

## AN ABSTRACT OF THE THESIS OF

Erica A. Ersch for the degree of Master of Science in Rangeland Ecology and Management presented on March 17, 2009.

Title: Effects of Plant Community Characteristics on Insect Abundance: Implications for Sage-grouse Brood-rearing Habitat.

Abstract approved:

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A causative factor in declining greater sage-grouse (*Centrocercus urophasianus*) populations is reduced annual recruitment due to poor habitat quality. Sage-grouse population decline is concurrent with a decline in the extent and quality of the sagebrush (*Artemisia* sp.) biome. However, current research has shown a positive relationship between sage-grouse brood and chick survival and the abundance of Lepidoptera larva (caterpillars of moths and butterflies). This two-year (2007-2008) study focused on linking the abundance of litter and ground dwelling insects with plant community characteristics in sagebrush steppe ecosystems, in anticipation of improving sage-grouse brood-rearing habitat management. Focus was placed on insects that have been found in the diet of sage-grouse chicks and included ants, grasshoppers, darkling beetles, and scarab beetles, with a special emphasis on caterpillars. Four sites were chosen in central Oregon for this research. Two sites were dominated by *A. tridentata* ssp. *vaseyana* (mountain big sagebrush) and were managed under two different seasons of cattle grazing, spring and winter. The remaining two sites were split between a *Chrysothamnus viscidiflorus* (yellow rabbitbrush) dominated upland and an *Ericameria nauseosa* (rubber rabbitbrush) dominated meadow. Line-point intercept, plant height, and basal gap intercept were employed to measure plant community structure and composition. Insect abundance

was measured two ways: 1) pitfall traps for ground crawling insects, and 2) black light traps to capture adult moths. Identification of Lepidoptera species by caterpillars is difficult; therefore, documenting Lepidoptera species within an area by conducting an inventory of the adults was necessary. Results show the meadow site had more rabbitbrush, shrub, and vegetative cover, as well as taller shrubs and smaller basal gaps than the upland rabbitbrush site. Although the impact of grazing management was not quantified in this study, spring grazed sites exhibited more sagebrush and shrub cover, taller grasses and shrubs, and larger basal gaps when compared to the winter grazed sites. Within the *A. tridentata* ssp. *vaseyana* sites, forb cover, total vegetative cover, grass heights, and species richness were different between years. The meadow site provided the highest abundance of caterpillars compared to all other sites. Both rabbitbrush sites provided more caterpillars throughout May and June than the *A. tridentata* ssp. *vaseyana* communities, corresponding to early sage-grouse brood-rearing. The winter grazed *A. tridentata* ssp. *vaseyana* site and the upland rabbitbrush site exhibited the highest abundance of grasshoppers. Correlations of vegetation characteristics with insect abundance highlighted several relationships: 1) caterpillars were negatively associated with percent basal gap, mean basal gap size, and sagebrush cover, 2) caterpillars were positively associated with perennial grass cover, rabbitbrush cover, shrub height, and total vegetative cover, and 3) darkling beetles were positively associated with annual forb and annual grass cover. Moth abundance and species richness were highest during July, August, and September, with relatively few moths being caught in May or June. Overall, 222 moth species were present at the study location. Rabbitbrush and sagebrush sites had 145 species in common, with the rabbitbrush sites having 194 species overall and *A. tridentata* ssp. *vaseyana* sites having 173 species overall. Moth abundance was negatively correlated with perennial grass cover, basal cover, rabbitbrush cover, shrub and grass height, and total vegetative cover. Additionally, moth abundance was positively correlated with basal gap percent and size, as well as sagebrush cover. In conclusion, the upland rabbitbrush site exhibited the highest abundance of moths, whereas the meadow site presented the most diverse and unique number of moth species. The results of this study suggest rabbitbrush communities may be an important and intricate component

within the sagebrush-steppe landscape, contributing to the quality of sage-grouse brood-rearing habitat.

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Effects of Plant Community Characteristics on Insect Abundance: Implications for  
Sage-grouse Brood-rearing Habitat

by  
Erica A. Ersch

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

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Erica A. Ersch, Author

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## CONTRIBUTION OF AUTHORS

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**Effects of Plant Community Characteristics on Insect Abundance:  
Implications for Sage-grouse Brood-rearing Habitat**

## Chapter 1: Introduction

Current interest in the sagebrush-steppe and sagebrush obligate species is fueled by a decline in sagebrush dominated rangelands and a subsequent decline in many populations of wildlife dependent upon sagebrush. A species receiving much attention from researchers, ranchers, wildlife biologists, and ecologists is the greater sage-grouse (*Centrocercus urophasianus*). This bird holds a unique relationship with the sagebrush community and ensuing insect biodiversity. Sage-grouse are a species of concern in central Oregon and many other areas throughout the western United States and southwestern Canada. Sage-grouse have been petitioned for enlistment as a threatened and endangered species under the United States Endangered Species Act (1973) numerous times.

It has been well documented that sage-grouse chicks feed on insects during the first few weeks after hatching, which contributes to their nutritional intake and increases the chick's chance of survival. Most studies report ants and beetles to be the most common insects in the sage-grouse chick diet during this time period (Drut et al. 1994b, Klebenow and Gray 1968, Rasmussen and Griner 1938). However, research by Gregg (2006) showed a positive relationship between Lepidoptera larval abundance and sage-grouse chick survival. Lepidoptera larvae are high in protein and fats (Fagan 2002, Landry et al. 1986, Mathavan et al. 1976, Moon and Carefoot 1972) making them a suitable item in sage-grouse chick diets, when available.

Currently, there is a lack of information regarding Lepidoptera in sagebrush-steppe ecosystems. In particular, literature regarding caterpillar foodplant relationships and relationships between abundance of species and plant communities is lacking. These relationships may have a significant impact on habitat management for sage-grouse as well as those activities (ex: off-road vehicle use, livestock grazing, recreation, etc.) occurring within their habitat.

Habitat management is one of the most important factors in maintaining stable populations of sage-grouse. Connelly and Braun (1997) stated that "habitat



deterioration, loss, and fragmentation have reduced the quantity and quality of nesting and early brood-rearing habitat causing population declines.” Managing for factors that affect survival, such as nesting habitat, food resources, and predator control is critical for sage-grouse populations. Therefore, if plant community structure and composition can be related to food resources, such as forbs and insects, land managers will have a greater breadth of information with which to make decisions about sage-grouse habitat. In habitats other than rangelands, several studies have reported on relationships between certain habitat characteristics and Lepidoptera diversity and abundance (Beck et al. 2002, Burford et al. 1999, Devries and Walla 2001). Beck et al. (2002) reported that understory plant species diversity was a significant predictor of geometrid moth diversity. Burford et al. (1999) suggested that forest management practices, like clear cutting, can influence the diversity and abundance of moth species. Vertical stratification of fruit-feeding butterfly species diversity was confirmed between the canopy and understory (Devries and Walla 2001). Although these studies focused on forest and agricultural habitats, similar principles can be applied to sagebrush (*Artemisia* sp.) plant communities to determine relationships between habitat variables and Lepidoptera biodiversity.

