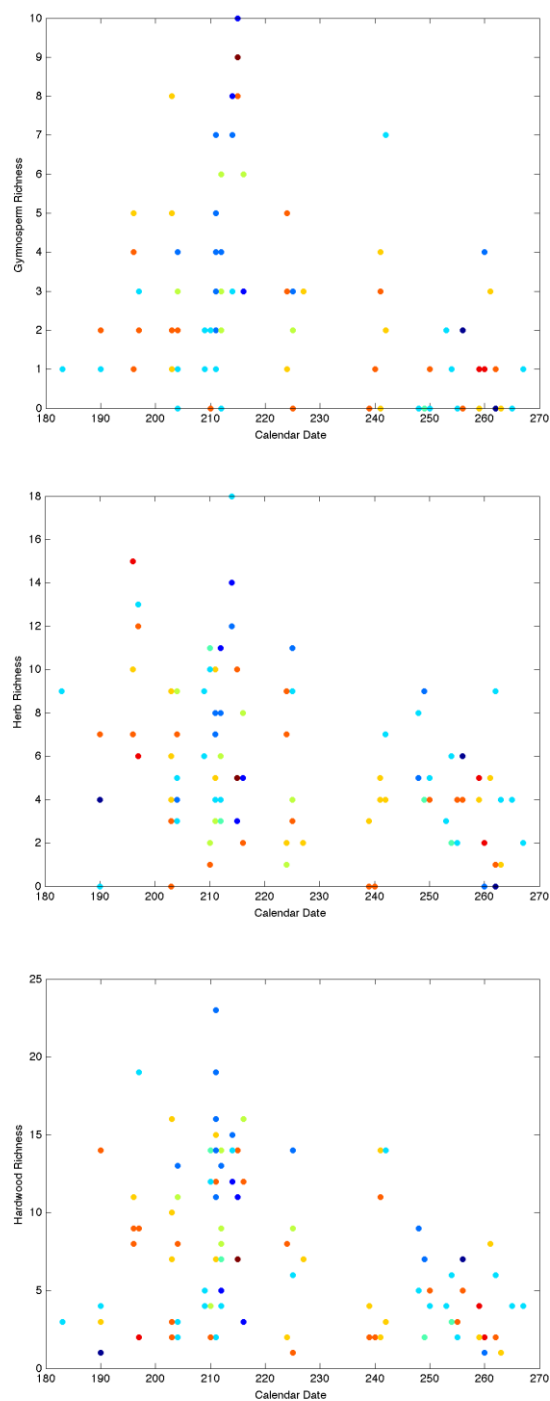


Figure 4. 24. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of calendar day. Color codes as in Figure 4.16.

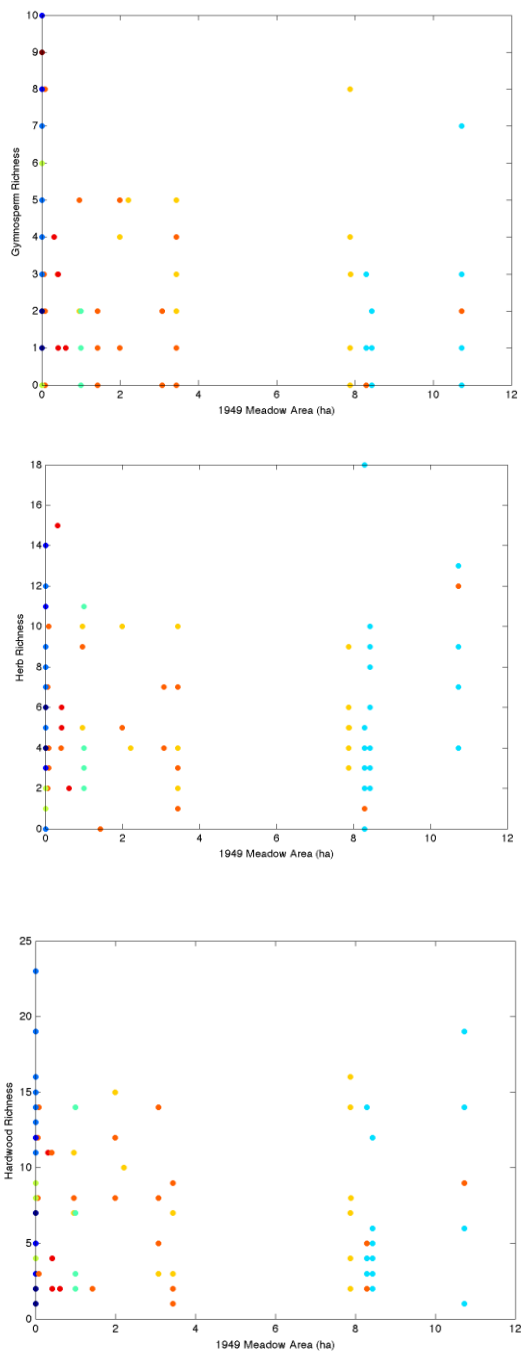


Figure 4. 25. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of meadow area in 1949 (ha). Color codes as in Figure 4.16.

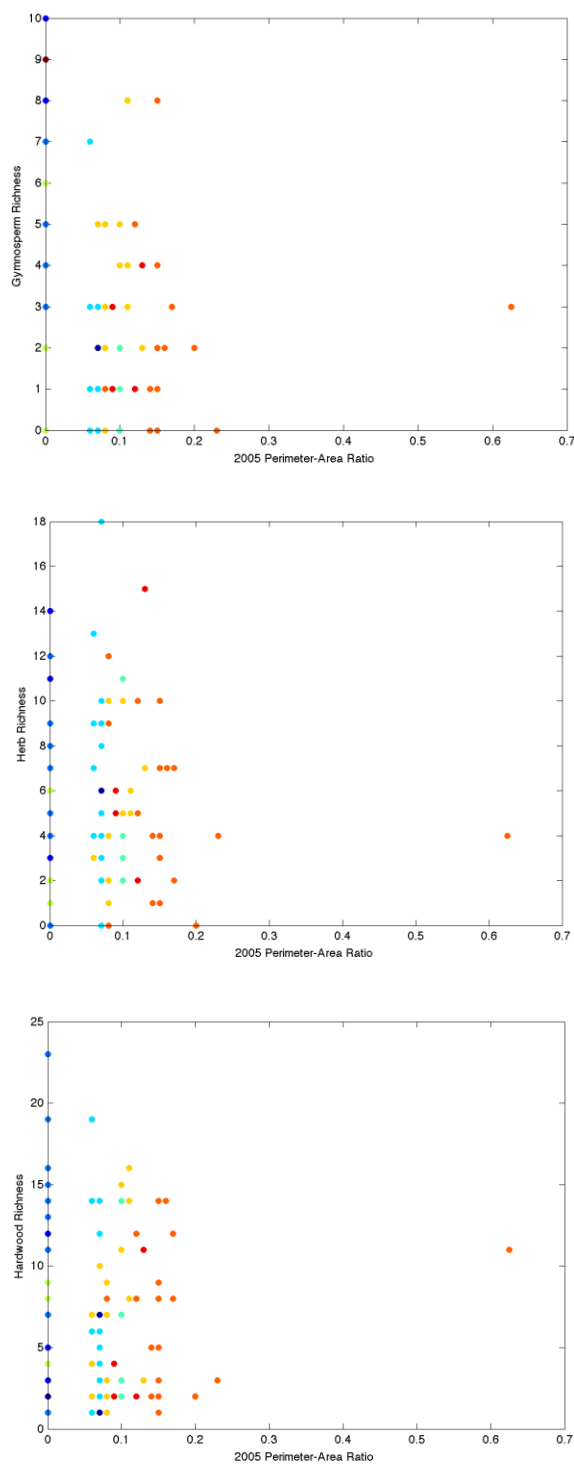


Figure 4. 26. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of meadow perimeter-area ratio in 2005. Color codes as in Figure 4.16.

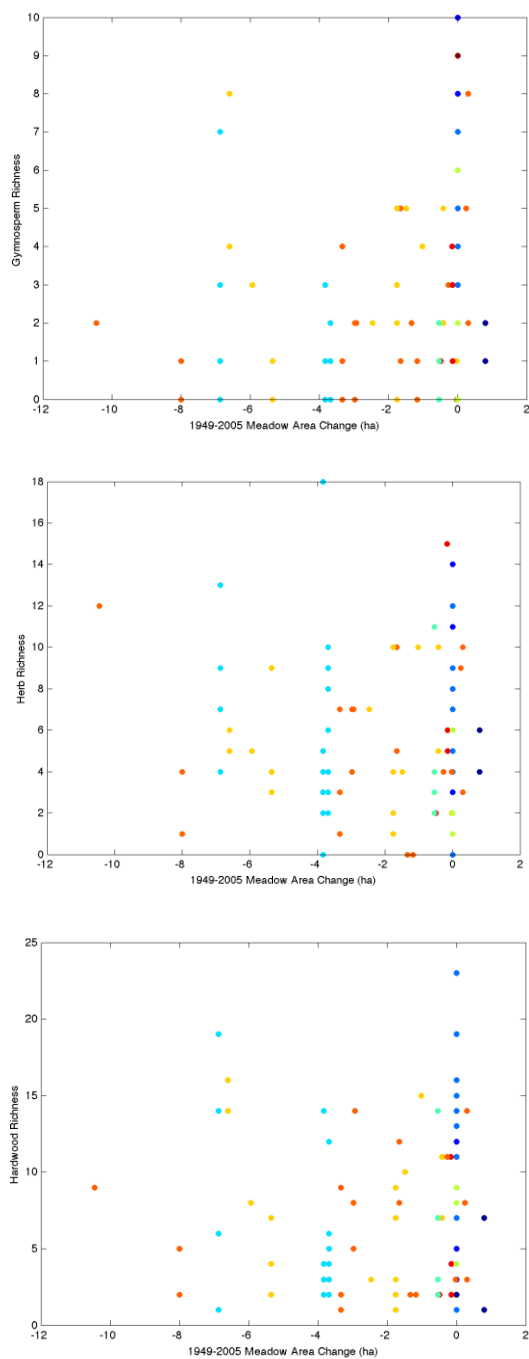


Figure 4. 27. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of change in meadow area from 1949 to 2005 (ha). Color codes as in Figure 4.16.

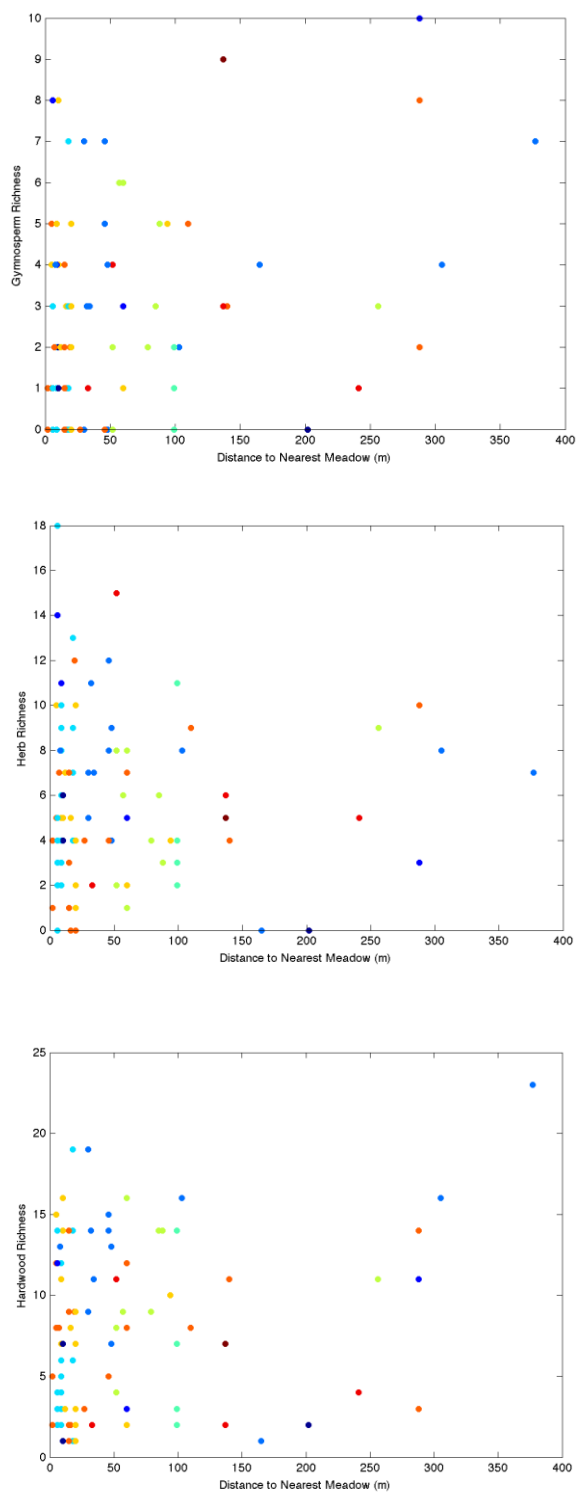


Figure 4. 28. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of distance to nearest meadow (m). Color codes as in Figure 4.16.

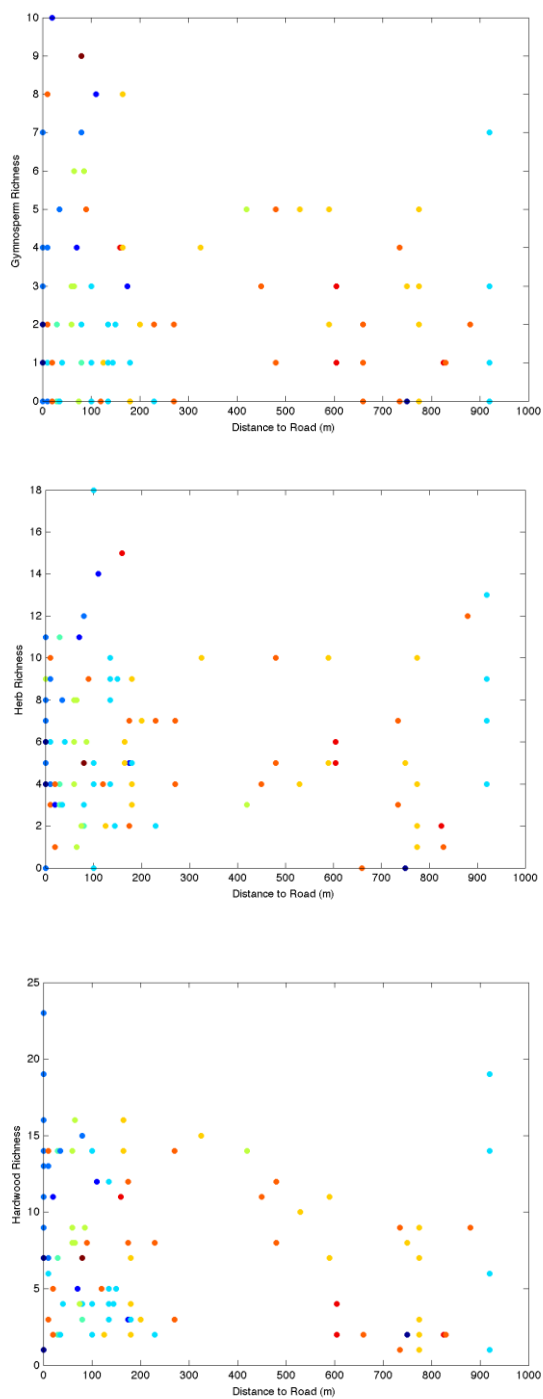


Figure 4. 29. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of distance to road (m). Color codes as in Figure 4.16.

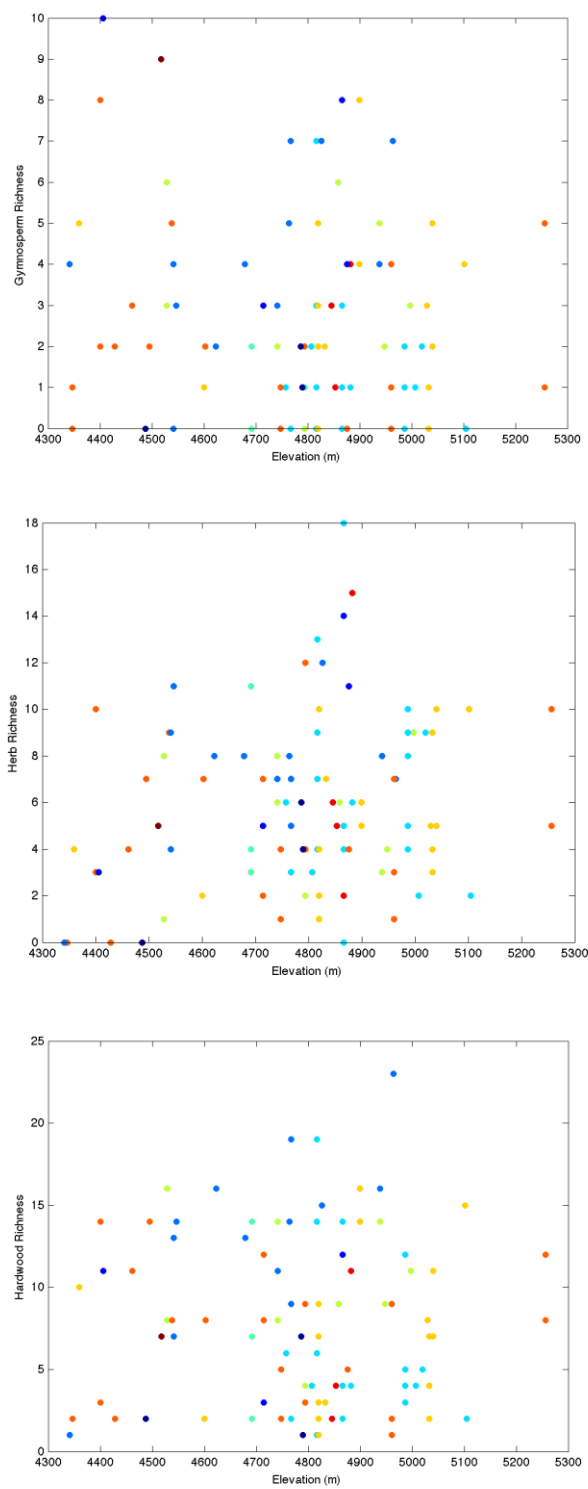


Figure 4. 30. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of elevation (m). Color codes as in Figure 4.16.