## **Sage-grouse Population Status**

Greater sage-grouse populations are declining throughout most of their range. Sage-grouse presently occur in eleven US states and two Canadian provinces: California, Colorado, Idaho, Montana, Nevada, North Dakota, Oregon, South Dakota, Utah, Washington, Wyoming, Alberta, and Saskatchewan (Schroeder et al. 2004). The greater sage-grouse species has been extirpated from four states: Arizona, New Mexico, Oklahoma, Kansas, and the Canadian province of British Columbia (Schroeder et al. 2004). A synthesis study by Connelly and Braun (1997) reported range-wide sage-grouse breeding population declines of 17-47% and production declines between 10-51%, based on long-term averages. However, some sage-grouse

populations are showing stable or increasing numbers. Connelly and Braun (1997) suggest that at least 2.25 juveniles per successful female should be present in the fall to allow for stable or increasing populations. Hagan (2005) reported that among the western states, the number of young in the fall population varies from 1.40 to 2.96 juveniles per female. He also stated that in recent years this ratio had declined to 1.21 to 2.19 juveniles per female (Hagan 2005). According to Connelly et al. (2004), annual reproductive success, defined as the probability of a female hatching more than one egg in a season, is greater than the rate of nest success because of the reneesting attempts. Survival rates are difficult to measure, but Crawford et al. (2004: Table 1) compiled data from several studies and found: 1) annual survival of breeding-aged males was 48.9%; 2) annual survival of breeding-aged females was 60.6%; and 3) survival of juveniles was 10%. The low survival rates for juvenile sage-grouse can be attributed to several factors including food availability, habitat quality, harvest, predation, and weather (Connelly et al. 2004).

Within Oregon, spring population indices have demonstrated an overall decline since the 1940's, although data collected before 1980 should be evaluated with caution due to small sample sizes and no survey protocols (Hagan 2005). Hanf et al. (1994) reported a substantial decline in male numbers between 1989 and 1993 in central Oregon; although, these were all considered drought years. However, Hagan (2005) indicated that population indices over the previous decade reveal stable or increasing population numbers in Oregon.

Sage-grouse habitat decline can be attributed to alterations in fire regime, historical and current excessive livestock grazing, expansion of invasive species (native and introduced), conversion of rangeland to cropland, general decline in area of sagebrush biome, energy development, urban expansion, and fragmentation due to roads and power lines. In the western states, the area considered to be sagebrush dominated has been declining. Connelly et al. (2004) reported that only 55%, of the area that exhibits the potential to be dominated by sagebrush, was actually sagebrush habitat. West (1999) estimated that 4.5 million hectares of sagebrush steppe have been lost due to urban and agricultural development. Changes in plant composition in

non-cultivated areas are primarily attributed to altered fire regimes, improperly managed livestock grazing, introduction of exotic species, and herbicide use (Miller et al. 1994). These factors all affect sage-grouse reproduction and survival, but on different temporal and spatial scales.

Greater sage-grouse have been considered for listing under provisions of the Endangered Species Act (ESA 1973) eight times. In January of 2005, after 12 months of review, the United States Fish and Wildlife Service (USFWS) reported their findings that greater sage-grouse did not warrant listing as a threatened or endangered species, but efforts still needed to be made to conserve sage-grouse and improve sagebrush habitat (United States Fish and Wildlife Service 2005). The USFWS (2005) stated that if the greater sage-grouse was listed, there would be a reduction of freedom and private property rights and public land use, and therefore, a negative impact on the economy. In December 2007, a court ruling decided to re-evaluate the 2005 USFWS decision to not list greater sage-grouse and a status review was initiated. In December, 2008, a press release informed the public that a ruling on the sage-grouse status will be released in July, 2009.

## **Sage-grouse Life History and Habitat Relationships**

Sage-grouse are sagebrush obligate species. Sage-grouse habitat requirements vary seasonally and spatially, with sagebrush being an indispensable component. Sagebrush habitats vary widely across sage-grouse range, corresponding with changes in elevation, topography, precipitation, plant associations, and soils. Sage-grouse use sagebrush throughout the year for food, nesting, and protection. Large, woody species of sagebrush, such as *A. tridentata* Nutt. (big sagebrush), *A. cana* Pursh (silver sagebrush), and *A. tripartita* Rybd. (threetip sagebrush), are used by sage-grouse throughout the year (Dalke et al. 1963, Patterson 1952). Other species of sagebrush, such as *A. nova* (A. Nels.) Cronq. (black sagebrush) and *A. arbuscula* Nutt. (low

sagebrush), are seasonally important components of the habitat (Dalke et al. 1963, Patterson 1952).

Patterson (1952) reported that sagebrush is almost exclusively eaten by sage-grouse during the winter months. Several studies showed that sage-grouse typically utilize winter habitat where *A. tridentata* cover ranges from 12 to 43% with shrub heights generally above 25 cm (Connelly et al. 2000: Table 2). In central Oregon, birds were observed during the winter period in sagebrush communities with  $\geq 20\%$  cover, but using sections within those stands that averaged 12-17% cover (Hanf et al. 1994). During the winter period, it is important to remember that sagebrush height is needed above the snow level for protection and food. Variations in yearly snowfall may alter the availability of suitable wintering habitat.

In the western US, female sage-grouse begin attending leks in late February to early March (Connelly et al. 2004), with the studied populations in central Oregon starting in early to mid March (Hanf et al. 1994). Leks are typically located in sparsely vegetated areas, such as *A. arbuscula* sites, ant mounds, roads, gravel pits, stock ponds and dry lakebeds, in close proximity to suitable nesting habitat (Crawford et al. 2004, Connelly et al. 2004, Patterson 1952). Peak hen attendance is typically late March to early April for birds in central Oregon (Hanf et al. 1994), with a range wide average from mid March to mid April (Connelly et al. 2004). During the pre-laying period, which is the 5 weeks prior to incubation of eggs (Barnett 1992), females typically reside in *A. arbuscula* and *A. tridentata* ssp. *wyomingensis* Beetle and Young (Wyoming big sagebrush) communities (Crawford et al. 2004).

After mating, female sage-grouse move into the area of their nest location within a few days and remain sedentary until nesting (Patterson 1952). In southeastern Oregon, Coggins (1998) found that increased spring forb cover, food forb (forbs that sage-grouse consume) cover, and tall ( $> 18$  cm) grass cover was correlated with overall increased rates of nest initiation, renesting, and nesting success. Females generally nest under sagebrush plants, often in *A. tridentata* ssp. *vaseyana* Rybd (mountain big sagebrush) habitat (Gregg et al. 1994, Hanf et al. 1994). Sage-grouse also use other shrub species like rabbitbrush (*Chrysothamnus* and *Ericameria* ),

*Purshia tridentata* (Pursh) DC. (antelope bitterbrush), and *Tetradymia canescens* DC. (horsebrush) for nesting. Productive nesting habitat contains sagebrush with horizontal and vertical structural diversity to provide adequate protective cover of the nest, with the understory comprised of native grasses and forbs providing a food source for hens and chicks (Connelly et al. 2000, Schroeder et al. 1999). Wakkinen (1990) found that hens in southeastern Idaho nested under taller bushes with a larger area and greater lateral obstructing cover compared to random sites.

Clutch size of sage-grouse varies between 6.3 and 9.1 eggs (Connelly et al. 2004: Table 3.2). Nest success and survival rates are dependent upon many variables, including nesting cover, predation, renesting attempts, and nest interruptions. Nest success is highly variable ranging between 14.5% to 86.1% (Connelly et al. 2004: Table 3.2). Nesting success of 30% was reported for hens in central Oregon between 1991 and 1993 (Hanf et al. 1994) and 20% at Hart Mountain National Antelope Refuge in southeast Oregon in 1992 (Crawford and DeLong 1993).

Brood rearing is a critical time for sage-grouse. Chicks typically spend the first 12 weeks of life with the hen (M. Gregg, pers. comm., 1/09). Most sage-grouse chick mortality occurs within the first three weeks with predation being the primary cause (Gregg et al. 2007). Berry and Eng (1985) tracked hens with broods in Wyoming and reported that they stayed within the immediate vicinity of the nest for at least the first two to three weeks, after which 69% of hens initiated movement away from the nest location. Hens that initiated movement away from the nest did so before vegetation desiccation, suggesting that early movement is independent of changing moisture conditions (Berry and Eng 1985). Broods in central Oregon were most frequently observed in *A. tridentata* ssp. *vaseyana* communities (Hanf et al. 1994). Drut et al. (1994a) reported that most broods were produced in the *A. tridentata* cover type, but during early brood-rearing (first six weeks) hens with broods were most frequently found in *A. arbuscula* cover. Hens with broods then returned to the *A. tridentata* habitat type during weeks seven through twelve (Drut et al. 1994a).

Quality brood-rearing habitat has several components: 1) adequate amounts of forbs and insects; 2) open sites for feeding; and 3) small areas of dense sagebrush for

roosting (Hanf et al. 1994). Forb availability is an essential component for selection of brood habitat by hens (Drut et al. 1994a, Drut et al. 1994b, Klebenow 1969), relating not only to forbs as a food source, but as habitat and a food source for insects as well. A diversity of vegetation, especially forbs, allows for a wider range of habitat and host plants for insects. Holloran (1999) reported that mean total herbaceous cover (37%) and total forb cover (9%) were higher at early brood-rearing sites, compared to random locations in Wyoming. Also, mean live sagebrush cover (16%), total shrub canopy cover (19%), and average live sagebrush height (25 cm) were lower at early brood-rearing locations than at random sites (Holloran 1999). Holloran (1999) also reported that live grass and residual grass height averaged 18 cm and 11 cm, respectively, at early brood-rearing locations. In Oregon, late brood-rearing (weeks 7-12) habitat use shifted from *A. arbuscula* to *A. tridentata* dominated areas and use of meadows and lakebeds increased (Drut et al. 1994a). Drut et al. (1994a) also noted that cover types used by hens with broods typically had greater forb availability during periods of high use. In Wyoming, areas used during late brood-rearing had higher food forb cover and lower residual grass height than random locations (Holloran 1999). In Washington, food forb cover was greater at all brood locations compared to random locations (Sveum et al. 1998). Drut et al. (1994a) concluded that broods in low forb availability areas used a larger home range than those broods in areas with relatively abundant forbs. This preference for forb availability suggests that hens may select sites for food resource quality and availability rather than for protective cover. As the summer progresses and desiccation occurs in upland areas, broods tend to move to riparian areas, wet meadows, and agricultural fields (Connelly et al. 2004). Mesic sites provide forbs and insects for chicks and hens (Connelly et al. 2000, Schroeder et al. 1999). These studies suggest that a combination of grasses, forbs, shrubs, and associated insects are important factors for chick survival.

## Sage-grouse Diet and Habitat Relationships

Egg development requires hens to increase their dietary protein intake, which is typically accomplished by increasing the amount of forbs in the diet (Gregg 2006). Barnett and Crawford (1994) reported that annual differences in sage-grouse reproductive success positively correlated with increased consumption of forbs by pre-laying hens. Primary forbs ( $\geq 1\%$  of the diet by weight) consumed by pre-laying hens in Oregon were *Lomatium* Raf. (desert parsley), *Crepis* L. (hawksbeard), *Phlox longifolia* Nutt. (long-leaf phlox), *Agoseris* Raf. (agoseris), *Trifolium* L. (clover), *Antennaria* Gaertn. (pussytoes), *Astragalus purshii* Dougl. ex Hook. (Pursh's milkvetch), *A. obscurus* S. Watson (arcane milkvetch), and *Eriogonum* Michx. (buckwheat) (Barnett and Crawford 1994). In Oregon, sagebrush composed 50-82% and forbs 18-50% of the diet, both by relative dry weight (Barnett and Crawford 1994). Barnett and Crawford (1994) reported that all forbs were higher in crude protein (16.7% to 36.7%) and phosphorus (0.24% to 0.62%) and many forbs were higher in calcium (0.35% to 1.36%) when compared to sagebrush (averaged between *A. tridentata* and *A. arbuscula*: 15% protein, 0.23% phosphorus, and 0.55% calcium). Therefore, including forbs in the diet enhances the nutrient quality intake of hens during the critical pre-laying period.

Pre-laying nutrition of sage-grouse hens is important for reproductive success. Gregg (2006) found that chick survival was greatest when high values for total plasma protein (a measure of available protein in the body and an indicator of body condition) in hens corresponded with high abundance of Lepidoptera larvae at brood sites. This suggests that forbs and insects available to hens prior to nesting and chicks after hatching are crucial for chick survival. A study conducted on ruffed grouse (*Bonasa umbellus*) showed that as dietary protein increased, linear increases in duration and rate of egg laying, clutch size, weight of first egg, mean egg weight, clutch weight, hatching success, chick weight at hatching, and chick survival were observed (Beckerton and Middleton 1982).

Timing between forb growth and sage-grouse egg development is critical; however, this synchrony is not always on schedule. The pre-laying period is variable, but generally occurs from early March to early April, meaning that forbs may not be present or abundant depending on weather and snow depth. Gregg (2006) reported that sage-grouse productivity was greater during the year [of a two year study] of higher forb availability and consumption by hens. Gregg et al. (2006) suggested that consumption of forbs during early spring may increase nutritional status of pre-incubating females, thus positively affecting reproductive success. Thus, annual variation in reproductive success may be in part due to the availability of forbs during the pre-laying period.

Hens with broods are generally found where forb abundance is greatest (Drut et al. 1994a). In Oregon, chicks were collected and the diet determined to contain 122 different foods, which included 34 genera of forbs, 2 genera of shrubs, 1 genus of grass, and 41 families of invertebrates (Drut et al. 1994b). Sage-grouse chicks mainly feed on forbs and insects until 12 weeks of age, after which sagebrush becomes an integral part of the diet (Klebenow and Gray 1968). Peterson (1970) reported that insect use declined with increasing age of sage-grouse chicks: insects comprised 60% of the diet in one-week-old chicks, 33% in two-week-old chicks, and only 5% by the twelfth week. The forb composition in brood habitat should be diverse to provide a variety of succulent plants throughout the season (Peterson 1970). Peterson (1970) reported little use of *A. tridentata* as a food until 11 weeks of age, with forbs, mainly *Taraxacum officinale* F.H. Wigg. (common dandelion) and *Tragopogon dubius* Scop. (yellow salsify), averaging 75% of the diet through three months of age. However, where forb and insect availability is limited, chicks will consume sagebrush (Drut et al. 1994b).