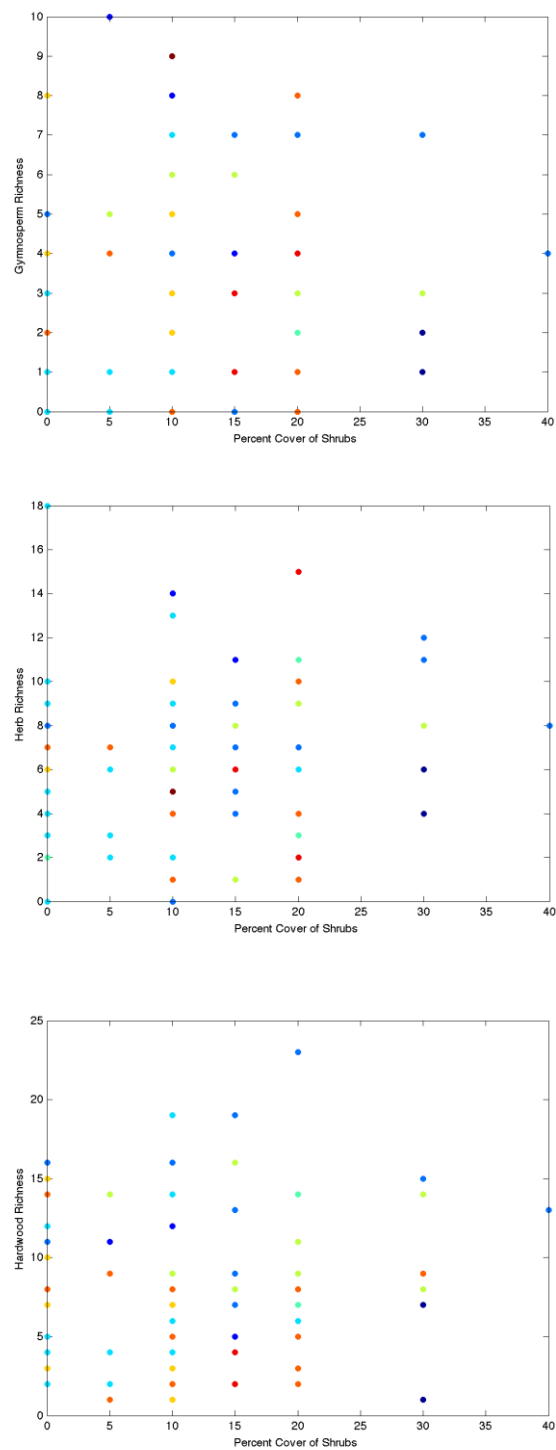


Figure 4. 31. Richness of (a) gymnosperm feeder moths, (b) herb feeder moths, and (c) hardwood feeder moths as a function of percent cover of shrubs. Color codes as in Figure 4.16.

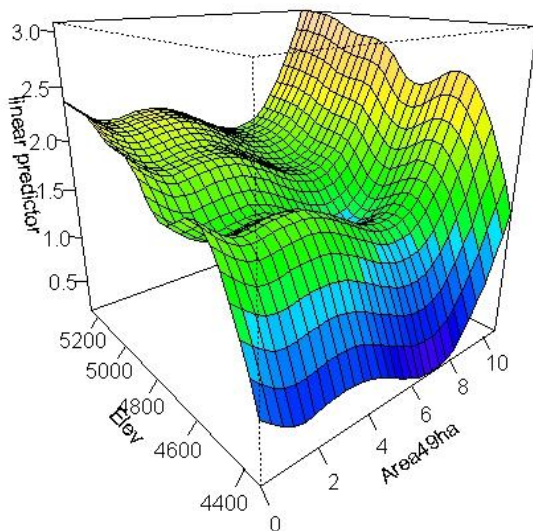
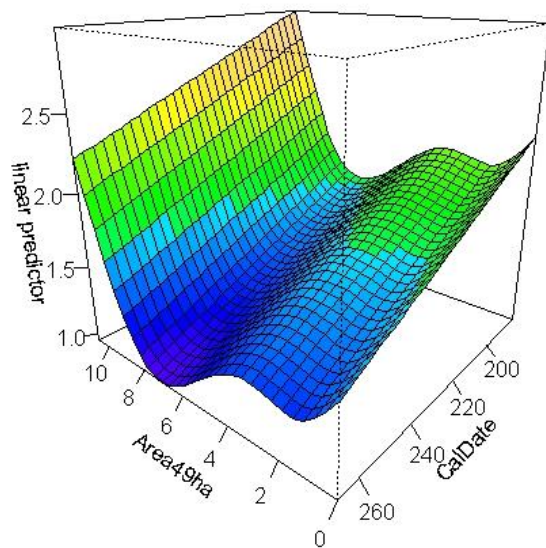


Figure 4. 32. Graphs showing the GAM relationships between 1949 meadow area, calendar day, and elevation for herb feeder richness.

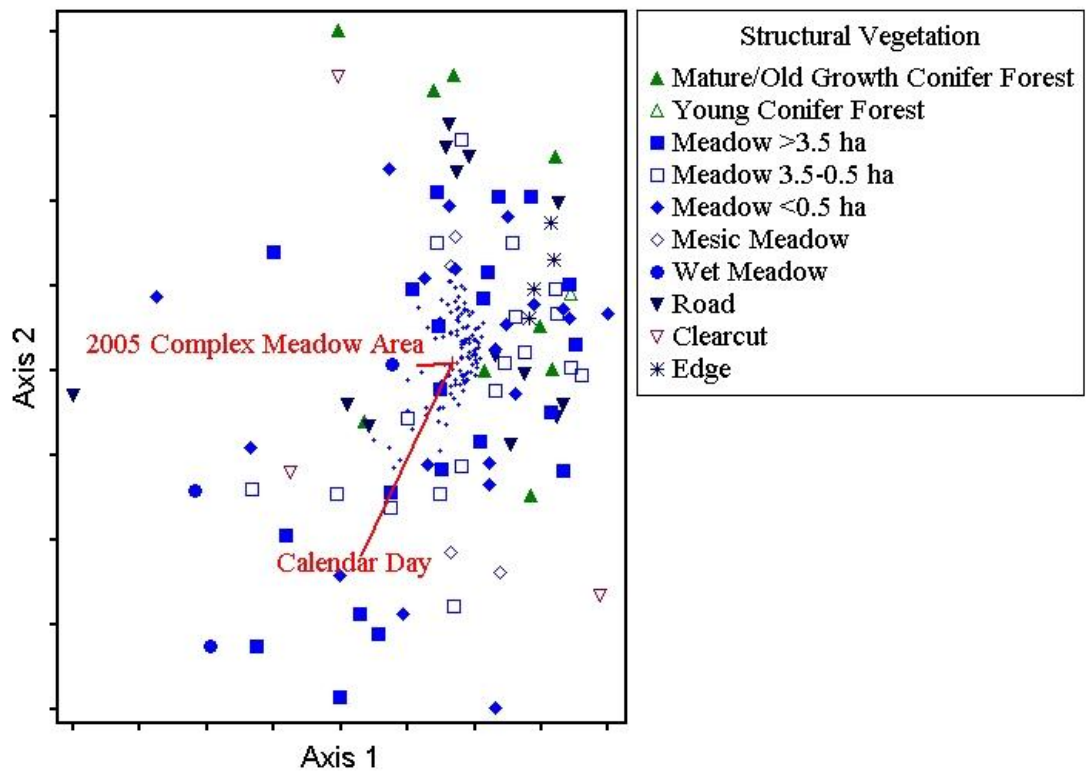


Figure 4. 33. 2-D NMS ordination graph of moth samples using structural vegetation groupings.

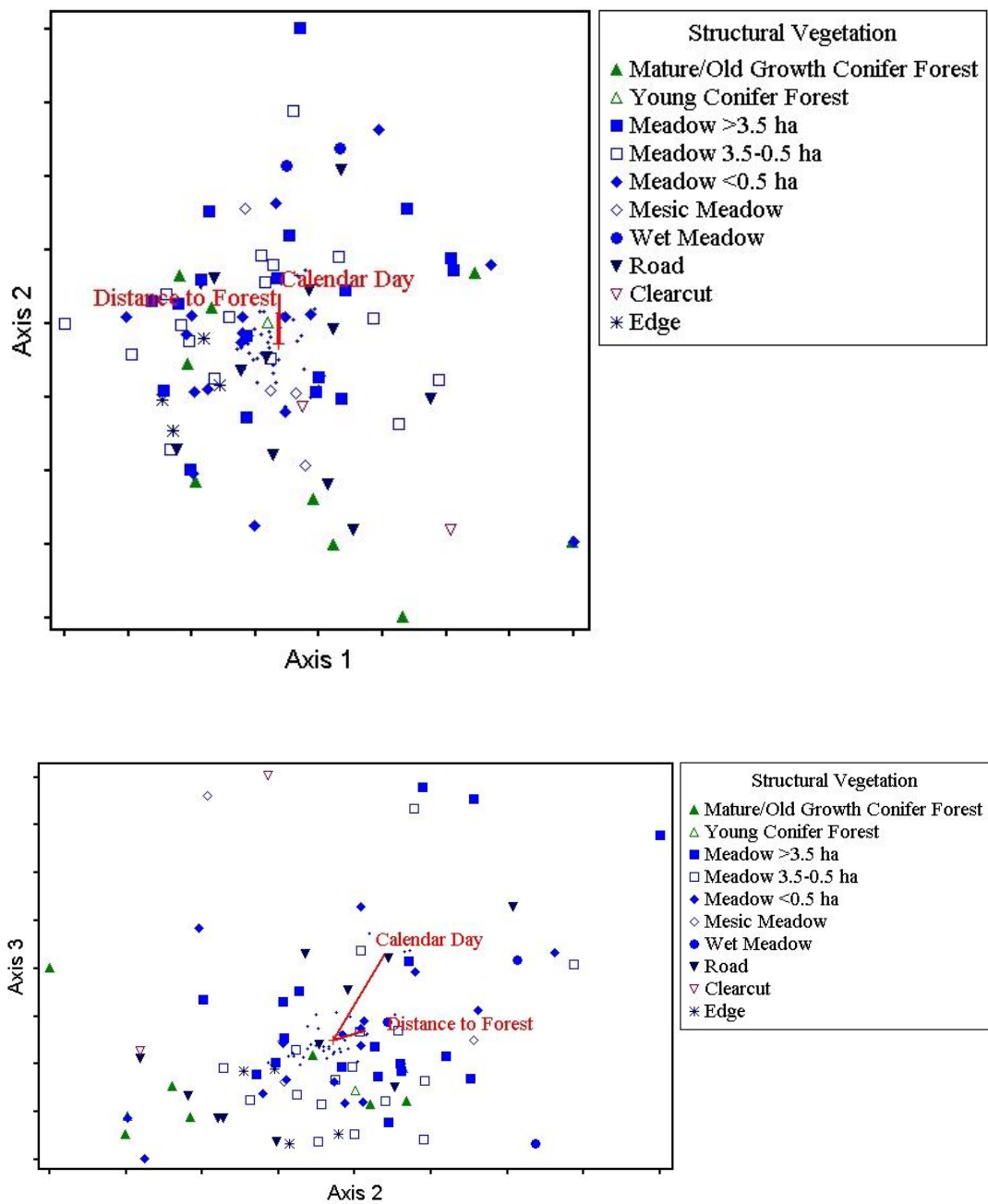


Figure 4. 34. 3-D NMS ordination graphs of herb feeders using structural vegetation groupings.

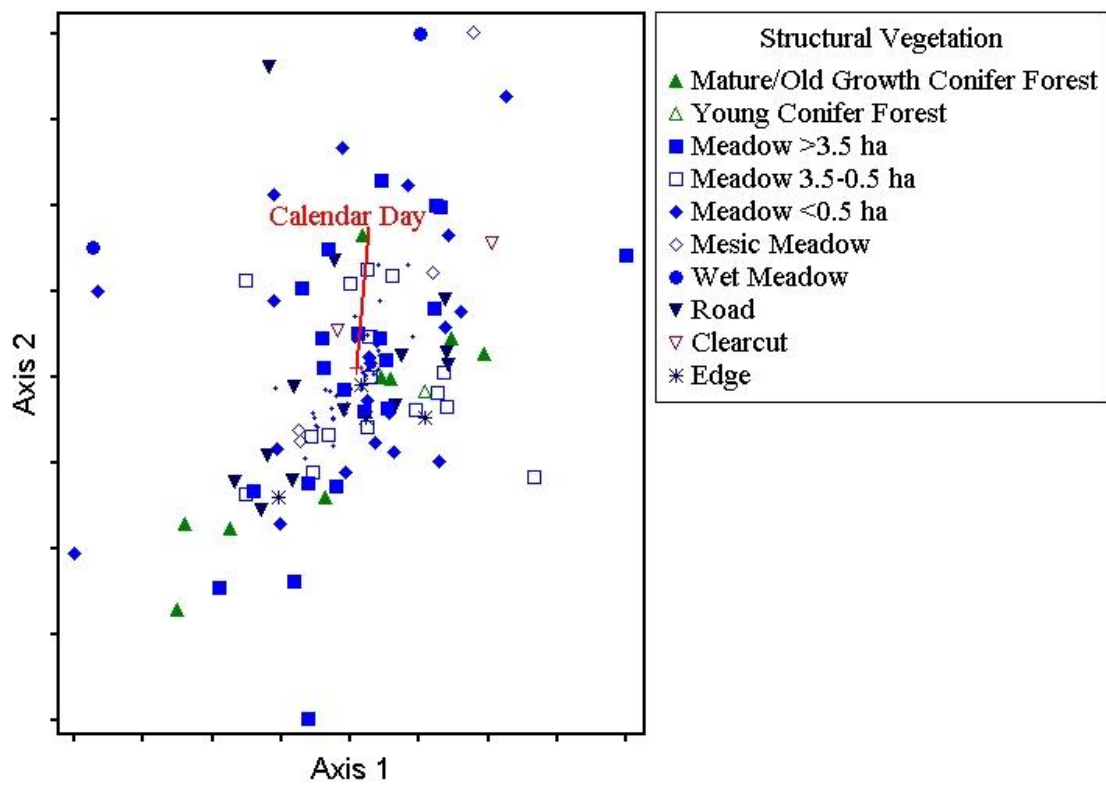


Figure 4. 35. 2-D NMS ordination graphs of hardwood feeders using vegetation category 1 groupings.

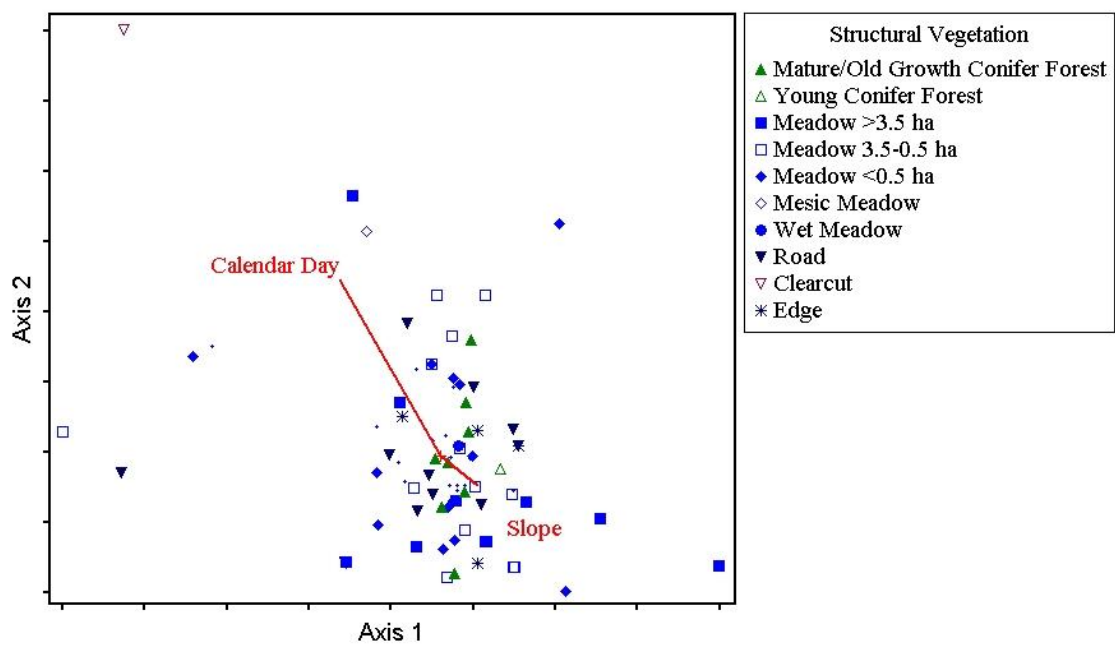


Figure 4. 36. 2-D NMS ordination graphs of gymnosperm feeders using vegetation category 1 groupings.

CHAPTER 5: CONCLUSIONS

Understanding the contemporary and historical context is important for understanding the contemporary ecology of a landscape. Identifying the changing configuration of a landscape, the potential causes of those configuration changes, and the contemporary patterns of plants and insects within this dynamic setting requires the combination of multiple disciplines and methods. Land use and climate change are the most severe threats to biodiversity today (Parmesan and Yohe 2003). Managing the landscape to preserve and, perhaps, enhance biodiversity requires knowledge of the forces that have shaped the current configuration of the organisms and communities of concern. To better understand the variable influencing the plant and moth diversity of montane meadow in the western Cascades of Oregon, I conducted studies on the archeology, meadow configuration, plant ecology, and moth ecology of the montane meadows in the Andrews Forest and surrounding area. Results of this research provide useful insight for managers interested in managing the overall landscape for biodiversity and the protection of rare habitats and species, and they provide insights into the ecological patterns of moths and plants in dynamic landscapes.

Prehistoric Land Use and Occupational Patterns

In chapter 2, the prehistoric patterns of land use and occupation in the western Cascades are examined. Prehistoric use patterns in the McKenzie River watershed display strong geographic patterns at several spatial scales, indicating particular patterns of use of vegetation, wildlife, and mineral resources. Prehistoric people preferred particular parts of the landscape, and these preferences varied among the lower, middle, and upper portions of the McKenzie River watershed. The lower, western portion of the McKenzie River valley is similar to the Willamette Valley, and prehistoric site locations indicate preferences for wide river valley riparian forests, woodlands, and prairies. These preferences are consistent with the availability of unique plant species (tarweed, hazelnut, oak) in these areas. The middle portion of the McKenzie River valley, represented by the western Cascades portion of the Willamette National Forest, was utilized both for riparian and upland resources. The high concentration of scrapers and projectile points in this section of wide, open McKenzie River valley floor indicates that this area was used for hunting, as well as for gathering camas and other riparian plant resources. In the middle portion of the McKenzie River valley, prehistoric people also utilized meadows and shrub/open forests along broad, gently sloping ridges. These areas were probably utilized for gathering huckleberries, meadow plants, and, to a lesser extent, hunting.

In both the lower and middle portions of the McKenzie river valley, high concentrations of scrapers and large sites with many artifacts indicate that wide valley floors were preferred locations for major campsites. These major camps may have served as bases from which small groups of people would depart for specific gathering activities in the uplands and to which they would return with partially dried or prepared foods. None of these sites, and very few in the McKenzie River valley as a whole, have been excavated and/or extensively investigated, so it is not known whether these camps were utilized all winter or were seasonal in nature.

Prehistoric people utilized the upper McKenzie River watershed, as represented by the High Cascades, very differently from the lower and middle McKenzie River watershed. Archaeological sites are uniformly distributed among landform and vegetation types in the High Cascades. This suggests that the High Cascades were not intensively utilized for food resources. Although the High Cascades were not avoided (this area contains 92 of the 363 known prehistoric archeological sites in the McKenzie River valley), the uniform distribution of prehistoric sites, as well as the presence of only four projectile points located near the boundary of the West and High Cascades, suggests that the High Cascades were used primarily for other purposes than food collection. Maps of the area from the late 1800s show many trails oriented generally north-south in the High Cascades, whereas trails in the western Cascades are oriented in all directions. It is possible that the High Cascades had little to offer concerning food resources, but was chiefly utilized as a travel corridor.