Invertebrates also have been documented to be essential components in the diet of other grouse species and grouse-like birds. A study in Scotland found that black grouse (*Tetrao tetrix*) and wood grouse (*Tetrao urogallus*) broods used habitat with taller vegetation that had more invertebrates, specifically moth and sawfly larvae (Baines et al. 1996). Baines et al. (1996) also reported that wood grouse showed



synchronization between peak hatch and availability of moth larvae on *Vaccinium myrtillus* L. (whortleberry). The abundance of moth larvae was rather short-lived and dropped by two-thirds within three weeks after peak grouse hatching (Baines et al. 1996). Baines et al. (1996) compared invertebrate abundance between brood and random locations and showed chicks selected areas with about twice the density of invertebrates; also, brood foraging areas contained three times as many bugs and twice as many beetles and flies as random sites. Jamison et al. (2002) and Hagen et al. (2005) conducted studies with lesser prairie-chickens (*Tympanuchus palidicinctus*) and reported that brood use areas had significantly higher grasshopper (Acrididae) and total invertebrate biomass than paired non-use areas. Invertebrates are the principal summer food source for lesser prairie-chicken chicks and adults (Jones 1963). Jamison et al. (2002) also reported that invertebrate biomass was positively correlated with forb cover and that forbs more strongly associated to invertebrate biomass than shrubs, grasses, or bare ground. Borg and Toft (2000) showed that a diverse selection of insect fauna is crucial for the development of grey partridge (*Perdix perdix*) chicks. Similar to sage-grouse chicks, grey partridge chicks are highly dependent on arthropods as food for the first two to three weeks of life (Potts 1986).

Laboratory and field studies on sage-grouse chick diets have been conducted to determine the relative importance of invertebrates and forbs on survival. Johnson and Boyce (1990) reported that all sage-grouse chicks hatched in captivity died between four and ten days when deprived of a mixed invertebrate diet consisting of grasshoppers, ants, beetles, crickets, the earthworm *Limbricus terrestris*, and the mealworm *Tenebrio molitor*, whereas all chicks given invertebrates survived the initial 10 days. Johnson and Boyce (1990) also reported that: 1) sage-grouse chicks required 15 g (live weight) of mealworms per day along with vegetation to keep healthy and rapidly growing between one and three weeks of age, 2) insects are required for survival until three weeks of age, and 3) that growth rates decreased when deprived of insects after three weeks of age. Growth rates of chicks were positively correlated with insect rations: as insect quantity increased, survival and growth rates also

increased (Johnson and Boyce 1990). These data imply that insects are necessary for normal growth rates of chicks, even after three weeks of age.

Availability of invertebrates and forbs during brood-rearing is crucial to sage-grouse chick survival. Data from Drut et al. (1994b) positively correlated sage-grouse chick survival with the availability of forbs and invertebrates. Drut et al. (1994b) listed numerous forbs found in sage-grouse chick crops collected in southeastern Oregon: *Astragalus* L. (milkvetch), *Agoseris* sp., *Crepis* sp., *Microsteris gracilis* (Hook.) Greene (microsteris), *T. officinale*, *Trifolium* sp., *Lomatium* sp., *Orobancha* L. (broomrape), *Erigeron* L. (fleabane), and *Blepharipappus scaber* Hook. (blepharipappus). Drut et al. (1994b) also reported that scarab beetles (Scarabaeidae), darkling beetles (Tenebrionidae) and ants (Formicidae) constituted the majority of the arthropods eaten by chicks in Oregon. An important food in the diet of chicks up to five weeks of age in central Montana was *Lepidium densiflorum* Schrad. (common pepperweed) (Peterson 1970). Chick crops collected in Idaho contained 45% (by volume) of *Leptosiphon harknessii* (Curran) J.M. Porter & L.A. Johnson (Harkness' flaxflower) and 52% insects (mainly scarab beetles) during the first week of age, after which the insect volume fluctuated below 25%, except in week three (Klebenow and Gray 1968).

As sage-grouse chicks mature, their diets change and become almost completely dominated by sagebrush. Rasmussen and Griner (1938) reported that diets of very young sage-grouse were very different than adult diets. The major difference is a change from a diet consisting mainly of invertebrates to a vegetarian diet, occurring in a period of time from spring to summer. During summer, juvenile sage-grouse prefer to eat forbs and utilize sagebrush for cover (Peterson 1970). In Utah, juveniles ate 52.5% plant material in June, 56.4% in July, 95.5% in August, 94.5% in September, and 99.5% in October (Rasmussen and Griner 1938); suggesting that young sage-grouse adapt to an adult diet at about three months of age. Klebenow and Gray (1968) noted that when plants were desiccated, juvenile sage-grouse ceased to feed upon them. Rasmussen and Griner (1938) also reported finding Lepidoptera in the stomach contents of juvenile grouse during June and July along with a large

amount of ants during June and July (36% and 26%, respectively) with an abrupt decline in August (3%). Rasmussen and Griner (1938) concluded that the choice of insects in the juvenile diets was principally due to relative availability. However, different insect species are not nutritionally equivalent (Borg and Toft 2000), so when evaluating habitat for insectivorous avian species, both insect abundance and quality should be considered.

## **Grazing and Shrub Management**

It is commonly accepted that grazing by domestic ungulates can be used to manipulate vegetation. Manier and Hobbs (2007) reported that domestic and wild ungulate grazing decreased sagebrush cover by almost 10% when compared to ungrazed areas. A simulated grazing (defoliation by clipping) study conducted by Cook (1971) showed that *A. tridentata* percent crown death and percent plants dead increased with various levels of treatment. Cook (1971) also reported an average 75% decrease in production of *A. tridentata* after three years of defoliation during four periods at three different intensities.

Blaisdell et al. (1982) noted that the most effective reduction of sagebrush cover was with sheep. The greatest effect of sheep grazing on sagebrush is the reduction of size rather than plant mortality (Frischknecht and Harris 1973). Under spring cattle grazing, shrubs gain a competitive growth advantage and shrub production increases (Austin 1983). Conversely, where there is winter use of shrubs, the growth advantage shifts to grasses (Scotter 1980). Mueggler (1950) reported that spring grazing by sheep reduced the percentage of grasses and forbs while increasing shrubs. Also, fall grazing by sheep increased the percentage of palatable grasses and forbs while decreasing *A. tripartita* (Mueggler 1950). These same findings were corroborated by Bork et al. (1998), with live shrub cover increasing with spring grazing and more perennial grass and forb cover with fall grazing. Herbaceous species tend to be more palatable to livestock than shrubs during the growing season,

so sagebrush and other shrubs prosper at the expense of grasses and forbs (Blaisdell et al. 1982). Winter grazing by cattle in central Oregon began with the assumption that it was beneficial to grass health (E. McKinney, pers. comm., 2/09). The unintentional, yet desirable at that time (1970's and 80's), outcome of this practice was that trampling effects and consumption by cattle reduced sagebrush density (E. McKinney, pers. comm. 2/09).

It must be mentioned that *A. tridentata* maintains a relatively high level of crude protein throughout the year. Data from Tueller (1979) show a seasonal low percentage of crude protein in *A. tridentata* during December (10.5%) to almost the seasonal high in February (14.0%). In addition, concentrations of terpenes in sagebrush are at their lowest levels during winter, which enables animals to eat more sagebrush (BEHAVE 2009). Therefore, sagebrush is a quality forage item for ungulates during a time of the year when grasses are generally lacking in crude protein.

## **Insect Relationships with Vegetation and Management**

Some invertebrates have relationships to the vegetation characteristics within their environment. These relationships are important for land managers to understand when manipulating vegetation because it could have a drastic effect on the invertebrate populations.

Several studies have evaluated the indirect or direct effects of livestock grazing on invertebrate populations (Bromham et al. 2002, Dennis et al. 1998, Gibson et al. 1992, Kruess and Tscharntke 2002, Morris 1973, Read 1999). Kruess and Tscharntke (2002) conducted a study in northern Germany and reported a weak positive correlation between mean vegetation height and the log number of individuals and log number of species of Lepidoptera larvae. Kruess and Tscharntke (2002) also determined that grazing intensity had a negative effect on the number of individual Lepidoptera larvae, probably due to the effect of grazing on vegetation height.