The high ridges of the western Cascades were utilized by prehistoric people, though not to the degree that wide valley bottoms were. Still, prehistoric people utilized high ridges, with archeological sites showing a clear association with relatively flat saddles currently identified as small meadow or very open forest containing various *Vaccinium* spp. Additionally, the use of the high ridges for hunting is likely as projectile points are also found there. Ridges were also utilized for trail systems, as indicated by historic maps and ethnographic information. Ethnographic and historic records suggest that ridgeline trails, hunting yards, and huckleberry patches were all managed with fire. This suggests that low intensity, frequent fires may have been utilized on ridges, keeping meadows open, and the cessation of these management activities have lead to the large contractions of the meadows since early historic times.

Moth Distribution in the western Cascades and Visualization Tool

In chapter 3, the overall patterns of moth distribution in the western Cascades is examined along with a new tool useful for examining ecological patterns in large datasets. Moths in the western Cascades are closely tied to the distribution of vegetation in the landscape through feeding-guild associations (Hammond and Miller 1998, Miller et al 2003). Moths are far more likely to be found in

parts of the landscape that are associated with their host-plants. When aggregated by year, moth community structure was explained very well by both structural and taxonomic vegetation descriptors, as the two types of vegetation categorization matched closely. Grouping moths by host-plant taxonomically derived vegetation communities showed some advantages over structural vegetation descriptors, but both functioned well as identifiers of moth community structure. Taxonomically derived vegetation communities allowed for the identification of indicator plant species that can be used to identify localities of specific moth species assemblages, while structural vegetation descriptors cannot. Structural vegetation descriptors, though, are simpler and less time-consuming, yet still provide significant grouping descriptors for moth communities. While Ober and Hayes (2010) found that percent cover, similar to our structural vegetation categories, was a better indicator of moth community patterns than taxonomic vegetation descriptors in the Oregon Coast Range, we found that using host-plant richness and distribution is slightly better at identifying moth community patterns.

Moth species richness and abundance is higher in the lower elevations and lower in the higher elevations. Moth communities at higher elevations experience much more year to year variability. Moth richness and abundance was also found to be positively associated with mature/old-growth conifer forests and, secondarily, young conifer plantations. When not aggregated by year, moth diversity is driven by seasonality far more than by vegetation or landscape patterns. The changes in community structure and diversity in any one location is far larger over the course of a few months than the changes in community structure and diversity in very different habitats at any one time.

We found that rare moths were more likely to occur in rare, open habitats. This finding agrees with previous research (Miller et al. 2003), who found that the rare, open habitats on the higher ridges of the western Cascades were associated with rare moths. We also found that while rare moths are more likely to be associated with open habitats such as meadows, they are more likely to be hardwood-feeders and secondarily herb-feeders. Common moths, on the other hand, were more likely to occur in low elevation conifer forests. Hammond and Miller (1998) identified the conifer-feeding guild as containing the most abundant moth species in the western Cascades, though not the most species. This finding is supportive of prior findings that link biomass abundance to insect abundance (Knops et al. 1999) and is a driver in the overall abundance patterns that we found, as there are a few hyper-abundant moth species in the Andrews Forest and they are associated with lower elevation conifers and riparian hardwoods, secondarily.

Moths are temperature sensitive and their maturation and survival is partially influenced by alterations in climatic patterns. We found that common moths emerge as adults earlier in warmer years and later in colder years. While previous studies have linked moth survivorship and butterfly range expansions to warmer climates (Han and Bauce 1998, Parmesan et al. 1999), no studies have shown that slight changes in yearly climate will affect the emergence patterns of adult moths as a group. As moth species are largely synchronous in their behavior regarding weather (Raimondo et al. 2004), this finding identifies alterations in moth behavior as a potential concern in regards to the landscape effects of climate change. Additionally, the effects of climate may have a larger impact on moth communities at a higher elevation. As survivorship of some moths has been found to be related to winter and spring temperature patterns (Han and Bauce 1998) and the upper elevations of the Andrews Forest experience heavier snow and freezing temperatures than the mid and lower elevations,

Moth diversity is linked with the diversity of their host-plants. Knowledge of and management for moth host-plants is an important step in managing for moth diversity. This is especially true when managing for rare species. Rare moth species are linked to rare habitats, specifically high elevation openings in the Andrews Forest and, likely, western Cascades. As these habitats are rare and are currently contracting (Miller and Halpern 1998, Takaoka and Swanson 2008), management for the preservation and expansion of these habitats is a priority, if biodiversity is a goal. Additionally, as the moth communities in these habitats are subject to higher variability from year to year and are potentially more at risk due to climate change, effective management strategies for conserving and expanding these habitats now and under potential future scenarios is needed. The visualization tool that we developed has the capacity to help managers identify these trends and others and to help direct the focus of managers to important but vulnerable parts of the landscape. Collaboration between ecologists and computer scientists can potentially provide powerful tools for ecologists and managers for identifying important ecological trends. Collaboration from the beginning of a project and interactive construction of the tools is important and can result in the creation of relevant and useful tools for creating, focusing, and generating ecological hypotheses as well as providing a useful, easy, and interactive tool for managers interested in exploring patterns of biodiversity on a landscape.

Effects of Changing Meadow Configuration on Plant and Moth Distribution

This study showed that species and groups of species respond to changes in landscape configurations in different ways and at different rates. Richness and abundance of herbaceous plants, grasses, and herb-feeding moths associated with contracting meadows in the Andrews Forest was

more closely related to the configuration of the landscape in 1949 than to the contemporary landscape. In contrast, richness and abundance of moths that are reliant on non-meadow host plants, such as hardwood shrubs and conifer (gymnosperm) trees, were more closely related to characteristics of the present-day landscape.

Plants and insects reliant on contracting meadow habitats in the Andrews Forest appear to be subject to extinction debt. Over the past half-century, as meadow habitats have decreased in size and become more isolated, the richness, abundance, and community structure of plants and moths in that habitat did not respond immediately, but rather have persisted for multiple decades. Moth communities appeared to have responded more rapidly than plant communities, but moth community response to changing meadow habitat may be obscured by complexities of moth community diversity, including high turnover of moths within the spring to autumn, differences in responses among feeding guilds, and the fact that the study was based on sampling of adult moths, which are less likely to be found near host plants than caterpillars.

This study provides evidence for compensatory dynamics among groups of moth species associated with meadow, hardwood shrub, and conifer forest habitats in high-elevation areas of the Andrews Forest. Although meadow-dependent (herb-feeder) moth species appear to have declined with meadow contraction over the past 60 years, richness and abundances of hardwood and gymnosperm feeders, whose habitats expand with the contraction of meadows, appear to have increased. In contrast, Houlahan et al (2007) found evidence for synchronous changes in populations in response to external drivers such as temperature and moisture, rather than compensatory dynamics. In this study, the reciprocal relationships among groups of moth species were only evident in conjunction with a detailed study of changes in various habitat types and their relationships with moth host plant feeding guilds.

Paradoxically, the construction of roads in the high-elevation ridges of the Andrews Forest appears to have helped preserve habitat connectivity and counteract the loss of meadow plant and moth species as a result of meadow contraction. Roads apparently had a positive effect on herbaceous plants and herb-feeder moth species because they created and connected open meadow habitats, or because they were constructed in, and therefore maintained, highly diverse open habitats, or both. Moreover, meadow contraction rates, and implied rates of decline of associated moth and plant species, differed between the meadow complexes. The differential rates of meadow decline may be related to patterns of prehistoric vegetation management, which may have been more intensive in some portions of the high ridges of the Andrews Forest than in others (see Chapter 2, this dissertation). Thus, moth and plant species response to recent meadow contraction is not a simple

function of meadow area, but also depends on many other factors including moth-plant interactions, historical legacies, and counteracting factors, such as connectivity provided by roads.

Meadows account for a very small part of the landscape of the western Cascades, but contribute a great deal of biodiversity. Herb and hardwood feeding moths are positively influenced by the presence of meadows, whether through the plants in the interior or edge of the meadows. These two feeding guilds account for the majority of rare moth species in the western Cascades. If managers wish to preserve rare species and landscape biodiversity, it will be necessary to actively manage meadows to increase their sizes and connectivities. Active conservation measures should be undertaken soon, because some rare moths and plants have persisted despite recent declines in meadow area, but these species are likely to go extinct in the future unless meadow area increases.

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APPENDICES

Appendix A. Presence-absence assessment for host-plant species within a 50-m radius of the 20 moth trap sites.

Trap Sites	23 A	23 Q	16 B	16 M	18 A	18 G	15 E	15 D	28 D	28 C	5P	5O	26 H	26 B	39 H	39 B	3K	3G	13 B	13 C	Total Trap Sites with Plant
Coniferous Trees																					
<i>Abies amabilis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	1	1	1	5
<i>Abies grandis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
<i>Abies lasiocarpa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	2
<i>Abies procera</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	-	1	3
<i>Abies sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1	2
<i>Calocedrus decurrrens</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Pseudotsuga menziesii</i>	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	-	1	1	19
<i>Thuja plicata</i>	-	-	1	1	1	1	1	-	1	1	1	1	1	-	-	-	-	-	-	-	10
<i>Tsuga heterophylla</i>	1	1	1	1	-	1	1	-	1	1	1	1	1	1	-	1	-	-	1	-	14
<i>Tsuga mertensiana</i>	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	1	-	2
Total Coniferous Trees	2	2	3	3	2	3	3	1	3	4	3	3	3	2	4	4	2	2	5	4	
Hardwood Trees and Shrubs																					
<i>Acer circinatum</i>	1	1	1	1	1	1	1	-	1	1	1	1	1	1	-	1	1	-	1	-	16
<i>Acer macrophyllum</i>	-	1	1	1	1	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-	6
<i>Alnus rubra</i>	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Alnus sinuata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	-	2

Trap Sites	23 A	23 Q	16 B	16 M	18 A	18 G	15 E	15 D	28 D	28 C	5P	5O	26 H	26 B	39 H	39 B	3K	3G	13 B	13 C	Total Trap Sites with Plant	
<i>Arbutus menziesii</i>	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Betula spp</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Castanopsis chrysophylla</i>	-	-	-	1	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	3
<i>Cornus nuttalli</i>	1	-	-	1	-	-	1	-	-	1	-	1	-	-	-	-	-	-	-	-	-	5
<i>Cornus stolonifera</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Fraxinus alnifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Myrica sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Oemleria cerasiformis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Populus trichocarpa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Prunus sp.</i>	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Quercus garryana</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Amelanchier alnifolia</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	1
<i>Arctostaphylos manzanita</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Arctostaphylos nevadensis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
<i>Arctostaphylos uva-ursi</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Ceanothus cuneatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1

Trap Sites	23 A	23 Q	16 B	16 M	18 A	18 G	15 E	15 D	28 D	28 C	5P	5O	26 H	26 B	39 H	39 B	3K	3G	13 B	13 C	Total Trap Sites with Plant
<i>Ceanothus velutinus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	2
<i>Cercocarpus montanus</i>	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	1
<i>Corylus cornuta</i>	1	1	1	1	1	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	7
<i>Cretaegus douglasii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Gaultheria shallon</i>	1	1	1	1	-	1	1	-	1	-	-	1	1	1	-	1	-	-	-	-	11
<i>Holodiscus discolor</i>	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	3
<i>Juniperus sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
<i>Physocarpus capitatus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Purshia tridentata</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Rhamnus purshiana</i>	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	2
<i>Rhododendron macrophyllum</i>	1	1	1	1	-	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	14
<i>Ribes sp.</i>	-	-	-	-	-	-	-	1	-	-	-	-	1	-	1	-	1	1	1	1	6
<i>Rosa sp.</i>	1	1	-	-	1	-	-	1	-	-	-	-	-	-	-	1	1	1	1	1	8
<i>Rubus parviflorus</i>	-	-	-	-	1	-	-	-	-	-	1	-	-	-	1	1	1	1	1	-	7
<i>Rubus spectabilis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1
<i>Salix sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0

Trap Sites	23 A	23 Q	16 B	16 M	18 A	18 G	15 E	15 D	28 D	28 C	5P	5O	26 H	26 B	39 H	39 B	3K	3G	13 B	13 C	Total Trap Sites with Plant	
<i>Sambucus cerulea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Sambucus racemosa</i>	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-	3
<i>Spirea douglasii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Symphoricarpus albus</i>	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	1	-	-	1	-	3
<i>Vaccinium sp.</i>	1	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1	1	-	1	1	1	18
Total Hardwood Trees and Shrubs	7	7	8	9	6	4	6	8	4	6	7	6	5	4	8	5	9	4	9	3		
Herbaceous Plants and Grasses																						
<i>Achillea millefolium</i>	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	3
<i>Angelica sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
<i>Aquilegia formosa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	1	-	2
<i>Asteraceae</i>	-	-	1	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	4
<i>Castilleja sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
<i>Delphinium sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	1
<i>Epilobium angustifolium</i>	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Ligusticum grayii</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	3
<i>Lonicera spp</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Lupinus sp.</i>	-	-	1	-	-	1	-	-	-	-	1	1	-	-	1	1	1	-	1	1	-	9

Trap Sites	23 A	23 Q	16 B	16 M	18 A	18 G	15 E	15 D	28 D	28 C	5P	5O	26 H	26 B	39 H	39 B	3K	3G	13 B	13 C	Total Trap Sites with Plant	
<i>Penstemon sp.</i>	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
<i>Phlox diffusa</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	1
<i>Polystichum munitum</i>	1	1	1	1	1	1	1	-	-	1	1	1	1	-	-	-	-	-	1	-	-	12
<i>Pteridium aquilinum</i>	1	1	1	1	-	1	-	-	-	-	1	-	-	-	1	1	1	1	1	1	1	12
<i>Rubus sp.</i>	1	-	-	1	1	1	-	1	1	-	1	-	1	-	1	-	1	1	1	1	-	12
<i>Senecio jacobaea</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Unk. Grass</i>	-	-	1	1	-	-	1	1	-	-	1	-	-	1	1	1	1	1	1	1	1	12
<i>Unk. Sedge or Rush</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	2
<i>Urtica sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0
<i>Vicia sp.</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	1	1	3
Total Herbaceous Plants/ Grasses	3	2	5	4	4	4	2	4	1	1	6	2	2	2	4	3	8	3	9	11		
Total Plant spp. in Trap Site	12	11	16	16	12	11	11	13	8	11	16	11	10	8	16	12	19	9	23	18		

Appendix B. Summary of the characteristics of the 26 most common and 66 rare moths species trapped in 20 moth traps in the Andrews Forest over May to October of 2004 through 2008. . Rare species were defined as those for which 5-10 individuals were trapped over the five-year period.

Common Moth Species		Total Individuals Captured Per Year					
	Foodplant	2004	2005	2006	2007	2008	Total
<i>Achytonix</i>							
<i>epipaschia</i>	Conifer	172	158	105	164	118	717
<i>Caripeta divisata</i>	Conifer	181	149	89	69	99	587
<i>Ceratodalia</i>							
<i>gueneata</i>	Unknown	92	85	110	58	190	535
<i>Clemensia albata</i>	Hardwood	607	986	1574	256	350	3773
<i>Enypia packardata</i>	Conifer	413	535	375	332	183	1838
<i>Enypia venata</i>	Conifer	25	172	192	269	112	770
<i>Euchlaena tigrinaria</i>	Hardwood	149	96	151	147	110	653
<i>Eupithecia graefii</i>	Hardwood	185	144	225	278	293	1125
<i>Gabriola dyari</i>	Conifer	160	193	138	175	244	910
<i>Hydriomena</i>							
<i>renunciata</i>	Hardwood	70	159	271	263	117	880
<i>Iridopsis emasculata</i>	Hardwood	544	380	405	306	73	1708
<i>Lacinipolia cuneata</i>	Hardwood	210	194	134	197	43	778
<i>Melanolophia</i>							
<i>imitata</i>	Conifer	69	331	945	386	1269	3000
<i>Nadata gibbosa</i>	Hardwood	99	155	262	156	38	710
<i>Neocalcis</i>							
<i>californiaria</i>	Mix	119	805	199	189	42	1354
<i>Nepytia umbrosaria</i>	Conifer	400	900	981	1287	1128	4696
<i>Orthosia</i>							
<i>transparentes</i>	Hardwood	10	64	106	45	304	529
<i>Panthea portlandia</i>	Conifer	384	619	896	354	135	2388
<i>Perizoma grandis</i>	Unknown	258	349	270	138	185	1200
<i>Pero behrensaria</i>	Conifer	333	161	191	242	496	1423
<i>Pero mizon</i>	Hardwood	682	356	359	429	456	2282
Common Moth Species		Total Individuals Captured Per Year					
<i>Semiothisa</i>							
<i>burneyata</i>	Conifer	348	86	38	57	18	547
<i>Semiothisa signaria</i>	Conifer	1590	1821	1447	883	1077	6818
<i>Stannoctenis</i>							
<i>pearsalli</i>	Unknown	162	144	167	196	261	930
<i>Venusia pearsalli</i>	Hardwood	54	386	656	79	25	1200

<i>Zale minerea</i>	Hardwood	15	100	279	86	58	538
<i>Grand Total</i>		7331	9528	10565	7041	7424	41889

Rare Moth Species	Foodplant	Total Individuals Captured Per Year					Total
		2004	2005	2006	2007	2008	
<i>Abagrotis erratica</i>	hardwood	1	1	1	2	2	7
<i>Abagrotis forbesi</i>	unknown	5	0	0	3	1	9
<i>Abagrotis placida</i>	unknown	7	0	0	1	0	8
<i>Abagrotis scopeops</i>	hardwood	4	1	0	1	1	7
<i>Abagrotis variata</i>	hardwood	3	1	1	2	0	7
<i>Acronicta impressa</i>	hardwood	3	1	1	0	0	5
<i>Acronicta perditia</i>	hardwood	1	0	4	4	1	10
<i>Agrotis vancouverensis</i>	herb	2	1	3	0	0	6
<i>Apamea finitima</i>	herb	0	0	5	0	0	5
<i>Apamea occidentis</i>	herb	0	2	1	1	3	7
<i>Autographa corusca</i>	herb	2	1	3	1	0	7
<i>Behrensia conchiformis</i>	hardwood	0	7	0	0	2	9
<i>Catocala relictia</i>	hardwood	1	0	1	2	1	5
<i>Cosmia calami</i>	hardwood	8	1	1	0	0	10
<i>Crassivesica bocha</i>	herb	3	2	0	0	1	6
<i>Crymodes devastator</i>	herb	1	3	0	1	2	7
<i>Cucullia postera</i>	unknown	1	0	0	5	1	7
<i>Discestra oregonica</i>	unknown	0	1	1	3	1	6
<i>Drepana bilineata</i>	hardwood	1	1	1	2	0	5
<i>Dryotype opina</i>	herb	2	0	4	3	1	10