Bromham et al. (2002) reported that the number of invertebrates (especially ants and beetles) increased from ungrazed woodland to grazed woodland pasture in northern Victoria. Grasshoppers formed a higher proportion of the catch in the pasture compared to either woodland treatment (Bromham et al. 2002). However, Bromham et al. (2002) also reported that the number of insect orders in the pasture treatment was lower than in either woodland treatment. Ant diversity and richness were higher in grazed woodland compared to ungrazed woodland (Bromham et al. 2002). In Britain, mean numbers of Heteroptera (“true bugs”) were higher on winter and fall grazed (by sheep) sites compared to sites with spring and summer grazing (Morris 1973). Also, Auchenorrhyncha larvae (cicadas, treehoppers, leafhoppers, etc.) abundance was lower in spring grazed plots (Morris 1973). Read (1999) reported that, in Australia, the abundance of ants increased after grazing, but other invertebrates showed inconsistent responses. Read (1999) also noted that January rainfall had a marked effect on grass cover and small and large beetle abundance. Baines (1996) reported a difference between the mean numbers of Lepidoptera larvae in lightly grazed (3.1 individuals) versus heavily grazed (0.7 individuals) pastures in Scotland. Baines (1996) also reported that overall there were 41% fewer invertebrates caught on heavily grazed moors than on lightly grazed moors, which was mostly attributed to a 77% reduction in Lepidopteran larvae and reductions in a few other insect orders. Mean vegetation height differences between heavily and lightly grazed moors ranged between 9% and 43% (Baines 1996). Overall, the effects of livestock grazing on invertebrates are likely to be indirect through the effects on vegetation.

Engle et al. (2008) studied invertebrate response to patch burning in the tallgrass prairie of Oklahoma. Their results showed that invertebrate biomass was significantly greater in the transitional areas (12 to 24 months post burn) compared to traditional management areas (Engle et al. 2008). Invertebrate community composition and mass were sensitive to the habitat heterogeneity provided by the patch burning treatments (Engle et al. 2008).

## **Lepidoptera Life History**

Lepidoptera include moths, butterflies, and skippers. Species of Lepidoptera develop through a four-stage life cycle: 1) egg, 2) larva (caterpillar), 3) pupa or chrysalis, and 4) adult. Most Lepidoptera have one generation per year in cooler climates and typically overwinter as a pupa. However, many species overwinter in the egg stage and some others overwinter as adults (Triplehorn and Johnson 2005). In cold climates, larvae typically do not overwinter and are present in the spring and summer. Generally caterpillars develop in four to eight weeks, but occasionally development may take more than eight months, depending on the species (Miller 1995). Lepidoptera larvae generally pass through five instars as they eat and grow (Miller 1995). An instar is the individual larva between molts. Most larvae are phytophagous, such as foliage feeders and leaf miners. Some species are entomophagous, gall makers, borers, or detritivores. The larger larvae generally feed at the leaf edge and consume all but the large veins; whereas, the smaller larvae skeletonize the leaf or eat small holes in it (Triplehorn and Johnson 2005).

Caterpillar growth rates are dependent on temperature, growing more slowly at cold temperatures (Miller 1995). Caterpillars in extremely cold climates may take one or two years to develop because the short warm season hinders feeding and growth (Miller 1995). Caterpillar development is also dependent upon nutritional quality of vegetation and is strongly influenced by the amount of protein, water content, and allelochemicals present (Miller 1995). The allelochemicals in plants can deter or stimulate caterpillar feeding, depending on the chemical (Miller 1995). Miller (1995) also stated that many aposematic caterpillars are poisonous due to ingestion of toxic allelochemicals found in the plants they consume that are then stored in their body.

Lepidopterans can be split into two categories based on feeding strategies: generalists (polyphagous) and specialists (monophagous). Generalist caterpillars can feed upon a variety of plants species and still develop into an adult in the normal period of time (Miller 1995). Specialists are defined as those species that have a

restricted range of suitable food plants which ranges from feeding on a single species, to a few species or all species within a genus (Miller 1995).

Most caterpillars typically feed on foliage, but some also feed on roots, within branches and woody stems, in seeds, and on flowers. Foodplant relationships are critical for understanding the Lepidoptera-vegetation dynamics and ecological function of Lepidoptera in any community. Miller and Hammond (2003) reported on species of macromoths and found that 10-12% were supported by conifers, 52-66% were supported by flowering trees and shrubs, and 20-33% were supported by forbs and grasses. A few foodplant relationships are known for Lepidoptera species occurring in central Oregon from other studies in near-by areas; for example, *A. tridentata* supports *Speranza colata* and *Abagrotis duanca* (Miller and Hammond 2003). Other known relationships are: 1) *E. nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird (rubber rabbitbrush) with *Chlorochlamys triangularis*, *Eupithecia misturata*, and *Digrammia curvata*; 2) *Chrysothamnus viscidiflorus* (Hook.) Nutt. (yellow rabbitbrush) with *Chesiadodes cinerea*, *Chlorochlamys triangularis*, and *Cucullia pulla*; 3) *Juniperus occidentalis* Hook. (western juniper) with *Digrammia continuata*, *Abagrotis glenni*, *Lithophane longior*, and *Sphinx sequoiae*. There are many other known foodplant relationships, but to date many species have no known foodplant. Another unknown in sagebrush rangelands is how many species, and their abundance, of Lepidoptera occur in a given place.

Natural enemies of caterpillars include rodents, reptiles, bats, birds, spiders, nematodes, and other insects (Miller 1995). Natural defense mechanisms of caterpillars include physical and physiological features, such as stinging hairs, camouflage, glands that emit repellant chemicals, storage of allelochemicals, and aposematic coloring. Chemical components of larvae may influence the selectivity of sage-grouse chicks when feeding on caterpillars.

When a caterpillar reaches a critical size, it will change behavior from feeding to searching for a pupation site. Pupation can occur in various situations, ranging from an elaborate cocoon, which is a pupa wrapped in silk, to no cocoon at all (Triplehorn and Johnson 2005). Butterflies do not make a cocoon and are often

referred to as a chrysalis. Moth pupae are usually brownish and smooth, whereas butterfly pupa are variously colored and often tuberculate or sculptured (Triplehorn and Johnson 2005). Miller (1995) stated that the pupal stage may last only nine to twelve days or longer than one year.

## **Nutrient Content of Lepidoptera**

When sage-grouse chicks are foraging for diet items, it is important to maximize nutrient intake in a given amount of time. Choosing items in the diet that are high in protein, lipids, and carbohydrates will help chicks maximize growth and survival. Insects, in general, are excellent sources of nitrogen, potassium, and magnesium (Studier and Seveck 1992). Lepidopterans accumulate reserve food energy during the larval period for the benefit of the subsequent non-feeding pupal and adult stages (Panadian 1973). This accumulation of reserves results in a high caloric content of the larva (Moon and Carefoot 1972).

Mathavan et al. (1976) conducted a study on Lepidopteran larvae and concluded that larvae feeding on increasing rates of dry matter (100 to 600 mg dry weight/g live insect/day) had an asymptotically increasing caloric content (5,320 to 5,900 g cal/g dry weight). The positive relationship noted by Mathavan et al. (1976) between the feeding rates and caloric value was not affected by differences in temperature, ration, foodplant, and species, therefore when enough phytomass is available, caterpillars will maximize their intake and ultimately their caloric content. These data give some idea of the caloric value of the caterpillar as a dietary item for predators.

Water and nitrogen content of foodplants have been found to influence the rate and efficiency of growth in Lepidoptera larvae (Schroeder and Malmer 1980). Scriber (1977) conducted a study using *Hyalophora cecropia* and *Prunus serotina* Ehrh. (wild cherry) and concluded that larvae fed leaves low in water content grew more slowly and were less efficient at utilizing plant biomass, energy, and nitrogen than those fed



leaves fully supplemented with water. Scriber (1977) also stated the relative accumulation rate of nitrogen was suppressed nearly two-fold for larvae on low-water leaves. Therefore, as desiccation of vegetation occurs, the growth rates of caterpillars decline.

Fagan et al. (2002) synthesized several studies (Hattenschwiler and Schafellner 1999, Landry et al. 1986, Mattson et al. 1983, Montgomery 1982, Schroeder 1977, Schroeder and Malmer 1980, Siemann et al. 1996) and concluded that nitrogen content for 29 species of adult Lepidoptera ranged between 6.2% and 10.0%. With previously discussed information, a conclusion can be drawn that the percent nitrogen would be higher in the larval form. For example, Landry et al. (1986) determined crude protein content of six species of Lepidoptera larvae to range from 7.8% to 11.8% for freshly killed specimens and 49.4% to 58.1% on a dry-weight basis. The proximate analyses (percent protein, moisture, fat, ash, crude fiber, and carbohydrate) indicated the fat content was higher in larval powders (10.0% to 20.7%) than in the conventional supplements (1.0-9.4%) typically fed to poultry (Landry et al. 1986). Landry et al. (1986) also noted that poultry chicks fed the experimental diets (larval powders used as protein) tended to eat less, and the feed-to-gain ratios were as good as or better than those on the control diets (soybean meal used as protein supplement). These data confirm that Lepidoptera larvae are good sources of protein and energy for chicks, poultry or sage-grouse.

## **Project Goal**

The goal for this project was to determine relationships between insect abundance and plant community characteristics in a central Oregon sagebrush-steppe. These insect-plant relationships can then be used to help guide management regarding sage-grouse brood-rearing habitat. The objectives of this study were to quantify plant community composition and structure in *A. tridentata* ssp. *vaseyana* dominated sites under winter and spring grazing management as well as in a rabbitbrush

(*Chrysothamnus* sp. or *Ericameria* sp.) dominated meadow and an upland-type community. The abundance of insect species that sage-grouse chicks consume were also of interest and included: 1) ants, 2) darkling beetles, 3) scarab beetles, 4) grasshoppers, and 5) Lepidoptera larvae (caterpillars). In addition, the species of moths present at the study location were identified in order to examine the caterpillar foodplant relationships and allow for further investigation of caterpillars as a food resource for sage-grouse chicks.

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## **Chapter 2: Insect Abundance and Plant Community Characteristics: Implications for Sage-grouse Brood-rearing Habitat in Central Oregon, USA**

### **Abstract**

Greater sage-grouse (*Centrocercus urophasianus*) populations have been declining over the past half century, in part due to low annual recruitment, which has been attributed to poor quality brood-rearing habitat. Sage-grouse population decline is concurrent with a decline in the extent and quality of the sagebrush (*Artemisia* sp.) biome. However, current research has shown a positive relationship between sage-grouse brood and chick survival and the abundance of Lepidoptera larva (caterpillars of moths and butterflies). This two-year (2007-2008) study focused on linking the abundance of litter and ground dwelling insects with plant community characteristics in sagebrush steppe ecosystems, in hopes of improving sage-grouse brood-rearing habitat management. Focus was placed on insects that have been found in the diet of sage-grouse chicks and included ants, grasshoppers, darkling beetles, and scarab beetles, with a special emphasis on caterpillars. Four sites were chosen in central Oregon for this research. The first two were *A. tridentata* ssp. *vaseyana* (mountain big sagebrush) dominated communities under two different seasons of cattle grazing management, spring and winter. The remaining two sites were split between a *Chrysothamnus viscidiflorus* (yellow rabbitbrush) dominated upland and an *Ericameria nauseosa* (rubber rabbitbrush) dominated dry meadow. Line-point intercept, plant height, and basal gap intercept were employed to measure plant community structure and composition. Insect abundance was measured using pitfall traps during May, June, and the first half of July. Results show the meadow community provided the highest abundance of caterpillars compared to all other sites. The upland rabbitbrush site exhibited higher grasshopper abundance than the meadow site. Also, in comparison, rabbitbrush sites provided more caterpillars throughout May and June than the *A. tridentata* ssp. *vaseyana* communities. The meadow site had

more rabbitbrush, shrub, and vegetative cover, as well as taller shrubs and smaller basal gaps than the upland site. Compared to all other sites, the meadow had the highest forb cover. Within the *A. tridentata* ssp. *vaseyana* communities, the winter grazed sites exhibited greater darkling beetle and grasshopper abundance compared to the spring grazed site. Also, within the *A. tridentata* ssp. *vaseyana* sites, caterpillar abundance, forb cover, total vegetative cover, grass heights, and species richness were different between years. Spring grazed sites exhibited more sagebrush and shrub cover, taller grasses and shrubs, and larger basal gaps when compared to the winter grazed sites. Correlation of vegetation characteristics with insect abundance highlighted several relationships: 1) caterpillars were negatively associated with percent basal gap, mean basal gap size, and sagebrush cover, 2) caterpillars were positively associated with perennial grass cover, rabbitbrush cover, shrub height, and total vegetative cover, and 3) darkling beetles are positively associated with annual forb and annual grass cover. In conclusion, the meadow *E. nauseosa* dominated community provided the most forb cover and caterpillars, suggesting that inclusion of this community type within the landscape would provide quality sage-grouse brood-rearing habitat.

## Introduction

Greater sage-grouse (*Centrocercus urophasianus*) are sagebrush obligate species and a species of concern throughout the western United States and western provinces of Canada. The sagebrush biome has decreased in area over the past century, coinciding with a loss in suitable sage-grouse habitat. Habitat loss is due to several factors including urbanization, fragmentation, and invasion by exotic and native species, increased occurrence of wildfires, and energy development (Connelly et al. 2004).

Low annual recruitment, due to poor quality brood-rearing habitat, has been attributed to the decline in sage-grouse populations (Crawford and Lutz 1985,

Connelly and Braun 1997). Early brood-rearing is a critical time period for sage-grouse chick survival (Gregg et al. 2007), which is directly linked to availability of food and cover (Gregg and Crawford *in press*). It has been well documented that sage-grouse chicks need insects during early brood-rearing to enhance diet quality and increase chances of survival (Gregg and Crawford *in press*, Johnson and Boyce 1990). Insects are excellent sources of nitrogen, potassium, and magnesium (Studier and Sevick 1992). Numerous studies show ants and beetles to be the majority of insects consumed by sage-grouse chicks during early brood-rearing (Drut et al. 1994b, Klebenow and Gray 1968, Peterson 1970, Rasmussen and Griner 1938). Less commonly reported in the diet, Lepidoptera larvae (caterpillars) are high in protein and fats (Fagan 2002, Landry et al. 1986, Mathavan et al. 1976, Moon and Carefoot 1972, Studier and Sevick 1992) and, when available, are high-quality components in sage-grouse chick diets (Gregg and Crawford *in press*).