Rare Moth Species		Total Individuals Captured Per Year					Total
		2004	2005	2006	2007	2008	
<i>Entephria multivagata</i>	gymno	1	2	0	1	1	5
<i>Eosphropteryx thyatyroides</i>	herb	0	2	0	3	0	5
<i>Eupithecia columbrata</i>	mix	2	4	0	0	0	6
<i>Eupithecia miserulata</i>	unknown	2	0	6	0	0	8
<i>Euxoa auxiliaris</i>	herb	0	1	0	6	0	7
<i>Euxoa brunneigera</i>	herb	2	0	0	3	0	5
<i>Euxoa declarata</i>	herb	2	1	2	0	1	6
<i>Euxoa infausta</i>	herb	2	1	0	5	2	10

<i>Euxoa plagigera</i>	herb	5	1	0	1	1	8
<i>Euxoa simona</i>	herb	0	0	0	4	2	6
<i>Euxoa tessellata</i>	herb	2	0	0	3	0	5
<i>Euxoa tocoyae</i>	unknown	0	0	0	0	9	9
<i>Grammia ornata</i>	herb	0	1	5	1	0	7
<i>Hesperumia fumosaria</i>	unknown	0	0	0	2	3	5
<i>Homorthodes discreta</i>	unknown	0	0	0	0	7	7
<i>Hydriomena manzanita</i>	hardwood	3	1	3	0	1	8
<i>Hypena humuli</i>	herb	3	4	0	0	0	7
<i>Idaea dimidiata</i>	herb	1	1	0	0	3	5
<i>Ipimorpha nanaimo</i>	unknown	0	5	1	0	0	6
<i>Lacanobia subjuncta</i>	hardwood	2	2	1	3	0	8
<i>Lacinipolia patalis</i>	hardwood	2	4	1	2	0	9
<i>Leucania anteoclara</i>	herb	0	5	2	0	0	7
<i>Litholomia napaea</i>	hardwood	1	8	0	0	0	9
<i>Lithophane baileyi</i>	unknown	2	0	6	0	1	9
<i>Metarranthis duaria</i>	hardwood	0	1	1	1	3	6
<i>Mycterophora longipalpata</i>	herb	4	1	0	1	1	7
<i>Nola minna</i>	hardwood	0	1	2	3	1	7
<i>Nycteola columbiana</i>	hardwood	2	5	0	0	0	7

Rare Moth Species		Total Individuals Captured Per Year					
<i>Oncocnemis newspecies</i>	unknown	0	0	0	6	0	6
<i>Papestra invalida</i>	hardwood	0	0	0	5	1	6
<i>Pleromella opter</i>	hardwood	2	5	2	0	0	9
<i>Protitame matilda</i>	hardwood	0	0	0	5	3	8
<i>Protorthodes curtica</i>	herb	1	2	0	1	1	5
<i>Pyrrhia exprimens</i>	hardwood	1	1	1	3	1	7
<i>Scoliopteryx libatrix</i>	hardwood	0	0	4	2	2	8
<i>Semiothisa neptaria</i>	hardwood	0	0	0	8	0	8
<i>Semiothisa ulsterata</i>	hardwood	2	1	3	1	3	10
<i>Sphinx perelegans</i>	hardwood	1	0	0	2	3	6
<i>Spodoptera praefica</i>	herb	2	2	1	0	1	6
<i>Stretchia plusiaeformis</i>	hardwood	0	3	2	0	4	9
<i>Syngrapha orophila</i>	hardwood	4	1	0	0	0	5
<i>Syngrapha</i>	gymno	2	7	0	1	0	10

<i>rectangula</i>							
<i>Xanthorhoe</i>							
<i>ferrugata</i>	herb	2	3	1	0	2	8
<i>Xestia vernilis</i>	unknown	0	6	0	0	1	7
<i>Xylena cineritia</i>	hardwood	0	0	1	0	4	5
<i>Zothecca tranquila</i>	hardwood	0	0	0	0	7	7
Grand Total		100	105	72	104	86	467

Appendix C. Abundance (4955 total individuals), richness (248 total species and 16 unidentified groups), Simpson's Diversity Index, Shannon's Diversity Index, and Pielou's Evenness Index for all moths species based on 98 moth samples. Meadow complexes are C=Carpenter Mountain, B=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, L=Lookout Mountain.

Moth Sample	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
bx311	125	37	0.77	2.79	0.87
bx32a1	44	23	0.87	2.74	0.90
bx35a1	146	30	0.74	2.52	0.83
lx4a5	80	31	0.84	2.89	0.91
lx4c2	43	24	0.93	2.96	0.93
m1x1a3	50	15	0.83	2.25	0.85
m2cc11	11	8	0.91	1.89	0.81
m2x21a4	5	5	1.00	1.61	0.80
m2x23c1	56	14	0.61	1.61	0.61
m2x23g1	59	25	0.88	2.84	0.92
bx32a2	79	28	0.78	2.61	0.87
bx32b1	127	38	0.84	3.06	0.93
bx32fr1	110	27	0.76	2.51	0.86
bx35a2	72	17	0.72	2.03	0.74
cx281	10	9	0.99	2.16	0.88
cx41a1	94	19	0.72	2.12	0.78
cx41c1	109	35	0.84	2.97	0.91
cx431	43	21	0.92	2.79	0.92
cx432	55	20	0.88	2.63	0.91
cx44a1	17	5	0.54	0.87	0.40
frsa1	114	34	0.86	3.05	0.93
frsgs1	106	42	0.91	3.41	0.96
lw21	26	14	0.92	2.43	0.89
lx1a4	103	40	0.92	3.38	0.95
lx1b1	43	24	0.87	2.77	0.89
m1asa2	120	46	0.90	3.46	0.96
m1gs2	95	27	0.83	2.72	0.89
m1m2r1	43	29	0.96	3.22	0.95
m1m2rj2	34	24	0.94	2.99	0.94
m1m53	55	33	0.95	3.33	0.96
m1m54	27	16	0.93	2.58	0.91
m1x1a1	29	9	0.81	1.79	0.79
m1x1a4	70	29	0.88	2.95	0.93
m1x1ae1	75	22	0.88	2.73	0.92
m1x1aL1	64	14	0.64	1.70	0.65

Moth Sample	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
m1x1au1	80	18	0.64	1.85	0.68
m1x1m5f1	12	9	0.92	2.02	0.83
m1x1m5F1	90	25	0.76	2.45	0.84
m1x1m5f2	87	21	0.87	2.66	0.90
m1x1m5g1	62	24	0.88	2.80	0.92
m1x1m5r1	50	28	0.94	3.14	0.95
m221afF1	86	33	0.91	3.17	0.95
m221afr1	38	23	0.96	3.01	0.94
m2x21a3	28	11	0.90	2.16	0.86
m2x21a5	14	8	0.92	1.91	0.83
m2x21a1	19	5	0.63	1.02	0.50
m2x21au1	37	10	0.83	1.90	0.81
m2x21f1	5	4	0.96	1.33	0.72
m2x23f1	58	22	0.88	2.73	0.91
b44x43f1	66	33	0.91	3.17	0.94
b44x43f2	26	16	0.97	2.69	0.93
bsa1	143	34	0.84	2.94	0.90
bx431	98	30	0.88	2.98	0.93
bx441	33	20	0.92	2.76	0.92
bx442	70	23	0.90	2.84	0.92
bx44e1	17	14	0.95	2.51	0.90
bx45a1	8	8	1.00	2.08	0.88
cx282	139	38	0.81	2.96	0.91
cx28e1	73	29	0.85	2.85	0.90
cx28f1	56	24	0.86	2.74	0.90
lx1a5	54	19	0.91	2.68	0.91
lx4a2	44	15	0.84	2.28	0.85
lx4c3	9	7	0.97	1.89	0.84
lx4cf1	36	19	0.95	2.79	0.93
m221afF2	159	44	0.87	3.29	0.94
m2x21a1	111	38	0.85	3.09	0.93
m2x21ae1	185	38	0.81	2.96	0.91
cx41a2	9	9	1.00	2.20	0.89
cx41c2	91	28	0.81	2.69	0.87
cx44c1	4	4	1.00	1.39	0.75
cx44c2	4	3	0.95	1.04	0.63
cxL41a3	11	8	0.97	2.02	0.86
lx1a1	76	31	0.88	3.02	0.92
lx4a3	24	12	0.91	2.27	0.88

Moth Sample	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
m1asa1	19	18	0.99	2.87	0.94
m1m2rj1	25	21	0.98	2.98	0.94
m1m51	9	8	0.98	2.04	0.86
m1m52	13	8	0.93	1.93	0.83
m1x141	18	9	0.92	2.03	0.85
m1x1a2	46	18	0.81	2.33	0.86
m1x1ac1	17	10	0.89	2.04	0.82
m1x1anw1	8	4	0.88	1.21	0.66
m1x1asw1	27	14	0.92	2.42	0.89
m2cc1r1	23	17	0.96	2.71	0.92
m2s1	13	12	0.99	2.46	0.91
m2x21a2	20	13	0.93	2.39	0.89
m2x23a1	16	14	0.99	2.60	0.92
ltc1	2	2	1.00	0.69	0.50
ltr1	8	7	0.98	1.91	0.84
lw11	7	6	0.98	1.75	0.82
lw22	17	13	0.97	2.48	0.91
lx15b1	31	22	0.97	3.00	0.94
lx1a2	29	21	0.95	2.90	0.93
lx1a3	17	6	0.72	1.29	0.61
lx4a1	4	3	0.95	1.04	0.63
lx4a4	12	9	0.92	2.02	0.83
lx4c1	6	5	0.97	1.56	0.78
m2x21au2	17	8	0.81	1.69	0.73

Appendix D. Hardwood-feeder moth species abundance (1413 total individuals), richness (113 total species), Simpson's Diversity Index, Shannon's Diversity Index, and Pielou's Evenness Index for the 98 moth samples. Meadow complexes are C=Carpenter Mountain, B=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, L=Lookout Mountain.

Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
b44x43f1	37	16	0.85	2.37	0.86
b44x43f2	12	8	0.97	2.02	0.86
bsa1	42	14	0.88	2.33	0.87
bx311	21	11	0.88	2.11	0.83
bx32a1	8	8	1.00	2.08	0.88
bx32a2	15	12	0.96	2.40	0.90
bx32b1	30	15	0.90	2.43	0.88
bx32fr1	39	14	0.74	1.95	0.75
bx35a1	21	11	0.94	2.24	0.88
bx35a2	19	7	0.93	1.81	0.82
bx431	34	8	0.74	1.54	0.70
bx441	17	12	0.92	2.28	0.87
bx442	24	8	0.88	1.83	0.80
bx44e1	6	3	0.79	0.87	0.50
bx45a1	2	2	1.00	0.69	0.50
cx281	4	3	0.95	1.04	0.63
cx282	36	14	0.89	2.36	0.88
cx28e1	15	11	0.96	2.30	0.89
cx28f1	9	7	0.94	1.83	0.81
cx41a1	21	7	0.85	1.66	0.75
cx41a2	4	4	1.00	1.39	0.75
cx41c1	37	16	0.80	2.21	0.81
cx41c2	29	14	0.92	2.43	0.89
cx431	20	10	0.90	2.08	0.85
cx432	19	11	0.92	2.22	0.87
cx44a1	14	2	0.37	0.26	0.13
cx44c1	2	2	1.00	0.69	0.50
cx44c2	2	2	1.00	0.69	0.50
cxL41a3	3	2	0.92	0.64	0.44
frsa1	51	16	0.90	2.48	0.90
frsgs1	44	23	0.93	2.92	0.93
ltc1	2	2	1.00	0.69	0.50
ltr1	1	1	0.00	0.00	0.00
lw11	2	2	1.00	0.69	0.50
lw21	2	2	1.00	0.69	0.50

Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
lw22	5	4	0.96	1.33	0.72
lx15b1	11	8	0.97	2.02	0.86
lx1a1	28	14	0.89	2.36	0.88
lx1a2	11	6	0.86	1.54	0.73
lx1a3	1	1	0.00	0.00	0.00
lx1a4	33	19	0.97	2.85	0.94
lx1a5	13	6	0.93	1.67	0.79
lx1b1	13	9	0.93	2.03	0.84
lx4a1	1	1	0.00	0.00	0.00
lx4a2	21	7	0.68	1.33	0.59
lx4a3	4	3	0.95	1.04	0.63
lx4a4	2	2	1.00	0.69	0.50
lx4a5	11	9	0.98	2.15	0.88
lx4c1	3	2	0.92	0.64	0.44
lx4c2	9	9	1.00	2.20	0.89
lx4c3	1	1	0.00	0.00	0.00
lx4cf1	19	9	0.94	2.06	0.85
m1asa1	9	9	1.00	2.20	0.89
m1asa2	43	19	0.89	2.61	0.90
m1gs2	42	11	0.83	1.98	0.82
m1m2r1	27	16	0.93	2.59	0.91
m1m2rj1	10	7	0.94	1.83	0.82
m1m2rj2	23	13	0.91	2.34	0.88
m1m51	2	2	1.00	0.69	0.50
m1m52	6	3	0.79	0.87	0.50
m1m53	25	14	0.93	2.45	0.90
m1m54	16	7	0.89	1.73	0.80
m1x141	4	3	0.95	1.04	0.63
m1x1a1	9	4	0.83	1.15	0.62
m1x1a2	5	5	1.00	1.61	0.80
m1x1a3	3	3	1.00	1.10	0.67
m1x1a4	24	12	0.79	1.96	0.76
m1x1ac1	9	4	0.72	1.00	0.52
m1x1ae1	27	5	0.78	1.26	0.66
m1x1aL1	8	4	0.88	1.21	0.66
m1x1anw1	2	2	1.00	0.69	0.50
m1x1asw1	10	6	0.95	1.70	0.80
m1x1au1	15	5	0.89	1.44	0.73
m1x1m5f1	4	4	1.00	1.39	0.75

Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
m1x1m5F1	33	14	0.84	2.22	0.84
m1x1m5f2	21	8	0.91	1.89	0.83
m1x1m5g1	23	9	0.84	1.85	0.81
m1x1m5r1	24	13	0.94	2.42	0.90
m221afF1	29	14	0.91	2.40	0.89
m221afF2	38	15	0.95	2.57	0.92
m221afr1	16	11	0.96	2.31	0.89
m2cc11	1	1	0.00	0.00	0.00
m2cc1r1	12	7	0.92	1.79	0.81
m2s1	5	5	1.00	1.61	0.80
m2x21a1	28	14	0.84	2.21	0.83
m2x21a2	4	4	1.00	1.39	0.75
m2x21a3	8	4	0.91	1.26	0.69
m2x21a4	4	4	1.00	1.39	0.75
m2x21a5	5	2	0.72	0.50	0.32
m2x21ae1	42	12	0.83	2.06	0.82
m2x21al1	4	2	0.81	0.56	0.38
m2x21au1	8	3	0.67	0.74	0.41
m2x21au2	4	4	1.00	1.39	0.75
m2x21f1	2	2	1.00	0.69	0.50
m2x23a1	7	5	0.96	1.55	0.78
m2x23c1	3	3	1.00	1.10	0.67
m2x23f1	17	8	0.91	1.89	0.82
m2x23g1	22	14	0.91	2.41	0.88

Appendix E. Herb-feeder moth species abundance (1488 total individuals), richness (67 total species), Simpson's Diversity Index, Shannon's Diversity Index, and Pielou's Evenness Index for the 98 moth samples. Meadow complexes are C=Carpenter Mountain, B=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, L=Lookout Mountain.

Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
b44x43f1	10	8	0.95	1.97	0.84
b44x43f2	1	1	0.00	0.00	0.00
bsa1	72	11	0.71	1.70	0.70
bx311	38	15	0.82	2.21	0.82
bx32a1	15	10	0.90	2.08	0.84
bx32a2	8	5	0.86	1.39	0.69
bx32b1	42	10	0.76	1.75	0.74
bx32fr1	6	3	0.79	0.87	0.50
bx35a1	24	10	0.87	2.00	0.82
bx35a2	45	5	0.49	0.79	0.38
bx431	24	9	0.80	1.75	0.76
bx441	5	2	0.72	0.50	0.32
bx442	12	7	0.96	1.86	0.83
bx44e1	5	5	1.00	1.61	0.80
bx45a1	2	2	1.00	0.69	0.50
cx281	3	3	1.00	1.10	0.67
cx282	17	10	0.96	2.20	0.88
cx28e1	5	3	0.87	0.95	0.56
cx28f1	5	5	1.00	1.61	0.80
cx41a1	62	9	0.54	1.19	0.53
cx41a2	3	3	1.00	1.10	0.67
cx41c1	16	6	0.86	1.55	0.75
cx41c2	6	5	0.97	1.56	0.78
cx431	8	4	0.88	1.21	0.66
cx432	13	4	0.74	1.03	0.56
cx44a1	0	0	na	na	na
cx44c1	0	0	na	na	na
cx44c2	0	0	na	na	na
cxL41a3	5	4	0.96	1.33	0.72
frsa1	24	8	0.81	1.69	0.74
frsgs1	18	7	0.84	1.63	0.74
ltc1	0	0	na	na	na
ltr1	0	0	na	na	na
lw11	2	2	1.00	0.69	0.50
lw21	10	6	0.95	1.70	0.80

Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
lw22	5	5	1.00	1.61	0.80
lx15b1	5	5	1.00	1.61	0.80
lx1a1	14	7	0.90	1.75	0.80
lx1a2	10	9	0.99	2.16	0.88
lx1a3	15	4	0.69	0.95	0.51
lx1a4	35	13	0.85	2.18	0.84
lx1a5	34	9	0.89	1.96	0.83
lx1b1	16	12	0.96	2.39	0.90
lx4a1	2	1	0.00	0.00	0.00
lx4a2	2	2	1.00	0.69	0.50
lx4a3	5	4	0.96	1.33	0.72
lx4a4	7	4	0.83	1.15	0.61
lx4a5	19	10	0.87	2.01	0.81
lx4c1	1	1	0.00	0.00	0.00
lx4c2	15	7	0.95	1.84	0.83
lx4c3	5	3	0.96	1.06	0.64
lx4cf1	6	4	0.90	1.24	0.67
m1asa1	5	5	1.00	1.61	0.80
m1asa2	21	7	0.85	1.66	0.75
m1gs2	36	9	0.59	1.30	0.54
m1m2r1	8	8	1.00	2.08	0.88
m1m2rj1	10	9	0.99	2.16	0.88
m1m2rj2	4	4	1.00	1.39	0.75
m1m51	4	4	1.00	1.39	0.75
m1m52	4	2	1.00	0.69	0.50
m1m53	18	11	0.92	2.22	0.87
m1m54	3	3	1.00	1.10	0.67
m1x141	7	4	0.92	1.28	0.69
m1x1a1	12	4	0.60	0.84	0.42
m1x1a2	28	8	0.73	1.52	0.71
m1x1a3	38	9	0.81	1.78	0.77
m1x1a4	34	10	0.86	1.99	0.84
m1x1ac1	4	3	0.95	1.04	0.63
m1x1ae1	31	11	0.89	2.13	0.86
m1x1al1	47	6	0.47	0.85	0.37
m1x1anw1	6	2	0.92	0.64	0.44
m1x1asw1	15	6	0.85	1.53	0.74
m1x1au1	54	9	0.39	0.85	0.33
m1x1m5f1	2	2	1.00	0.69	0.50

Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
m1x1m5F1	8	6	0.97	1.73	0.81
m1x1m5f2	19	8	0.93	1.94	0.84
m1x1m5g1	7	6	0.98	1.75	0.82
m1x1m5r1	10	8	0.97	2.03	0.86
m221afF1	14	8	0.90	1.87	0.81
m221afF2	37	12	0.81	2.02	0.82
m221afr1	11	7	0.95	1.85	0.83
m2cc11	4	4	1.00	1.39	0.75
m2cc1r1	7	6	0.98	1.75	0.82
m2s1	5	4	0.96	1.33	0.72
m2x21a1	58	18	0.78	2.24	0.83
m2x21a2	11	5	0.88	1.41	0.71
m2x21a3	16	4	0.88	1.22	0.68
m2x21a4	0	0	na	na	na
m2x21a5	7	4	0.92	1.28	0.69
m2x21ae1	38	14	0.86	2.27	0.86
m2x21al1	15	3	0.44	0.49	0.24
m2x21au1	23	5	0.75	1.21	0.64
m2x21au2	10	2	0.72	0.50	0.32
m2x21f1	2	1	0.00	0.00	0.00
m2x23a1	4	4	1.00	1.39	0.75
m2x23c1	48	7	0.56	1.08	0.48
m2x23f1	22	7	0.79	1.53	0.70
m2x23g1	19	7	0.88	1.72	0.78

Appendix F. Gymnosperm-feeder moths species abundance (966 total individuals), richness (24 total species), Simpson's Diversity Index, Shannon's Diversity Index, and Pielou's Evenness Index for the 98 moth samples. Meadow complexes are C=Carpenter Mountain, B=BCM, M2=Meadow 2, M1=Meadow 1, FR=Frissel Ridge, L=Lookout Mountain.

Moth Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
b44x43f1	11	6	0.92	1.64	0.78
b44x43f2	6	3	0.92	1.01	0.61
bsa1	3	3	1.00	1.10	0.67
bx311	46	4	0.40	0.55	0.27
bx32a1	11	1	0.00	0.00	0.00
bx32a2	31	5	0.58	0.94	0.46
bx32b1	9	4	0.83	1.15	0.62
bx32fr1	17	5	0.62	1.00	0.48
bx35a1	71	5	0.45	0.72	0.36
bx35a2	4	2	0.81	0.56	0.38
bx431	12	5	0.94	1.52	0.76
bx441	3	3	1.00	1.10	0.67
bx442	12	3	0.98	1.08	0.65
bx44e1	3	3	1.00	1.10	0.67
bx45a1	1	1	0.00	0.00	0.00
cx281	2	2	1.00	0.69	0.50
cx282	61	8	0.61	1.27	0.64
cx28e1	45	10	0.78	1.79	0.78
cx28f1	23	9	0.89	1.96	0.83
cx41a1	7	1	0.00	0.00	0.00
cx41a2	0	0	na	na	na
cx41c1	43	8	0.67	1.40	0.63
cx41c2	20	4	0.92	1.28	0.69
cx431	12	5	0.77	1.23	0.61
cx432	21	3	0.95	1.05	0.63
cx44a1	2	2	1.00	0.69	0.50
cx44c1	0	0	na	na	na
cx44c2	2	1	0.00	0.00	0.00
cxL41a3	0	0	na	na	na
frsa1	5	4	0.96	1.33	0.72
frsgs1	19	7	0.82	1.60	0.74
ltc1	0	0	na	na	na
ltr1	5	4	0.96	1.33	0.72
lw11	1	1	0.00	0.00	0.00
lw21	10	3	0.82	0.90	0.54

Moth Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
lw22	2	1	0.00	0.00	0.00
lx15b1	5	3	0.87	0.95	0.56
lx1a1	13	7	0.91	1.78	0.80
lx1a2	1	1	0.00	0.00	0.00
lx1a3	0	0	na	na	na
lx1a4	19	3	0.90	0.99	0.60
lx1a5	0	0	na	na	na
lx1b1	13	2	0.39	0.27	0.14
lx4a1	0	0	na	na	na
lx4a2	11	3	0.83	0.91	0.53
lx4a3	6	2	0.65	0.45	0.28
lx4a4	0	0	na	na	na
lx4a5	33	5	0.77	1.23	0.63
lx4c1	1	1	0.00	0.00	0.00
lx4c2	15	4	0.92	1.27	0.69
lx4c3	0	0	na	na	na
lx4cf1	3	2	0.92	0.64	0.44
m1asa1	0	0	na	na	na
m1asa2	23	7	0.75	1.46	0.67
m1gs2	8	3	0.82	0.90	0.53
m1m2r1	3	2	0.92	0.64	0.44
m1m2rj1	0	0	na	na	na
m1m2rj2	4	4	1.00	1.39	0.75
m1m51	0	0	na	na	na
m1m52	1	1	0.00	0.00	0.00
m1m53	4	2	0.81	0.56	0.38
m1m54	3	2	0.92	0.64	0.44
m1x141	0	0	na	na	na
m1x1a1	0	0	na	na	na
m1x1a2	0	0	na	na	na
m1x1a3	6	1	0.00	0.00	0.00
m1x1a4	7	2	0.86	0.60	0.41
m1x1ac1	2	2	1.00	0.69	0.50
m1x1ae1	6	4	0.90	1.24	0.67
m1x1aL1	1	1	0.00	0.00	0.00
m1x1anw1	0	0	na	na	na
m1x1asw1	1	1	0.00	0.00	0.00
m1x1au1	4	2	0.81	0.56	0.38
m1x1m5f1	0	0	na	na	na

Moth Sample Name	Abundance	Richness	Simpson's Diversity Index	Shannon's Diversity Index	Pielou's Evenness Index
m1x1m5F1	11	3	0.55	0.60	0.31
m1x1m5f2	18	2	0.92	0.64	0.44
m1x1m5g1	18	6	0.84	1.50	0.72
m1x1m5r1	8	4	0.88	1.21	0.66
m221afF1	24	5	0.83	1.33	0.69
m221afF2	52	7	0.73	1.43	0.68
m221afr1	6	3	0.92	1.01	0.61
m2cc11	4	1	0.00	0.00	0.00
m2cc1r1	2	2	1.00	0.69	0.50
m2s1	1	1	0.00	0.00	0.00
m2x21a1	8	3	0.82	0.90	0.53
m2x21a2	0	0	na	na	na
m2x21a3	0	0	na	na	na
m2x21a4	1	1	0.00	0.00	0.00
m2x21a5	1	1	0.00	0.00	0.00
m2x21ae1	75	8	0.67	1.38	0.65
m2x21al1	0	0	na	na	na
m2x21au1	1	1	0.00	0.00	0.00
m2x21au2	2	1	0.00	0.00	0.00
m2x21f1	0	0	na	na	na
m2x23a1	0	0	na	na	na
m2x23c1	3	2	0.92	0.64	0.44
m2x23f1	5	2	0.72	0.50	0.32
m2x23g1	13	2	0.39	0.27	0.14

APPENDIX G. PLANT SPECIES PERCENT COVER DATA FOR THE 17 STOHLGREN-WHITTAKER PLOTS SAMPLED IN THE ANDREWS FOREST.

Plant Species	M2- x21a	CM- x28	M1- x1a	M2- x23c	M2- x23a	BCM- x32b	BCM- x44	BCM- x45a	M2- x21f	LOM- x4a	LOM- x4c	LOM- x1a	FR-gs	M1- pt	CM- x44c	CM- x43	CM- x41a
<i>Abies alnifolia</i>	0.00	19.71	0.00	0.00	0.00	0.00	0.50	9.43	3.67	0.00	21.00	0.00	0.00	0.00	0.00	0.00	5.00
<i>Abies amabilis</i>	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00	2.50	0.00	2.67	9.33	7.20	0.00	0.00
<i>Abies grandis</i>	0.00	0.00	0.00	0.00	9.67	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00
<i>Abies lasiocarpa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	2.67	0.00	0.00	7.00	0.00	1.70	0.00	0.00
<i>Abies procera</i>	0.00	3.53	0.00	0.00	11.67	0.00	2.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Acer circinatum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	2.07	0.00	0.00	0.00
<i>Achillea millefolium</i>	0.29	0.83	4.07	3.79	0.01	1.48	0.00	0.08	1.81	0.07	0.40	7.20	0.00	0.00	1.20	6.70	0.75
<i>Agroseris sp</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Alnus sitkaensis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.33	0.00	0.00	0.00
<i>Angelica arguta</i>	0.36	0.00	4.80	0.00	0.67	0.00	0.00	0.00	0.00	2.00	0.00	1.47	0.00	0.00	0.00	2.40	2.07
<i>Aquilegia formosa</i>	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.07
<i>Arctostaphylos nevadensis</i>	0.00	6.18	0.00	0.00	0.00	0.67	13.00	7.64	0.00	0.00	0.00	0.00	15.67	0.00	0.00	0.00	0.00
<i>Arnica sp</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Aster spp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
<i>Veronica sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
<i>Bromus carinatus</i>	4.71	0.00	1.47	0.01	2.00	1.33	0.00	0.00	13.33	0.00	0.00	0.40	0.00	1.33	0.00	3.70	2.55
<i>Bromus sp</i>	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	3.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Calochortus tolmei/subalpinus</i>	0.00	0.01	0.01	0.01	0.00	0.00	0.30	0.15	0.14	0.07	0.40	0.09	0.13	0.00	0.00	0.02	0.01
<i>Carex breweri</i>	0.00	0.00	1.60	0.00	0.67	0.00	0.00	0.00	3.68	4.67	0.00	0.53	0.00	0.00	0.60	3.70	0.00
<i>Carex pensylvanica</i>	2.29	10.29	4.47	15.50	5.81	8.73	0.80	5.07	12.00	10.00	5.50	0.00	0.73	0.67	15.70	0.70	0.00
<i>Caryophyllaceae sp</i>	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Castilleja sp</i>	0.00	0.00	0.21	0.37	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.87	0.00	0.00	0.00	0.00	0.00
<i>Cerastium arvense</i>	0.00	0.00	2.08	2.79	0.00	0.81	0.70	0.86	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	1.08

Plant Species	M2- x21a	CM- x28	M1- x1a	M2- x23c	M2- x23a	BCM- x32b	BCM- x44	BCM- x45a	M2- x21f	LOM- x4a	LOM- x4c	LOM- x1a	FR-gs	M1- pt	CM- x44c	CM- x43	CM- x41a
<i>Cerastium sp</i>	0.00	0.00	0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Cerastium viscosum</i>	1.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.15	0.00	0.00	0.00	0.20	0.01
<i>Cirsium undulatum</i>	0.29	0.00	0.80	0.00	0.00	0.40	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	1.10	0.53
<i>Collinsia parviflora</i>	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.17	0.00	0.00	0.00	0.00	0.40
<i>Comandra umbellate</i>	0.00	0.29	0.00	0.00	1.00	0.00	0.70	1.72	0.80	0.07	0.00	0.00	0.07	0.00	0.00	0.00	0.00
<i>Compositae sp.1</i>	0.00	0.00	0.00	0.36	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.10	3.00
<i>Compositae sp.2</i>	0.00	0.60	0.00	0.14	0.47	0.13	3.00	2.50	0.33	0.07	0.10	0.00	0.07	0.40	1.60	0.13	3.33
<i>Compositae sp. 3</i>	0.00	0.00	0.00	0.29	0.00	0.13	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Cruciferae sp. Danthonia californica</i>	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.87
<i>Delphinium menziesii</i>	0.07	0.00	0.00	0.00	0.01	0.00	0.00	0.72	0.00	0.01	0.00	0.20	0.00	0.00	0.00	0.23	0.43
<i>Elymus Glaucus</i>	1.57	0.00	0.00	0.00	0.41	2.41	0.00	0.00	0.40	5.33	2.30	0.00	0.00	0.00	0.00	4.70	0.00
<i>Epilobium minutum</i>	0.08	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.34	0.00	0.00	0.00	0.00	0.03
<i>Epilobium angustifolium</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.00	0.80	0.00	0.00	0.00	0.00	0.00	0.00
<i>Erigeron foliosus</i>	2.86	0.88	1.67	0.00	6.20	6.00	0.00	0.00	4.73	9.47	3.30	0.73	0.00	0.00	4.10	4.20	6.13
<i>Eriogonum compositum</i>	0.00	0.00	0.00	3.22	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Eriogonum nudum</i>	0.00	0.00	0.00	0.72	0.33	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Eriogonum umbellatum</i>	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Eriophyllum lanatum</i>	6.57	0.00	5.13	1.79	0.00	5.40	0.00	0.21	0.13	0.67	0.10	8.60	0.00	0.00	0.00	0.00	3.20
<i>Veratrum sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Smilacina racemosa</i>	0.00	0.00	0.00	0.00	0.87	0.00	0.00	0.00	1.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00
<i>Festuca idahoensis</i>	2.57	0.00	7.93	3.86	0.00	2.33	0.00	0.00	0.00	0.00	0.00	2.73	0.00	0.00	0.00	0.00	0.00
<i>Fragaria vesca</i>	0.00	2.42	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	4.07	0.00	0.10	0.14

Plant Species	M2- x21a	CM- x28	M1- x1a	M2- x23c	M2- x23a	BCM- x32b	BCM- x44	BCM- x45a	M2- x21f	LOM- x4a	LOM- x4c	LOM- x1a	FR-gs	M1- pt	CM- x44c	CM- x43	CM- x41a
<i>Tellima grandiflora</i>	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Fritillaria sp</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00
<i>Galium bifolium</i>	0.08	0.00	0.09	0.07	0.01	1.01	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.21	0.00	0.00	1.28
<i>Galium oregonum</i>	0.36	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.13	1.20	0.10	0.00	0.00	0.00	0.00	0.50	0.00
<i>Gilia capitata</i>	0.09	0.00	0.27	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Solidago canadensis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.67	0.00	0.00	0.00	1.00	0.00
<i>Oemleria cerasiformis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00
<i>Cryptogramma crispa</i>	0.00	0.00	0.00	0.72	0.00	0.73	0.00	0.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Juniperus sp.</i>	0.00	0.00	0.00	5.36	0.00	0.33	0.00	0.71	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Arctostaphylos uva-ursi</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
<i>Lathyrus sp</i>	0.07	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Lathyrus torreyii</i>	2.86	0.00	2.01	1.36	0.01	1.61	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00
<i>Lewisia columbiana</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.53	0.00	0.00	0.00	0.20	0.13
<i>Ligusticum grayi</i>	14.93	0.00	15.00	0.00	1.53	0.00	0.00	0.00	8.34	5.73	2.30	4.27	0.00	0.00	0.00	8.50	0.00
<i>Lilium columbianum</i>	0.00	0.02	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
<i>Lithophragma parviflora</i>	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Lomatium sp. 1</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.27	0.00	0.00	0.00	0.00
<i>Lomatium sp.2</i>	0.00	0.00	0.07	1.02	0.01	0.53	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.20	0.00	0.14
<i>Lotus purshiana</i>	3.21	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Lupinus caudatus</i>	3.57	0.12	2.27	3.51	0.40	5.48	0.00	2.65	0.07	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.03
<i>Lupinus latifolium</i>	5.07	1.65	1.47	2.44	0.33	2.81	0.51	0.00	2.40	3.67	4.00	1.80	0.53	1.67	18.01	0.00	0.03
<i>Mimulus dentate</i>	0.36	0.00	2.47	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	3.07
<i>Mimulus sp.</i>	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	0.00
<i>Montia sibirica</i>	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67

Plant Species	M2- x21a	CM- x28	M1- x1a	M2- x23c	M2- x23a	BCM- x32b	BCM- x44	BCM- x45a	M2- x21f	LOM- x4a	LOM- x4c	LOM- x1a	FR-gs	M1- pt	CM- x44c	CM- x43	CM- x41a
<i>Moss sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	2.00	0.00	4.33	0.00	0.00	0.00	0.20
<i>Navarettia sp.</i>	0.93	0.00	0.14	0.01	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.30
<i>Nemophila sp.</i>	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Holodiscus discolor</i>	0.00	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Orthocarpus imbricatus</i>	1.07	0.00	0.33	0.00	0.00	0.60	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	1.67
<i>Aspidotis densa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Ozmorhiza chilensis</i>	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Adenocaulon bicolor</i>	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Penstemon davidsonii</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
<i>Penstemon procerus</i>	0.00	1.18	0.00	0.00	0.00	0.07	1.00	4.71	0.00	0.00	0.00	0.40	0.13	0.00	0.00	0.00	0.00
<i>Phacelia heterophylla</i>	0.01	0.06	0.00	0.00	0.40	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.10	0.00
<i>Phlox diffusa</i>	0.00	0.00	0.13	0.00	0.00	0.00	0.70	4.36	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.00	0.00
<i>Pinus Monticola</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.00	0.00
<i>Chimaphila umbellata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00
<i>Poa grayana</i>	0.00	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Poa sp</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.10	0.00
<i>Polemonium carneum</i>	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00
<i>Polygonum bistortoides</i>	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Polygonum douglasii</i>	0.01	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.31	0.00
<i>Polygonum minimum</i>	0.00	0.00	0.00	0.36	0.00	0.07	0.00	0.03	0.00	0.01	0.02	1.60	0.07	0.00	0.00	1.53	0.17
<i>Polygonum sp</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Plant Species	M2- x21a	CM- x28	M1- x1a	M2- x23c	M2- x23a	BCM- x32b	BCM- x44	BCM- x45a	M2- x21f	LOM- x4a	LOM- x4c	LOM- x1a	FR-gs	M1- pt	CM- x44c	CM- x43	CM- x41a
<i>Potentilla arguta</i>	0.72	0.06	3.80	0.71	0.00	0.80	0.00	0.00	0.01	0.00	0.02	6.67	0.00	0.00	1.10	0.40	0.13
<i>Prunella vulgaris</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
<i>Pseudotsuga menziesei</i>	0.00	0.00	0.00	0.00	11.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	3.13	0.50	0.00	0.00
<i>Pteridium aquilerium</i>	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.80	0.00	0.00	0.00	0.00	9.00
<i>Pteridium oregano</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Aquilegia formosa</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20	0.00	0.00
<i>Sambucus racemosa</i>	0.00	0.41	0.00	0.00	0.13	0.00	0.00	0.00	1.00	0.33	0.00	0.00	0.00	1.67	0.00	0.00	0.00
<i>Rhododendron macrophyllum</i>	0.00	5.29	10.60	14.43	2.33	11.67	2.50	17.64	0.33	1.67	0.00	4.33	10.67	2.67	0.50	9.40	5.00
<i>Ribes sp</i>	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
<i>Rock</i>	5.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.73	1.10	0.00	0.00
<i>Rosa sp</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Geum sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Rumex acetosella</i>	0.79	0.06	0.88	0.43	0.08	0.47	0.00	0.00	0.34	0.11	0.70	1.01	0.00	0.00	0.10	0.00	0.02
<i>Rumex sp</i>	0.00	0.00	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Rubus spectabilis</i>	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.33	0.00	0.00	0.00
<i>Saxifracaceae sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
<i>Carex A</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
<i>Carex B</i>	0.36	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Carex C</i>	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.07	0.00	0.20	0.00	0.00	0.00	0.00	0.01	0.00
<i>Sedum oreganum</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.64	0.00	0.00	0.00	0.00	2.07	0.00	0.00	0.00	0.00
<i>Sedum oregonense</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Senecio sella</i>	0.00	0.00	0.01	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Amelanchier alnifolia</i>	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Plant Species	M2- x21a	CM- x28	M1- x1a	M2- x23c	M2- x23a	BCM- x32b	BCM- x44	BCM- x45a	M2- x21f	LOM- x4a	LOM- x4c	LOM- x1a	FR-gs	M1- pt	CM- x44c	CM- x43	CM- x41a
<i>Agroseris sp</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unk sp.1</i>	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Polygonum sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00
<i>Smilacina stellata</i>	3.71	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Hypericum perforatum</i>	0.00	0.00	0.00	0.21	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
<i>Xerophyllum tenas</i>	0.00	6.76	0.00	0.00	0.33	0.00	26.00	3.57	0.00	21.80	46.00	0.00	15.67	15.80	29.50	0.00	0.00
<i>Rubus parviflorus</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	1.20	0.00
<i>Trifolium sp.</i>	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Tsuga heterophylla</i>	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Tsuga mertensiana</i>	0.00	0.29	0.00	0.00	0.00	0.00	3.50	0.00	0.00	0.00	3.00	0.00	0.00	5.33	0.00	0.00	0.00
<i>Aster sp.</i>	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unk sp.2</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unk sp.3</i>	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unk sp.4</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Ericaceae sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.57	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00
<i>Gramineae sp. 1</i>	2.29	5.82	0.00	0.51	2.07	0.80	0.10	0.00	0.33	1.00	2.00	5.80	0.20	0.00	0.80	4.70	0.00
<i>Gramineae sp. 2</i>	0.00	0.00	1.13	1.43	0.07	0.33	0.00	0.00	0.00	0.00	0.20	0.27	0.00	0.00	0.60	0.50	0.00
<i>Gramineae sp. 3</i>	0.00	0.00	3.13	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	2.00	0.00	0.00
<i>Gramineae sp. 4</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00
<i>Unk sp. 5</i>	1.79	0.01	0.00	0.36	0.47	0.00	0.00	0.00	0.01	0.07	0.00	0.00	0.00	0.13	0.00	5.50	0.00
<i>Unk sp. 6</i>	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unk sp. 7</i>	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unk sp. 8</i>	0.00	0.00	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Schrophulariaceae sp.</i>	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Unk sp. 9</i>	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Plant Species	M2- x21a	CM- x28	M1- x1a	M2- x23c	M2- x23a	BCM- x32b	BCM- x44	BCM- x45a	M2- x21f	LOM- x4a	LOM- x4c	LOM- x1a	FR-gs	M1- pt	CM- x44c	CM- x43	CM- x41a
<i>Lonicera sp.</i>	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.00	0.00
<i>Leguminosae sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.20	0.00
<i>Penstemon sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67
<i>Carex sp. 4</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
<i>Ericaceae sp.2</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
<i>Vaccinium membranaceum</i>	0.00	12.06	0.00	0.00	0.00	0.07	36.00	2.15	0.00	0.00	0.00	0.00	17.00	19.07	3.10	0.00	0.00
<i>Vicia americana</i>	1.57	0.00	1.93	0.50	0.14	0.81	0.00	0.00	0.27	0.00	0.00	0.73	0.00	0.00	0.00	0.62	1.81
<i>Viola sp</i>	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.01	0.41	0.01	0.00	0.00	0.21	0.50	0.00	0.00
<i>Erysimum sp.</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Antennaria lanata</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
<i>Zigadensus venenosus</i>	0.00	0.00	0.07	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
<i>Unk sp. 10</i>	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
<i>Unk sp. 11</i>	0.00	0.00	0.33	0.00	3.13	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00