Research by Gregg and Crawford (*in press*) reported evidence directly linking sage-grouse chick survival with Lepidoptera larvae abundance. They also reported their model for brood survivability revealed that year differences were associated with food abundance. There is a need for literature discussing Lepidoptera in sagebrush-steppe ecosystems. This deficiency warrants research to determine the relationships occurring between Lepidoptera and sagebrush-steppe plant community structure and composition to ultimately benefit sage-grouse habitat. These relationships may have a significant impact on habitat management for sage-grouse as well as affecting policies regarding a variety of land use activities, such as off-road vehicle use, livestock grazing, and public recreation, occurring within sage-grouse habitat. Managing for factors that can increase the chance of survival, such as structural habitat diversity, food quality and availability is critical for keeping sage-grouse populations stable. Arthropod diversity is greater in habitats with more structural complexity (Gardner et al. 1995). Therefore, if plant community structure and composition can be related to food resources, such as forbs and insects, land managers will have a greater breadth of information with which to make decisions about sage-grouse habitat.

The focus of this study was to investigate correlations between 19 vegetation measurements and insect abundance. To accomplish this, plant community composition and structure in *Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle (mountain big sagebrush) dominated sites under winter and spring grazing management as well as in rabbitbrush (*Chrysothamnus* sp. or *Ericameria* sp.) dominated dry meadow and upland type communities were quantified. In addition, we determined the abundance of insect taxa that sage-grouse chicks consume within each of these plant community types: 1) ants, 2) darkling beetles, 3) scarab beetles, 4) grasshoppers, and 5) caterpillars.

## Site Description

The study area was located in Deschutes and Crook County, in central Oregon, within 16 km of the town of Brothers. Average elevation is 1381 m, with a range of 1352 to 1421 m. Study sites were located within both the John Day and Mazama Ecological provinces (Anderson et al. 1998). The John Day Province is typified by exposed ancient sediments and a stony soil mantle over thick beds of fine sedimentary or tuffaceous materials. The Mazama Province is an area covered by aeolian deposits of pumice and volcanic materials from the Mt. Mazama eruption over 6500 years ago.

Soils in the study area include Luckycreek, Dester, and Stookmoor series (Soil Survey Staff 2009). Soils range from Vitritorrandic Haploxerolls to Vitrandic Argixerolls. Ecological sites include the Pumice 8-10 PZ and Mountain Swale 12-16 PZ (Natural Resources Conservation Service 2007). The potential native plant communities, as described by the Natural Resources Conservation Service (2007), were dominated by *A. tridentata* ssp. *vaseyana* and *Festuca idahoensis* Elmer (Idaho fescue) or *Leymus cinereus* (Scribn. & Merr.) A. Löve (basin wildrye) and *F. idahoensis*. Current dominant plant associations are: 1) *A. tridentata* ssp. *vaseyana* and *F. idahoensis*, 2) *Chrysothamnus viscidiflorus* (Hook.) Nutt. (yellow rabbitbrush) and *Achnatherum* P. Beauv. (needlegrass), or 3) *Ericameria nauseosa* (Pall. ex Pursh)

G.L. Nesom & Baird (rubber rabbitbrush), *Poa* L. (bluegrass), and *Carex* L. (upland sedges) (Table 2.1). A full species list can be found in Appendix B.

**Table 2.1** Dominant vegetation, soils, and ecological sites of the six research areas. Brothers, Oregon, 2007-2008.

Dominant Shrub Type	Soils	Ecological Site
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Dester	Pumice 8-10 PZ
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Dester	Pumice 8-10 PZ
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Stookmoor	Pumice 8-10 PZ
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Stookmoor	Pumice 8-10 PZ
<i>Ericameria nauseosa</i>	Luckycreek	Mountain Swale 12-16 PZ
<i>Chrysothamnus viscidiflorus</i>	Stookmoor	Pumice 8-10 PZ

Long term (1959-2008) temperature and precipitation data were obtained from the Brothers weather station (43°49'N, 120°36'W, elevation 1414 m; National Climate Data Center 2009). The mean annual temperature is 6.4°C. Maximum and minimum temperatures range from 37.2°C in the summer to -34.4°C in the winter. Mean yearly precipitation is 226 mm, with monthly means ranging between 11 mm and 29 mm. Much of the precipitation comes as snow from November to March. During 2007, the first year of this study, precipitation was 137 mm or 60% of the long-term mean. For the first nine months of 2008, precipitation was 76 mm or 56% of the nine month long-term mean. Thus, both years were characterized by less than average precipitation.

The study area is currently under public (Prineville District, Bureau of Land Management) and private ownership. This area has historically been subjected to a range of disturbances including dry-land farming, sagebrush removal, homesteading, and sheep and cattle grazing. Currently the study area is grazed by cattle on a seasonal basis and also experiences mild levels of public recreational use. The majority of research sites have been grazed under either a winter (December to March) or spring (April to June) season management plan for over 20 years (J. Swanson, Range Specialist, BLM, pers. comm., 2/09). Grazing treatments were managed under lease

agreements and not by a priori criteria used to define treatments for the sites used in this study.

## **Methods**

### *Experimental Design*

A completely randomized design was used to test insect, vegetation, and year differences between the two seasons of cattle grazing on the four locations dominated by *A. tridentata* ssp. *vaseyana*. Additionally, the same effects were tested on the rabbitbrush (*Chrysothamnus* sp. and *Ericameria* sp.) dominated sites in a meadow and an upland location. Sixteen randomly located plots were established in the spring of 2007, half on winter grazed sites and half on spring grazed sites. Eight additional plots were randomly located in the rabbitbrush dominated sites; four each in the meadow and upland plant communities.

The location of each plot was established by obtaining randomly generated plot coordinates and a Garmin GPS unit. Plots were established if the correct ecological site, soil, and dominant plant were present at the location; otherwise, the next suitable random coordinate was used. Plots were 30 m x 30 m and at least 100 m from the next nearest plot. Five, 30 m vegetation transects and six insect pitfall traps were established in each plot. Transects were systematically located 5 m apart and parallel to one another. Each year a random direction (north-south or east-west) was chosen for transects and a random location for pitfall traps. Vegetation and insect data were pooled by plot for statistical analyses.

### *Vegetation Assessment*

Plant community composition, by cover, and structure were quantified at similar phenological stages of plants each year following the removal of the cattle.

Plant foliar and basal cover and community composition were measured using line-point intercept (Herrick et al. 2005) along five, 30 m transects at each plot for two years. Sampling intervals were determined in 2007 by sampling a 10 m section of transect every 10 cm and then determining what interval (20 cm, 30 cm, or 40 cm) gave the same ( $\pm \leq 1\%$ ) percent cover for shrubs, forbs, and grasses. Sampling intervals were repeated during 2008. Measuring cover by points is considered the least biased and most objective out of the three (plots, line intercept, and point intercept) cover measures (Bonham 1989). However, a disadvantage of line-point intercept is that species with very low cover values are often not sampled efficiently (Elzinga et al. 1998). Therefore, to account for rare species, a species survey was conducted within each plot after the line-point intercept was completed. Species from this survey and the line-point intercept were used to create a species richness variable.