APPENDIX H. RESULTS FROM THE 98 MOTH SAMPLES ACQUIRED 2008-2010 AND USED IN CH 4 OF THIS STUDY.

	bcm.sa.081209	bcm.x31.071509	bcm.x32a.071509	bcm.x32a.073009	bcm.x32b.073009	bcm.x32for.073009	bcm.x35a.071509	bcm.x35a.073009	bcm.x43.081109	bcm.x43for.081109	bcm.x44.080308
Noctua pronuba	37	4	5	0	19	1	8	35	10	0	4
Pero occidentalis/behrensaria	0	39	11	1	5	0	56	1	0	0	1
Geometrid sp	11	10	4	16	20	33	11	1	7	3	0
Enypia packardata	0	0	0	22	0	12	3	0	2	0	0
Eurois astricta	3	0	0	0	7	2	1	5	10	2	5
Polia purpurissata	6	1	0	0	1	1	0	0	0	0	1
Semiothisa signaria	0	5	0	5	1	2	10	0	0	0	0
Eupithecia sp	1	0	2	4	3	3	4	0	2	0	0
Enypia venata	1	0	0	2	0	1	0	0	2	3	0
Noctuid sp	3	2	3	2	14	0	9	2	4	1	0
Euxoa divergens	0	4	0	1	0	0	3	1	0	0	0
Parabagrotis exertistigma	7	1	1	0	5	0	0	3	5	0	0
Perizoma grandis	0	0	0	0	0	0	0	0	0	0	0
Synedoida adumbrata	2	1	1	1	5	0	3	3	0	0	1
Unknown	0	0	0	0	0	0	0	0	0	0	5
Leucania insueta	0	3	2	0	0	0	0	0	0	0	0
Lasionycta											
perplexa/subfuscata	0	7	1	0	0	0	3	0	0	0	0
Pero mizon	4	1	1	0	3	6	0	3	5	2	1
Xestia oblata	0	2	0	0	1	0	0	0	0	0	1
Lacinipolia davena	2	2	1	0	3	4	2	0	1	0	0
Autographa californica	6	1	1	1	5	1	1	5	1	0	0
Lacanobia liquida	0	1	0	0	0	0	0	0	0	0	1
Lacinipolia rectilinea	0	14	0	0	0	0	0	0	1	0	0
Aseptis binotata	2	0	0	0	1	0	1	0	0	0	2
Perizoma curvilinea	0	0	0	0	0	0	0	0	0	0	0
Polia discalis	3	0	1	0	1	0	4	4	1	0	1
Zenopheps lignicolorata	0	0	0	1	2	7	0	0	9	2	0
Eupithecia misturata	0	0	0	0	0	18	0	0	0	1	0
Apamea castanea	6	1	1	0	5	0	0	0	0	0	0

	bcm.x44.081109	bcm.x44e.080308	bcm.x44x43for.080308	bcm.x45a.081109	cm.x28.072209	cm.x28.080208	cm.x28e.080208	cm.x28f.080208	cm.x41a.072209	cm.x41a.082608	cm.x41a.l.082808
Noctua pronuba	3	1	1	0	0	2	0	0	41	1	0
Pero occidentalis/behrensaria	0	1	2	0	0	5	3	3	7	0	0
Geometrid sp	13	0	0	1	0	0	0	0	1	0	0
Enypia packardata	4	0	1	1	0	27	10	4	0	0	0
Eurois stricta	5	1	11	1	0	9	2	0	3	0	1
Polia purpurissata	0	1	4	0	0	4	0	0	9	1	2
Semiothisa signaria	0	0	4	0	1	0	6	3	0	0	0
Eupithecia sp	0	1	2	0	0	3	3	13	0	0	0
Enypia venata	3	1	1	0	0	24	17	7	0	0	0
Noctuid sp	3	0	0	0	0	0	0	0	3	0	2
Euxoa divergens	0	0	1	0	0	3	0	0	2	0	0
Parabagrotis exertistigma	2	1	1	0	0	1	0	0	0	0	1
Perizoma grandis	0	0	0	0	0	0	0	0	0	0	0
Synedoida adumbrata	0	0	1	0	2	3	1	1	0	0	0
Unknown	0	0	5	0	0	5	2	5	0	0	0
Leucania insueta	0	0	0	0	0	0	1	0	1	0	0
Lasionycta											
perplexa/subfuscata	0	0	0	0	0	1	1	1	1	0	0
Pero mizon	3	0	3	0	0	0	1	3	0	0	0
Xestia oblata	0	0	1	0	0	5	0	0	2	0	0
Lacinipolia davena	0	0	0	0	0	0	0	1	4	0	0
Autographa californica	2	1	3	0	0	0	3	1	1	0	0
Lacanobia liquida	0	0	0	0	0	0	0	0	0	0	0
Lacinipolia rectilinea	1	0	0	0	0	0	0	1	0	0	0
Aseptis binotata	0	0	1	0	0	0	2	0	0	0	0
Perizoma curvilinea	0	0	2	0	0	0	1	0	0	0	0
Polia discalis	1	0	5	0	0	2	0	1	0	0	0
Zenopheps lignicolorata	4	0	0	0	0	0	0	0	0	1	1
Eupithecia misturata	3	0	0	0	0	0	0	0	3	0	0
Apamea castanea	0	0	1	0	0	3	0	0	0	0	0

	cm.x41c.072209	cm.x41c.082808	cm.x43.072209	cm.x44a.072209	cm.x44c.082608	cm.x44c.082708	cm.x47.082808	fr.sa.073009	fr.sgss.073009	lom.sx4a.092008	lom.tcc.091908
Noctua pronuba	0	1	4	0	0	0	1	11	8	2	0
Pero occidentalis/behrensaria	6	0	2	0	0	0	0	0	1	0	0
Geometrid sp	1	29	0	1	1	0	0	17	4	0	0
Enypia packardata	3	5	7	0	0	0	8	2	8	0	0
Eurois astricta	6	7	2	0	0	0	1	6	3	0	0
Polia purpurissata	1	1	0	0	0	0	0	0	2	0	0
Semiothisa signaria	25	0	0	1	0	0	0	0	4	0	0
Eupithecia sp	0	0	2	0	0	0	0	0	12	0	0
Enypia venata	1	3	1	0	0	0	0	1	3	0	0
Noctuid sp	4	4	0	0	0	0	0	13	0	0	0
Euxoa divergens	4	0	0	0	0	0	0	1	0	0	0
Parabagrotis exertistigma	0	2	0	0	0	0	1	2	1	0	0
Perizoma grandis	5	0	0	0	0	0	0	0	0	0	0
Synedoida adumbrata	1	0	1	0	0	0	0	8	1	0	0
Unknown	0	0	0	0	0	0	0	0	0	0	0
Leucania insueta	0	0	0	0	0	0	0	0	0	0	0
Lasionycta											
perplexa/subfuscata	1	0	1	0	0	0	0	0	0	0	0
Pero mizon	0	2	0	1	0	0	1	5	1	0	0
Xestia oblata	2	2	0	0	0	0	0	3	3	0	0
Lacinipolia davena	0	0	2	0	0	0	0	0	0	0	0
Autographa californica	0	0	0	0	0	0	0	3	1	0	0
Lacanobia liquida	0	0	0	0	0	0	0	0	2	0	0
Lacinipolia rectilinea	6	1	0	0	0	0	0	0	0	0	0
Aseptis binotata	0	1	0	0	0	0	0	5	0	0	0
Perizoma curvilinea	0	0	0	0	0	0	4	0	2	0	0
Polia discalis	0	0	0	0	0	0	1	6	3	0	0
Zenopheps lignicolorata	0	1	0	0	1	0	0	1	0	1	0
Eupithecia misturata	14	0	0	0	0	0	0	0	7	0	0
Apamea castanea	0	0	0	0	0	0	8	3	3	0	0

	lom.trd.091708	lom.w1.091708	lom.w2.071609	lom.w2.091608	lom.x15b.091809	lom.x1a.071609	lom.x1a.081209	lom.x1a.082908	lom.x1a.091908	lom.x1a.092008	lom.x1b.071609
Noctua pronuba	0	1	1	1	0	11	10	0	1	10	1
Pero occidentalis/behrensaria	0	0	3	0	0	10	0	2	0	0	12
Geometrid sp	0	0	0	0	0	6	4	16	1	0	0
Enypia packardata	0	0	1	0	0	3	0	3	0	0	0
Eurois astricta	0	0	0	0	0	0	1	5	0	0	0
Polia purpurissata	0	0	0	0	0	3	3	7	0	0	4
Semiothisa signaria	0	0	0	0	0	6	0	0	0	0	1
Eupithecia sp	0	0	0	0	0	3	0	0	0	0	0
Enypia venata	0	0	6	0	0	0	0	4	0	0	0
Noctuid sp	0	0	0	0	1	0	1	4	0	1	0
Euxoa divergens	0	0	0	0	0	2	2	1	1	0	1
Parabagrotis exertistigma	0	0	2	1	0	0	3	4	0	0	0
Perizoma grandis	1	0	2	1	0	0	0	0	0	0	0
Synedoida adumbrata	0	0	0	0	0	3	0	0	0	0	0
Unknown	0	0	0	0	0	0	0	0	0	0	0
Leucania insueta	0	0	0	0	0	5	0	4	0	0	0
Lasionycta											
perplexa/subfuscata	0	0	0	0	0	2	0	0	0	0	2
Pero mizon	0	0	0	0	0	0	0	0	0	0	0
Xestia oblata	0	0	0	0	0	2	0	1	1	0	1
Lacinipolia davena	0	0	1	0	1	1	0	0	1	0	2
Autographa californica	0	0	0	1	0	0	0	0	2	3	0
Lacanobia liquida	0	0	0	0	0	1	0	0	0	0	2
Lacinipolia rectilinea	0	0	3	0	0	0	2	1	0	0	1
Aseptis binotata	0	0	1	0	0	0	2	0	0	0	0
Perizoma curvilinea	0	0	0	0	0	0	0	0	0	0	0
Polia discalis	0	0	0	0	0	0	0	1	0	0	0
Zenopheps lignicolorata	0	0	0	0	0	0	0	0	2	0	0
Eupithecia misturata	0	0	0	0	0	0	0	0	0	0	0
Apamea castanea	0	0	0	0	0	1	5	0	1	0	0

	lom.x4a.071509	lom.x4a.081409	lom.x4a.082908	lom.x4a.091608	lom.x4c.071509	lom.x4c.081209	lom.x4c.091908	lom.x4cfor.081209	m1.gs.072309	m1.m1asa.073009	m1.m1asa.090508
Noctua pronuba	1	0	0	0	1	0	0	1	24	9	0
Pero occidentalis/behrensaria	18	0	0	0	6	0	0	0	2	0	0
Geometrid sp	0	0	4	0	1	1	0	0	0	9	0
Enypia packardata	3	2	0	0	2	0	0	1	5	12	0
Eurois astricta	0	13	0	0	1	1	0	5	9	9	1
Polia purpurissata	0	1	2	0	0	0	0	0	2	2	0
Semiothisa signaria	8	0	0	0	5	0	0	0	0	1	0
Eupithecia sp	10	0	0	0	0	1	0	0	4	5	0
Enypia venata	0	7	5	0	0	0	0	2	0	4	0
Noctuid sp	1	0	4	0	0	0	0	0	0	5	0
Euxoa divergens	0	1	0	4	3	0	0	0	2	2	1
Parabagrotis exertistigma	0	0	2	0	0	0	0	0	1	3	1
Perizoma grandis	0	5	0	0	0	0	0	4	0	0	2
Synedoida adumbrata	0	0	0	0	0	0	0	0	9	6	0
Unknown	0	0	0	0	0	0	0	0	0	0	0
Leucania insueta	1	0	0	0	2	0	0	0	0	0	0
Lasionycta											
perplexa/subfuscata	0	0	0	0	1	0	0	0	0	3	0
Pero mizon	0	0	0	0	0	0	0	0	3	1	0
Xestia oblata	1	0	1	0	0	0	0	0	0	2	0
Lacinipolia davena	1	1	0	0	0	0	0	0	1	0	0
Autographa californica	0	0	0	0	0	0	0	0	0	0	0
Lacanobia liquida	0	0	0	0	0	0	0	0	0	0	0
Lacinipolia rectilinea	0	0	0	0	2	2	1	1	0	1	0
Aseptis binotata	0	2	0	0	1	0	2	3	1	0	1
Perizoma curvilinea	1	0	0	0	0	0	0	2	0	0	0
Polia discalis	0	0	0	0	0	0	0	0	2	5	0
Zenopheps lignicolorata	0	4	0	1	0	0	1	2	0	0	0
Eupithecia misturata	0	0	0	0	0	0	0	0	0	0	0
Apamea castanea	0	0	0	0	1	0	0	0	1	0	0

	m1.x1aL.072809	m1.x1am5.for1.072910	m1.x1am5.for2.073110	m1.x1am5.gap.073110	m1.x1am5.rd.073110	m1.x1am5f2.073108	m1.x1anw.091208	m1.x1asw.091108	m1.x1au.072809	m1m2.rd.073010	m1m2.rdj.072309
Noctua pronuba	37	0	0	0	0	0	0	1	44	1	0
Pero occidentalis/behrensaria	0	0	1	4	2	12	0	0	3	0	0
Geometrid sp	1	0	0	0	0	0	0	0	0	0	0
Enypia packardata	0	0	0	2	1	6	0	0	0	0	0
Eurois astricta	1	0	1	0	1	0	0	2	2	2	4
Polia purpurissata	4	0	4	1	3	4	0	0	4	0	1
Semiothisa signaria	0	0	9	8	4	0	0	0	0	2	1
Eupithecia sp	0	0	0	0	1	5	0	0	0	0	1
Enypia venata	0	0	0	0	0	0	0	0	0	0	1
Noctuid sp	5	0	0	0	0	0	0	0	6	0	0
Euxoa divergens	2	0	2	0	1	2	0	0	1	0	0
Parabagrotis exertistigma	3	0	0	0	0	0	0	0	2	0	1
Perizoma grandis	0	1	31	10	6	0	0	0	0	2	0
Synedoida adumbrata	0	0	0	0	0	1	0	0	2	0	0
Unknown	0	0	0	0	0	4	0	0	0	0	0
Leucania insueta	0	0	1	1	1	5	0	0	0	0	0
Lasionycta											
perplexa/subfuscata	0	0	1	5	1	3	0	0	0	1	0
Pero mizon	0	0	0	0	0	0	0	0	0	0	3
Xestia oblata	0	0	0	0	2	3	0	0	6	1	0
Lacinipolia davena	0	0	0	1	1	0	0	0	0	1	0
Autographa californica	0	0	0	0	1	0	0	0	2	0	1
Lacanobia liquida	0	0	1	2	1	4	0	0	0	1	0
Lacinipolia rectilinea	0	0	0	0	0	0	0	2	0	1	0
Aseptis binotata	0	0	0	0	1	0	0	3	0	0	1
Perizoma curvilinea	0	0	11	6	2	6	0	0	0	0	0
Polia discalis	0	0	0	0	0	0	0	0	0	0	0
Zenopheps lignicolorata	0	0	0	0	0	0	0	0	0	0	1
Eupithecia misturata	0	0	0	0	0	0	0	0	0	0	0
Apamea castanea	2	0	0	0	0	1	0	0	1	0	0

	bcm.sa.081209	bcm.x31.071509	bcm.x32a.071509	bcm.x32a.073009	bcm.x32b.073009	bcm.x32for.073009	bcm.x35a.071509	bcm.x35a.073009	bcm.x43.081109	bcm.x43for.081109	bcm.x44.080308
<i>Eustroma semiatrata</i>	0	1	0	0	0	0	1	0	0	0	0
<i>Euxoa</i> sp	6	2	1	4	1	0	0	0	1	0	0
<i>Eulithis xyliina</i>	0	0	0	0	0	1	3	0	0	0	1
<i>Euxoa aequalis</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Euxoa satis</i>	0	0	0	0	0	0	0	0	1	0	0
<i>Panthea portlandia</i>	0	1	0	0	1	1	1	3	0	0	1
<i>Hesperumia sulphuraria</i>	0	0	0	3	0	0	0	0	5	0	0
<i>Diarsia esurialis</i>	0	0	0	0	0	0	1	0	0	0	1
<i>Eupithecia subcolorata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Gabriola dyari</i>	1	0	0	0	0	0	0	0	3	2	0
<i>Hydriomena</i> sp	0	0	0	0	0	0	0	0	0	0	0
<i>Nepytia umbrosaria</i>	0	0	0	0	0	1	0	0	0	0	0
<i>Epirrhoe alternata</i>	0	0	0	1	0	0	0	0	0	1	0
<i>Chersotis juncta</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Xanthorhoe pontiaria</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Lacinipolia cuneata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Anaplectoides prasina</i>	3	0	1	0	0	1	2	2	0	0	0
<i>Agrotis obliqua</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Eurois astricta</i> -like	8	0	0	0	0	0	0	0	7	0	0
<i>Euphyia unangulata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Parabagrotis sulinaris</i>	0	0	0	0	1	0	0	0	3	0	0
<i>Syngrapha orophila</i>	0	0	0	0	2	0	0	1	0	0	0
<i>Itame confederata</i>	0	3	0	1	0	2	0	0	0	1	1
<i>Parabagrotis formalis</i>	0	1	0	0	2	0	0	0	0	0	2
<i>Triphosa haesitata</i>	1	0	0	0	2	1	0	1	0	0	0
<i>Hyppa brunneicrista</i>	0	4	1	0	2	0	6	1	0	0	0
<i>Synedoida divergens</i>	0	0	0	0	1	0	0	0	0	0	0
<i>Spaelotis bicava</i>	0	0	0	1	0	0	0	0	0	0	0
<i>Thera otisi</i>	0	0	0	0	0	3	0	0	1	0	0

	lom.trd.091708	lom.w1.091708	lom.w2.071609	lom.w2.091608	lom.x15b.091809	lom.x1a.071609	lom.x1a.081209	lom.x1a.082908	lom.x1a.091908	lom.x1a.092008	lom.x1b.071609
Eustroma semiatrata	0	0	0	0	0	4	0	0	0	0	0
Euxoa sp	0	0	0	0	0	0	0	0	1	0	0
Eulithis xyliina	0	0	0	0	1	0	4	0	1	0	0
Euxoa aequalis	0	0	0	0	0	0	0	0	0	0	0
Euxoa satis	0	0	0	0	0	1	0	0	0	0	0
Panthea portlandia	0	0	0	0	0	0	0	0	0	0	0
Hesperumia sulphuraria	0	0	0	0	0	0	0	2	0	0	0
Diarsia esurialis	0	0	0	0	0	0	0	0	0	0	0
Eupithecia subcolorata	0	0	0	0	0	0	0	0	0	0	0
Gabriola dyari	0	0	0	0	0	0	0	1	0	0	0
Hydriomena sp	0	0	0	0	0	1	0	0	0	0	0
Nepytia umbrosaria	0	0	0	0	0	0	0	0	0	0	0
Epirrhoe alternata	0	0	0	0	0	4	0	2	0	0	0
Chersotis juncta	0	0	0	0	0	0	0	0	0	0	0
Xanthorhoe pontiaria	0	0	0	0	0	0	0	0	0	0	0
Lacinipolia cuneata	0	0	0	0	0	3	0	0	0	0	0
Anaplectoides prasina	0	0	0	0	0	3	1	0	0	0	0
Agrotis obliqua	0	0	0	0	0	0	0	0	0	0	1
Eurois astricta-like	0	0	0	0	0	0	0	0	0	0	0
Euphyia unangulata	0	0	0	0	0	0	0	0	0	0	0
Parabagrotis sulinaris	0	0	0	0	0	0	0	0	0	0	0
Syngrapha orophila	0	0	0	0	0	1	0	0	0	0	1
Itame confederata	0	0	0	0	0	0	0	0	0	0	0
Parabagrotis formalis	0	0	0	0	0	0	0	0	0	0	0
Triphosa haesitata	0	0	0	0	0	0	2	0	0	0	0
Hyppa brunneicrista	0	0	0	0	0	0	0	0	0	0	0
Synedoida divergens	0	0	0	0	0	0	0	0	0	0	0
Spaelotis bicava	0	0	0	0	0	0	0	1	0	0	0
Thera otisi	0	0	0	3	1	0	0	0	1	0	0

	lom.x4a.071509	lom.x4a.081409	lom.x4a.082908	lom.x4a.091608	lom.x4c.071509	lom.x4c.081209	lom.x4c.091908	lom.x4cfor.081209	m1.gs.072309	m1.m1asa.073009	m1.m1asa.090508
Eustroma semiatrata	0	0	0	1	0	0	0	0	3	0	0
Euxoa sp	0	0	0	0	0	0	0	0	0	0	0
Eulithis xyliina	0	1	0	0	0	0	0	2	0	0	0
Euxoa aequalis	0	0	0	0	0	0	0	0	0	0	0
Euxoa satis	0	0	0	0	0	0	0	0	2	2	1
Panthea portlandia	0	0	0	0	0	0	0	0	0	0	0
Hesperumia sulphuraria	0	0	0	0	0	0	0	0	0	1	0
Diarsia esurialis	0	0	0	0	0	0	0	0	0	0	0
Eupithecia subcolorata	0	0	0	0	0	0	0	0	0	0	1
Gabriola dyari	0	2	0	0	0	0	1	0	0	0	0
Hydriomena sp	1	0	0	0	0	0	0	0	0	0	0
Nepytia umbrosaria	0	0	1	0	0	0	0	0	0	0	0
Epirrhoe alternata	0	0	0	0	0	0	0	0	0	0	0
Chersotis juncta	0	0	0	0	0	0	0	0	0	0	0
Xanthorhoe pontiaria	0	0	0	0	0	0	0	0	0	0	0
Lacinipolia cuneata	0	0	0	0	0	0	0	0	0	0	0
Anaplectoides prasina	1	0	0	0	0	0	0	0	0	0	0
Agrotis obliqua	2	0	0	0	4	0	0	0	0	0	0
Eurois astricta-like	0	0	0	0	0	0	0	0	3	0	0
Euphyia unangulata	7	0	0	0	0	0	0	3	0	0	0
Parabagrotis sulinaris	0	0	0	0	0	2	0	0	0	0	0
Syngrapha orophila	0	0	0	0	1	0	0	0	0	3	0
Itame confederata	0	2	0	0	0	0	0	1	1	0	0
Parabagrotis formalis	0	0	0	0	0	0	0	0	0	0	0
Triphosa haesitata	0	0	0	0	0	0	0	0	0	2	1
Hyppa brunneicrista	0	0	0	0	0	0	0	0	0	0	0
Synedoida divergens	0	0	0	0	0	0	0	0	8	0	0
Spaelotis bicava	0	0	0	0	0	0	0	0	0	0	1
Thera otisi	0	0	0	1	0	0	0	0	0	0	0

	m1.m5.072910	m1.m5.073110	m1.m5.090608	m1.m5.091108	m1.x14.091208	m1.x1a.070209	m1.x1a.072910	m1.x1a.073108	m1.x1a.090508	m1.x1ac.091008	m1.x1ae.073108
<i>Eustroma semiatrata</i>	0	0	0	0	0	0	0	0	0	0	5
<i>Euxoa</i> sp	1	0	0	0	0	0	0	0	0	0	0
<i>Eulithis xyliina</i>	0	0	0	0	0	0	0	2	0	1	0
<i>Euxoa aequalis</i>	0	0	0	0	0	0	0	0	10	0	0
<i>Euxoa satis</i>	1	0	0	2	3	0	0	1	1	0	0
<i>Panthea portlandia</i>	0	0	0	0	0	0	0	0	0	0	1
<i>Hesperumia sulphuraria</i>	1	0	0	0	0	0	0	0	0	0	0
<i>Diarsia esurialis</i>	3	4	0	0	0	0	1	0	0	0	0
<i>Eupithecia subcolorata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Gabriola dyari</i>	0	0	0	1	0	0	0	0	0	1	0
<i>Hydriomena</i> sp	0	0	0	0	0	0	0	0	0	0	0
<i>Nepytia umbrosaria</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Epirrhoe alternata</i>	3	0	0	0	0	0	1	0	0	0	0
<i>Chersotis juncta</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Xanthorhoe pontiaria</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Lacinipolia cuneata</i>	1	0	0	0	0	0	0	0	0	0	0
<i>Anaplectoides prasina</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Agrotis obliqua</i>	0	0	0	0	0	15	0	0	0	0	0
<i>Eurois astricta</i> -like	0	0	0	0	0	0	0	0	0	0	0
<i>Euphyia unangulata</i>	0	0	0	0	0	0	1	0	0	0	0
<i>Parabagrotis sulinaris</i>	0	0	1	0	0	1	0	0	1	0	1
<i>Syngrapha orophila</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Itame confederata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Parabagrotis formalis</i>	0	0	2	0	0	0	0	0	8	0	0
<i>Triphosa haesitata</i>	1	1	0	0	0	0	0	0	0	0	0
<i>Hyppa brunneicrista</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Synedoida divergens</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Spaelotis bicava</i>	3	0	0	0	0	0	2	0	1	0	0
<i>Thera otisi</i>	0	0	0	0	5	0	0	0	0	0	0

	m1m2.rdj.090608	m2.cc1.070909	m2.cc1rd.091308	m2.ss.090708	m2.x21a.070909	m2.x21a.073010	m2.x21a.080108	m2.x21a.090708	m2.x21a.092208	m2.x21ae.080108	m2.x21al.072309
Eustroma semiatrata	0	0	1	0	0	0	1	0	0	4	0
Euxoa sp	0	0	0	0	0	0	2	0	0	1	0
Eulithis xyliana	3	0	1	0	0	0	0	0	0	0	0
Euxoa aequalis	1	0	0	0	0	0	0	5	6	0	0
Euxoa satis	0	0	2	1	0	0	3	2	0	1	0
Panthea portlandia	0	0	0	0	0	0	1	0	0	0	0
Hesperumia sulphuraria	0	0	1	0	0	0	0	0	0	0	0
Diarsia esurialis	0	0	0	1	0	0	0	0	0	0	0
Eupithecia subcolorata	0	0	0	0	0	0	0	0	0	0	0
Gabriola dyari	0	0	1	0	0	0	0	0	0	0	0
Hydriomena sp	0	0	0	0	0	0	0	0	0	0	0
Nepytia umbrosaria	0	0	0	0	0	0	0	0	0	0	0
Epirrhoe alternata	0	0	0	0	0	0	0	0	0	0	0
Chersotis juncta	0	0	0	1	0	1	0	2	0	0	13
Xanthorhoe pontiaria	0	0	0	0	0	0	0	0	0	2	0
Lacinipolia cuneata	0	0	0	0	0	0	0	0	0	0	0
Anaplectoides prasina	0	0	0	0	0	0	0	0	0	0	0
Agrotis obliqua	0	0	0	0	0	0	0	0	0	0	0
Eurois astricta-like	0	0	0	0	0	0	0	0	0	0	0
Euphyia unangulata	0	1	0	0	0	0	0	0	0	0	0
Parabagrotis sulinaris	1	0	0	0	0	0	0	0	0	0	0
Syngrapha orophila	0	0	0	0	0	0	1	0	0	0	0
Itame confederata	0	0	0	1	0	0	0	0	0	0	0
Parabagrotis formalis	1	0	0	0	0	0	0	0	0	0	0
Triphosa haesitata	0	0	0	0	0	0	0	0	0	1	0
Hyppa brunneicrista	0	0	0	0	0	0	0	0	0	0	0
Synedoida divergens	0	0	0	0	0	0	0	0	0	0	0
Spaelotis bicava	0	0	0	0	0	0	0	0	0	0	0
Thera otisi	0	0	0	1	0	0	0	1	0	0	0

	lom.trd.091708	lom.w1.091708	lom.w2.071609	lom.w2.091608	lom.x15b.091809	lom.x1a.071609	lom.x1a.081209	lom.x1a.082908	lom.x1a.091908	lom.x1a.092008	lom.x1b.071609
Aplocera plagiata	0	0	0	1	0	0	0	0	0	0	0
Hydriomena irata	0	0	0	0	0	0	0	0	0	0	0
Leucania anteoclara	0	0	0	0	0	0	0	0	1	0	1
Parabagrotis insularis	0	0	0	0	0	0	1	0	0	0	0
Achytonix praeacuta	0	0	0	0	0	0	0	0	0	0	0
Dargida procinta	0	0	0	0	0	1	6	0	0	1	0
Apamea amputatrix	0	0	0	0	0	0	0	0	0	0	1
Euxoa terrena	0	0	2	0	0	0	0	0	0	0	0
Perizoma costiguttata	0	0	0	0	0	0	0	0	0	0	0
Prochoerodes forficaria	0	0	0	0	0	2	0	0	0	0	0
Chlorosea banksaria	0	0	0	0	0	0	0	0	0	0	0
Euxoa vetusta	0	0	0	0	0	0	4	0	0	0	0
Lacinipolia stricta	0	2	0	0	0	0	0	0	1	0	0
Oncocnemis "new species near columbia"	0	0	0	0	0	0	0	0	0	0	0
Apamea auranticolor	0	0	0	0	1	0	0	0	0	0	0
Autographa sansoni	0	0	1	0	0	5	0	0	0	0	1
Dysstroma formosa	0	0	0	0	0	0	0	0	0	0	0
Dysstroma mancipata	0	0	0	0	2	0	0	0	0	0	0
Eulithis propulsata	1	1	0	0	0	0	0	1	0	0	0
Eustroma fasciata	1	0	0	0	0	0	0	0	0	0	0
Itame sp	0	0	0	0	0	0	0	0	0	0	0
Miselia variolata	0	0	0	0	0	0	0	0	0	0	0
Agrotis vancouverensis	0	0	0	0	0	0	0	0	0	0	0
Caripeta divisata	0	0	0	0	0	0	0	0	0	0	0
Properigea albimacula	0	0	0	0	0	0	0	0	0	0	0
Pseudorthodes irrorata	0	0	0	0	0	0	0	2	0	0	0
Scopula junctaria	0	0	0	0	0	0	0	0	0	0	0
Spargania magnoliata	0	0	0	0	0	2	0	0	0	0	0

	m1.x1aL.072809	m1.x1am5.for1.072910	m1.x1am5.for2.073110	m1.x1am5.gap.073110	m1.x1am5.rd.073110	m1.x1am5f2.073108	m1.x1anw.091208	m1.x1asw.091108	m1.x1au.072809	m1m2.rd.073010	m1m2.rjic.072309
Aplocera plagiata	0	0	0	0	0	0	0	0	0	0	0
Hydriomena irata	0	1	0	0	0	0	0	0	0	0	0
Leucania anteoclara	0	0	0	0	0	0	0	0	1	0	0
Parabagrotis insularis	0	0	0	0	0	0	0	0	1	0	0
Achytonix praeacuta	0	0	0	0	0	0	0	0	0	0	1
Dargida procinta	0	0	0	0	0	0	0	0	0	0	0
Apamea amputatrix	0	0	0	0	0	0	0	0	0	0	0
Euxoa terrena	0	1	0	0	0	0	0	0	0	0	0
Perizoma costiguttata	0	0	3	1	0	0	0	0	0	1	0
Prochoerodes forficaria	0	1	1	0	0	0	0	0	0	0	0
Chlorosea banksaria	0	0	0	0	0	2	0	0	0	0	0
Euxoa vetusta	0	0	0	0	0	0	0	0	0	0	0
Lacinipolia stricta	0	0	0	0	0	0	0	0	0	0	0
Oncocnemis "new species near columbia"	0	0	0	0	0	0	1	0	0	0	0
Apamea auranticolor	0	0	0	1	0	0	0	0	0	0	0
Autographa sansoni	0	0	0	0	0	0	0	0	0	0	0
Dysstroma formosa	0	0	0	0	0	0	0	0	0	0	0
Dysstroma mancipata	0	0	0	0	0	0	0	0	0	0	0
Eulithis propulsata	0	0	0	0	0	0	0	0	0	0	1
Eustroma fasciata	0	0	0	0	1	0	0	0	0	1	0
Itame sp	0	0	0	0	0	0	0	0	0	0	0
Miselia variolata	0	0	0	0	0	0	0	0	0	0	0
Agrotis vancouverensis	0	0	0	0	0	2	0	0	0	1	0
Caripeta divisata	0	0	1	0	0	0	0	0	0	0	0
Properigea albimacula	0	0	0	0	0	0	0	0	0	0	0
Pseudorthodes irrorata	0	0	0	0	3	0	0	1	0	0	0
Scopula junctaria	0	1	2	1	0	2	0	0	0	1	0
Spargania magnoliata	0	0	0	1	2	0	0	0	0	1	0

	m2.x21au.072309	m2.x21au.092408	m2.x21ax21f.for.073010	m2.x21ax21f.for.080108	m2.x21ax21f.rd.073010	m2.x21f.072910	m2.x23a.091308	m2.x23c.070909	m2.x23f.072309	m2.x23g.070909
Aplocera plagiata	0	0	0	0	0	0	0	0	0	0
Hydriomena irata	0	0	0	1	0	0	0	0	0	0
Leucania anteoclara	0	0	0	0	0	0	0	0	0	0
Parabagrotis insularis	0	0	0	0	0	0	0	0	0	0
Achytonix praeacuta	0	0	0	0	0	0	0	0	0	0
Dargida procinta	0	0	0	0	0	0	1	0	0	0
Apamea amputatrix	0	0	0	0	0	0	0	5	1	0
Euxoa terrena	0	2	0	0	0	0	0	0	0	0
Perizoma costiguttata	0	0	1	4	0	0	0	0	0	0
Prochoerodes forficaria	0	0	1	0	0	0	0	0	0	5
Chlorosea banksaria	0	0	0	3	3	0	0	0	0	0
Euxoa vetusta	1	0	1	0	0	0	0	0	0	0
Lacinipolia stricta	0	0	0	0	0	0	1	0	0	0
Oncocnemis "new species near columbia"	0	1	0	0	0	0	0	0	0	0
Apamea auranticolor	1	0	1	0	1	0	0	0	0	0
Autographa sansoni	0	0	0	0	0	0	0	0	0	2
Dysstroma formosa	0	0	0	1	0	0	2	0	0	0
Dysstroma mancipata	0	0	0	0	0	0	0	0	0	0
Eulithis propulsata	0	0	0	0	0	0	0	0	0	0
Eustroma fasciata	0	0	2	2	0	0	0	0	0	0
Itame sp	0	0	0	4	0	0	0	0	0	0
Miselia variolata	0	0	0	0	0	0	0	1	0	2
Agrotis vancouverensis	0	0	0	1	1	0	0	0	0	0
Caripeta divisata	0	0	0	1	0	0	0	0	0	0
Properigea albimacula	0	0	0	0	0	0	0	0	9	0
Pseudorthodes irrorata	0	0	0	0	0	0	0	0	0	0
Scopula junctaria	0	0	0	1	1	0	0	0	0	0
Spargania magnoliata	0	0	2	0	1	0	0	0	0	0

	bcm.sa.081209	bcm.x31.071509	bcm.x32a.071509	bcm.x32a.073009	bcm.x32b.073009	bcm.x32for.073009	bcm.x35a.071509	bcm.x35a.073009	bcm.x43.081109	bcm.x43for.081109	bcm.x44.080308
Synaxis pallulata	0	0	0	0	0	0	0	0	0	0	0
Xestia finatimis	0	0	0	0	0	0	0	0	3	0	0
Agrotis venerabilis	0	1	0	0	0	0	1	0	0	0	0
Dysstroma sp	1	0	0	1	1	0	0	0	0	2	0
Eulithis destinata	0	0	0	0	0	0	0	0	1	0	0
Euxoa declarata	0	0	0	0	0	0	0	0	0	0	0
Fishia evalina	1	0	0	0	0	2	0	0	0	0	0
Homorthodes communis	0	0	0	0	0	0	0	0	0	2	1
Properigea niveirena	0	0	0	1	0	0	0	0	0	0	0
Synaxis cervinaria	0	0	1	1	0	1	0	0	0	0	0
Eustroma sp	0	0	0	0	0	0	0	0	0	0	0
Sicya crocearia	0	0	0	0	0	0	0	0	0	0	0
Zosteropoda hirtipes	0	0	0	0	0	0	0	0	1	0	0
Apodrepanulatrix litaria	0	0	0	0	0	0	0	0	1	0	0
Caripeta aequaliaria	1	1	0	0	0	0	0	0	1	0	0
Ceranemota tearlei	0	0	0	0	0	0	0	0	0	0	0
Euxoa biformata	0	0	0	0	0	0	0	0	0	0	0
Iridopsis emasculata	0	0	0	0	0	0	0	0	0	0	0
Lacanobia tacoma	0	0	0	0	0	0	0	0	0	0	0
Lacinipolia pensilis	0	0	0	2	0	0	0	0	1	0	0
Lacinipolia sp	4	0	0	0	0	0	0	0	3	0	0
Sabulodes edwardsata	0	0	0	0	2	0	0	0	0	0	0
Syngrapha celsa	0	0	0	0	0	0	0	0	0	0	0
Campaea perlata	0	0	0	0	0	1	0	0	0	0	0
Dysstroma citrata	0	0	0	0	0	1	0	0	0	0	0
Grammia ornata	0	0	0	0	0	0	1	0	0	0	0
Hydriomena marinata	0	0	0	0	0	0	0	0	0	0	0
Lophocampa maculata	0	0	0	0	0	0	0	0	0	1	0
Oligia indirecta	0	0	1	0	1	0	2	0	0	0	0

	m2.x21au.072309	m2.x21au.092408	m2.x21ax21f.for.073010	m2.x21ax21f.for.080108	m2.x21ax21f.rd.073010	m2.x21f.072910	m2.x23a.091308	m2.x23c.070909	m2.x23f.072309	m2.x23g.070909
Synaxis pallulata	0	2	0	0	0	0	0	0	0	0
Xestia finatimis	0	0	0	0	0	0	1	0	0	0
Agrotis venerabilis	0	0	0	1	0	0	0	0	0	0
Dysstroma sp	0	0	0	0	0	0	0	0	0	0
Eulithis destinata	0	0	0	0	0	0	0	0	0	0
Euxoa declarata	0	0	0	0	0	0	0	0	0	0
Fishia evalina	0	0	0	0	0	0	0	0	0	0
Homorthodes communis	0	0	0	0	0	0	0	0	0	0
Properigea niveirena	0	0	0	0	0	0	1	0	0	0
Synaxis cervinaria	0	0	0	0	0	0	0	0	0	1
Eustroma sp	0	0	0	0	0	0	0	0	0	0
Sicya crocearia	0	0	0	0	0	0	1	0	0	0
Zosteropoda hirtipes	0	0	0	0	0	0	0	0	0	0
Apodrepanulatrix litaria	0	0	0	0	0	0	0	0	0	0
Caripeta aequaliaria	0	0	0	0	0	0	0	0	0	0
Ceranemota tearlei	0	0	0	0	0	0	0	0	0	0
Euxoa biformata	0	0	0	0	0	0	1	0	0	0
Iridopsis emasculata	0	0	0	0	1	0	0	0	0	0
Lacanobia tacoma	1	0	0	0	0	0	0	0	0	1
Lacinipolia pensilis	0	0	0	0	0	0	0	0	0	0
Lacinipolia sp	0	0	0	0	0	0	0	0	0	0
Sabulodes edwardsata	0	0	0	0	0	0	0	0	0	0
Syngrapha celsa	0	0	0	0	0	0	0	0	0	1
Campaea perlata	0	0	1	0	0	0	0	0	0	0
Dysstroma citrata	0	0	0	0	0	0	0	0	0	0
Grammia ornata	0	0	0	0	0	0	0	0	0	0
Hydriomena marinata	0	0	0	0	0	0	0	0	0	0
Lophocampa maculata	0	0	0	0	0	0	0	0	0	1
Oligia indirecta	0	0	0	1	0	0	0	0	0	0

	bcm.sa.081209	bcm.x31.071509	bcm.x32a.071509	bcm.x32a.073009	bcm.x32b.073009	bcm.x32for.073009	bcm.x35a.071509	bcm.x35a.073009	bcm.x43.081109	bcm.x43for.081109	bcm.x44.080308
<i>Oncocnemis sandaraca</i>	3	0	0	0	1	0	0	0	0	0	0
<i>Oncocnemis youngi</i>	1	0	0	0	2	0	0	0	0	0	0
<i>Asticta victoria</i>	0	0	0	0	1	0	1	0	0	0	0
<i>Ceranemota fasciata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Dysstroma ochrofuscaria</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Itame bitactata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Pseudobryomima muscosa</i>	0	0	0	1	0	0	0	0	1	0	0
<i>Pseudorthosia variabilis</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Abagrotis forbesi</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Abagrotis trigona</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Achytonix epipaschia</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Acronicta impleta</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Agrotis sp</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Apharetra californiae</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Autographa speciosa</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Coloradia pandora</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Cryphia cuerva</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Drepanulatrix carnearia</i>	0	0	1	0	0	0	0	0	0	0	0
<i>Eupithecia graefii</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Euplexia benesimilis</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Euxoa atomaris</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Euxoa comosa</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Furcula scolopendrina</i>	0	2	0	0	0	0	0	0	0	0	0
<i>Hydriomena renunciata</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Hyppa indistincta</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Lacinipolia olivacea</i>	1	1	0	0	0	0	0	0	0	0	0
<i>Polia nimbosa</i>	0	0	0	0	0	0	0	0	0	0	0
<i>Pseudothordes irrorata</i>	0	0	0	0	0	0	0	0	0	0	1
<i>Apamea occidentis</i>	0	1	0	0	1	0	0	0	0	0	0

	bcm.x44.081109	bcm.x44e.080308	bcm.x44x43for.080308	bcm.x45a.081109	cm.x28.072209	cm.x28.080208	cm.x28e.080208	cm.x28f.080208	cm.x41a.072209	cm.x41a.082608	cm.x41a.l.082808
Oncocnemis sandaraca	0	0	0	1	0	0	0	0	0	0	0
Oncocnemis youngi	0	0	0	0	0	0	0	0	0	1	0
Asticta victoria	0	0	0	0	0	0	0	0	0	0	0
Ceranemota fasciata	0	0	0	0	0	0	0	0	0	0	0
Dysstroma ochrofuscaria	0	0	0	0	0	0	0	0	0	0	0
Itame bitactata	0	0	0	0	0	0	0	0	0	0	0
Pseudobryomima muscosa	1	0	0	0	0	0	0	0	0	0	0
Pseudorthosia variabilis	0	0	0	0	0	0	0	0	0	0	0
Abagrotis forbesi	0	0	0	0	1	0	0	0	0	0	0
Abagrotis trigona	2	0	0	0	0	0	0	0	0	0	0
Achytonix epipaschia	0	1	0	0	0	0	1	0	0	0	0
Acronicta impleta	0	0	0	0	0	0	0	0	0	0	0
Agrotis sp	0	0	0	1	1	0	0	0	0	0	0
Apharetra californiae	0	0	0	0	0	0	0	0	0	0	0
Autographa speciosa	0	0	0	0	0	0	0	0	0	0	0
Coloradia pandora	0	0	0	0	0	0	0	1	0	0	0
Cryphia cuerva	0	0	0	0	0	1	0	0	0	0	0
Drepanulatrix carnearia	0	0	0	0	0	0	0	0	0	0	0
Eupithecia graefii	0	0	0	0	0	0	0	0	0	0	0
Euplexia benesimilis	0	0	0	0	1	0	0	0	0	0	0
Euxoa atomaris	0	0	0	0	0	0	0	0	0	0	0
Euxoa comosa	0	0	0	0	0	0	0	0	0	0	0
Furcula scolopendrina	0	0	0	0	0	0	0	0	0	0	0
Hydriomena renunciata	0	0	1	0	0	0	0	0	0	0	0
Hyppa indistincta	0	0	0	0	0	0	0	0	0	0	0
Lacinipolia olivacea	0	0	0	0	0	0	0	0	0	0	2
Polia nimbosa	0	0	0	0	0	0	0	0	0	0	0
Pseudothordes irrorata	0	0	0	0	0	0	0	0	0	0	0
Apamea occidentis	0	0	0	0	0	0	1	0	0	0	0

	m1.x1aL.072809	m1.x1am5.for1.072910	m1.x1am5.for2.073110	m1.x1am5.gap.073110	m1.x1am5.rd.073110	m1.x1am5f2.073108	m1.x1anw.091208	m1.x1asw.091108	m1.x1au.072809	m1m2.rd.073010	m1m2.rdj.072309
Oncocnemis sandaraca	0	0	0	0	0	0	0	0	0	0	0
Oncocnemis youngi	0	0	0	0	0	0	0	0	0	0	0
Asticta victoria	0	0	0	0	0	0	0	0	0	0	1
Ceranemota fasciata	0	0	0	0	0	0	1	0	0	0	0
Dysstroma ochrofuscaria	0	0	1	0	0	0	0	0	0	0	0
Itame bitactata	0	0	0	0	0	0	0	0	0	0	0
Pseudobryomima muscosa	0	0	0	0	0	0	0	0	0	0	0
Pseudorthosia variabilis	0	0	0	0	0	0	0	0	0	0	1
Abagrotis forbesi	0	0	0	0	0	0	0	0	0	0	0
Abagrotis trigona	0	0	0	0	0	0	0	0	0	0	0
Achytonix epipaschia	0	0	0	0	0	0	0	0	0	0	0
Acronicta impleta	0	0	0	0	0	0	0	0	0	0	0
Agrotis sp	0	0	0	0	0	0	0	0	0	0	0
Apharetra californiae	0	0	0	0	0	0	0	0	0	0	0
Autographa speciosa	0	0	0	0	0	0	0	0	0	0	0
Coloradia pandora	1	0	0	0	0	0	0	0	1	0	0
Cryphia cuerva	0	0	0	0	0	0	0	0	0	0	0
Drepanulatrix carnearia	0	1	0	0	1	0	0	0	0	0	0
Eupithecia graefii	0	0	0	0	0	0	0	0	0	2	0
Euplexia benesimilis	0	0	0	0	0	0	0	0	0	2	0
Euxoa atomaris	0	0	0	0	0	0	0	1	0	0	0
Euxoa comosa	0	0	0	0	0	0	0	0	0	0	0
Furcula scolopendrina	0	0	0	0	0	0	0	0	0	0	0
Hydriomena renunciata	0	0	1	0	0	0	0	0	0	0	0
Hyppa indistincta	0	0	0	0	0	0	0	0	0	2	0
Lacinipolia olivacea	0	0	0	0	0	0	0	0	0	0	0
Polia nimbosa	0	0	0	0	1	0	0	0	0	0	0
Pseudothordes irrorata	0	0	0	0	0	0	0	0	0	0	0
Apamea occidentis	0	0	0	0	0	1	0	0	0	0	0

	bcm.x44.081109	bcm.x44e.080308	bcm.x44x43for.080308	bcm.x45a.081109	cm.x28.072209	cm.x28.080208	cm.x28e.080208	cm.x28f.080208	cm.x41a.072209	cm.x41a.082608	cm.x41a.l.082808
Ceratodalia gueneata	0	0	0	0	0	0	0	0	0	0	0
Crassivesica bocha	0	0	0	0	0	0	0	0	0	0	0
Cyclophora pendulinaria	0	0	0	0	0	0	0	0	0	0	0
Drepanulatrix unicalcararia	0	0	0	0	0	0	0	0	0	0	0
Dysstroma brunneata	0	0	0	0	0	0	0	0	0	0	0
Euchlaena tigrinaria	0	0	0	0	0	0	0	0	0	0	0
Euxoa punctigera	0	0	0	0	0	0	0	0	0	0	0
Euxoa tessellata	0	0	0	0	0	0	0	0	0	0	0
Hyles lineata	0	0	0	0	0	0	0	0	1	0	0
Hyppa sp	0	0	0	0	0	0	0	0	0	0	0
Lophocampa argentata	0	0	0	0	0	1	0	2	0	0	0
Nematocampa resistaria	0	0	0	0	0	0	0	0	0	0	0
Neoterpes trianguliferata	0	0	0	0	0	0	0	0	0	0	0
Platypolia contadina	0	0	0	0	0	0	0	0	0	0	0
Somatolophis ectrapelaria	0	0	0	0	0	0	0	0	0	0	0
Xanthorhoe sp	0	0	0	0	0	0	0	0	0	0	0
Aletia oxygala	0	0	0	0	0	0	0	0	0	1	0
Apamea atriclava	0	0	0	0	0	0	0	0	0	0	0
Bleptina caradinalis	0	0	0	0	0	2	0	0	0	0	0
Cucullia florea	0	0	1	0	0	0	0	0	0	0	0
Dystroma truncata	0	0	0	0	0	0	0	0	0	0	0
Euxoa infausta	0	0	0	0	0	0	0	0	0	0	0
Euxoa septentrionalis	0	0	0	0	0	0	0	0	0	0	1
Fishia evelina	0	0	0	0	0	0	0	0	0	0	0
Hesperumia sulphuraria	0	0	1	0	0	2	0	0	0	0	0
Homorthodes sp	0	0	0	0	0	0	0	0	0	0	0
Hydriomena perfracta	0	1	0	0	0	0	0	0	0	0	0
Papestra cristifera	0	1	0	0	0	0	1	0	0	0	0

	m2.x21au.072309	m2.x21au.092408	m2.x21ax21f.for.073010	m2.x21ax21f.for.080108	m2.x21ax21f.rd.073010	m2.x21f.072910	m2.x23a.091308	m2.x23c.070909	m2.x23f.072309	m2.x23g.070909
Neocalcis californiaria	0	0	0	0	0	0	0	0	0	0
Oncocnemis sp	0	0	0	0	0	0	0	0	0	0
Orthosia praeses	0	0	0	0	0	0	0	0	0	0
Parabagrotis cupidissima	0	0	0	0	0	0	0	0	0	0
Parabagrotis insularis	0	0	0	0	0	0	0	0	0	0
Phyllodesma americana	0	0	0	0	0	0	0	0	0	0
Protitame matilda	0	0	0	0	0	0	0	0	0	0
Pseudobriomina viscosa	0	0	0	0	0	0	0	0	0	0
Spaelotis sp	0	0	0	0	0	0	0	0	0	0
Sphinx perelegans	0	0	0	0	0	0	0	0	0	0
Sphinx vashti	0	0	0	0	0	0	0	0	0	0
Stenoporpia pulmonaria	0	0	0	0	0	0	0	0	0	0
Abagrotis placida	0	0	0	0	0	0	1	0	0	0
Abagrotis variata	0	0	0	0	0	0	0	0	0	0
Acronicta grisea	0	0	0	0	0	0	0	0	0	0
Adelphagrotis stellaris	0	0	0	0	0	0	0	0	0	0
Agroperina dubitans	0	0	0	0	0	0	0	0	0	0
Anavitrinella pampinaria	0	0	1	0	0	0	0	0	0	0
Andropolia aedon	0	0	0	0	0	0	0	0	0	0
Anticlea multiforata	0	0	1	0	0	0	0	0	0	0
Apamea anteoclara	0	0	0	0	0	0	0	0	0	0
Apamea vultuosa	0	0	0	0	0	0	0	0	0	0
Aseptis fumosa	0	0	0	0	0	0	0	0	0	0
Autographa v-alba	0	0	1	0	0	0	0	0	0	0
Bomolocha abalienalis	0	0	0	0	0	0	0	0	0	0
Campaea pertlata	0	0	0	0	0	0	0	0	0	0
Clemensia albata	0	0	0	0	0	0	0	0	0	0
Clostera apicalis	0	0	0	0	0	0	0	0	0	1
Colisia amorata	0	0	0	0	1	0	0	0	0	0

	bcm.x44.081109	bcm.x44e.080308	bcm.x44x43for.080308	bcm.x45a.081109	cm.x28.072209	cm.x28.080208	cm.x28e.080208	cm.x28f.080208	cm.x41a.072209	cm.x41a.082608	cm.x41a.l.082808
Oncocnemis barnesi	0	0	0	0	0	0	0	0	0	0	0
Oncocnemis chandleri	0	0	0	0	0	0	0	0	0	0	0
Oncocnemis dunbari	0	0	0	0	0	0	0	0	0	0	0
Oncocnemis extremis	0	0	0	0	0	0	0	0	0	0	0
Oncocnemis umbrifascia	0	0	0	0	0	0	0	0	0	0	0
Peridroma saucia	0	0	0	0	0	0	0	0	0	0	0
Perizoma forficaria	0	0	0	0	0	0	0	0	0	0	0
Platyperigea montana	0	0	0	0	0	0	0	0	0	0	0
Pseudothorsia variabilis	0	0	0	0	0	1	0	0	0	0	0
Scoliopteryx libatrix	0	0	0	0	0	0	0	0	0	0	0
Semiothisa sp	0	0	0	0	0	0	0	0	0	0	0
Sericosema juturnaria	0	0	0	0	0	0	0	0	0	0	0
Stamnoctenis pearsalli	0	0	0	0	0	0	0	0	0	0	0
Synaxis jubararia	0	0	0	0	0	0	0	0	0	0	0
Tesagrotis piscipellis	0	0	0	0	0	0	0	0	0	0	0
Thalophaga taylorata	0	0	0	0	0	0	0	0	0	0	0
Trichoplusia ni	0	0	0	0	0	0	0	0	0	0	0
Xanthorhoe ferrugata	0	0	0	0	0	0	0	0	0	0	0
Xanthorhoe munitata	0	0	0	0	0	0	0	0	0	0	0
Xanthorhoe sp.	0	0	0	0	0	0	1	0	0	0	0