A vegetation variable called “food forbs” was created. This variable is a sum of all the known annual and perennial forbs that sage-grouse consume. For this study area the “food forb” variable included *Achillea millefolium* L., *Agoseris glauca* (Pursh) Raf., *Antennaria dimorpha* (Nutt.) Torr. & A. Gray, *Antennaria rosea* Greene, *Astragalus letiginosus* Douglas ex Hook., *Astragalus peckii* Piper, *Astragalus purshii* Douglas ex Hook., *Castilleja pilosa* (S. Watson) Rydb., *Eriophyllum lanatum* (Pursh) Forbes, *Erigeron linearis* (Hook.) Piper, *Phlox hoodii* Richardson, *Ranunculus glaberrimus* Hook., *Taraxacum officinale* F.H. Wigg., *Trifolium* L., *Gayophytum* A. Juss., and *Microsteris gracilis* (Hook.) Greene.

Plant height and basal gap intercept (Herrick et al. 2005) were used to measure plant community structure. Average vegetative height of shrubs and height of standing dead shrubs, by species, was measured along all transects in both years. The average vegetative and reproductive heights of perennial grasses were also measured. Basal gap intercept of 20 cm or more was measured between perennial plant species during 2008 because it was hypothesized that the distance between perennial plants may affect the abundance of ground-crawling insects.



### *Insect Assessment*

Insect abundance was measured using pitfall traps. Pitfall trapping has been used extensively to study the occurrence, abundance, and activity of soil surface and litter inhabiting arthropods (Topping and Sunderland 1992). Although pitfall traps are not the standard for capturing caterpillars, sampling efforts were focused on insects available for sage-grouse chicks. Six traps per plot were located one or six meters to the north or east of a randomly chosen point along the 30 m vegetation transects. Traps were set out for a 10 week period, beginning the first week of May each year and continuing until the middle of July. This time period corresponds with probable sage-grouse brood rearing in central Oregon. Traps were collected and reset every two weeks. After collection, each 6-trap sample was combined and placed in a solution of 75% ethanol. Caterpillar, grasshopper, ant, scarab beetle, and darkling beetle specimens were sorted by group and counted for each 2-week sampling period to document within season occurrence. Insect abundance for each plot was pooled over the 10-week sampling period to provide an annual total. Due to logistics it was not feasible to count all insects of interest for both years, so grasshoppers, ants, and both beetles were only counted in 2007. Being the focal point of this study, caterpillars were counted for both years.

Traps consisted of plastic cups (7 cm depth and 10 cm diameter), one placed inside the other and sunk into the ground with the lip level with the soil surface. The top cup was filled with 200 ml of a 50/50 ethylene glycol/water mixture, after placing it in the ground and allowing it to “settle in” for one week to reduce disturbance effects caused by trap placement (Greenslade 1964). Traps were then covered with a 20 cm x 20 cm section of brown, matte finished aluminum suspended 2-3 cm above the trap by 20-penny nails. This cover acted as a rain guard and to prevent access to the liquid by cattle, antelope, coyotes, birds, and other wildlife.

## *Data Analysis*

A two-way analysis of variance (ANOVA) was used to test differences in: 1) insect abundance and vegetation characteristics between winter and spring grazed sagebrush sites by year, and 2) insect abundance and vegetation characteristics between meadow and upland rabbitbrush sites by year. Significant effects were tested at the 0.05  $\alpha$ -level. Correlations between insect abundance and vegetation characteristics were tested using Pearson's product moment correlation. To be considered significant, correlations had to exhibit a  $p$ -value  $< 0.05$  and a coefficient  $\geq (\pm) 0.6$ . All data were tested with and without transformations to determine if transformations were necessary. If necessary, the natural log transformation was used for count data of insects and the arcsine square root transformation was used for percent vegetation cover data (Sokal and Rohlf 1995). S-plus 7.0 (S-Plus 2005) was used for all statistical analyses.

## **Results**

### *Grazed Sagebrush Sites: Vegetation*

Vegetation measurements were significantly different for six of the 19 variables within the winter and spring grazed sagebrush sites (Table 2.2). Sites under spring grazing management had higher total ( $F_{1,14} = 9.78, p = 0.0074$ ), live ( $F_{1,14} = 8.15, p = 0.0127$ ), and dead shrub cover ( $F_{1,14} = 5.93, p = 0.0288$ ) than winter grazed sites. Sagebrush cover also was higher in the spring grazed sites (data were arcsine square root transformed;  $F_{1,14} = 5.17, p = 0.0391$ ). Mean plant basal gap was only measured during 2008, but showed a difference between seasons of grazing ( $F_{1,14} = 6.63, p = 0.0220$ ). Spring grazed plots had an average gap size of  $127.8 \pm 8.0$  cm compared to an average gap size of  $103.7 \pm 4.8$  cm for winter grazed plots.

Reproductive shoot height for grasses was greater under winter grazing management ( $F_{1,14} = 8.06, p = 0.0131$ ).

Of the measured vegetation parameters, eight of 17 variables showed significant differences between years within the sagebrush sites (Table 2.2). Among these differences, all but reproductive grass height showed higher values in 2007 than 2008. Year effects were apparent for all forb cover groups: 1) annual forbs ( $F_{1,15} = 25.64, p = 0.0001$ ), 2) perennial forbs ( $F_{1,15} = 21.59, p = 0.0003$ ), and 3) food forbs ( $F_{1,15} = 75.25, p < 0.0001$ ). Total vegetative cover and plant basal cover were greater in 2007 ( $F_{1,15} = 5.76, p = 0.0298$  and  $F_{1,15} = 19.46, p = 0.0005$ , respectively). Reproductive and vegetative grass height were different between years ( $F_{1,15} = 9.36, p = 0.0079$  and  $F_{1,15} = 36.55, p < 0.0001$ , respectively), with 2007 having taller vegetative grass heights, and 2008 having taller reproductive grass heights. Species richness was also different ( $F_{1,15} = 7.73, p = 0.0139$ ) between years, with 2007 having, on average, three more species present.

Total and live shrub height showed significant interactions between season of grazing and year ( $F_{1,14} = 14.02, p = 0.0022$  and  $F_{1,14} = 16.99$  and  $p = 0.0010$ , respectively); therefore, each year was analyzed separately. For 2007 and 2008, total shrub height (2007:  $F_{1,14} = 52.15, p < 0.0001$ ; 2008:  $F_{1,14} = 11.29, p = 0.0047$ ) and live shrub height (2007:  $F_{1,14} = 38.10$  and  $p < 0.0001$ ; 2008:  $F_{1,14} = 4.98$  and  $p = 0.0426$ ) were greater in the spring grazed site compared to the winter grazed site.

**Table 2.2** Vegetation parameters (mean  $\pm$  SE / plot) of sagebrush sites by season of grazing (spring/winter) and year (2007/2008). Shrub category = rabbitbrush and sagebrush combined. Brothers, Oregon.

<b>Variable</b>	<b>Spring</b>	<b>Winter</b>	<b>2007</b>	<b>2008</b>
<b><i>Cover (%)</i></b>				
Annual Forb	1.4 $\pm$ 0.4	1.4 $\pm$ 0.4	2.4 <sup>a</sup> $\pm$ 0.4	0.4 <sup>b</sup> $\pm$ 0.1
Perennial Forb	2.5 $\pm$ 0.3	2.3 $\pm$ 0.3	3.0 <sup>a</sup> $\pm$ 0.3	1.9 <sup>b</sup> $\pm$ 0.3
Food Forb	2.9 $\pm$ 0.5	2.4 $\pm$ 0.5	4.1 <sup>a</sup> $\pm$ 0.4	1.2 <sup>b</sup> $\pm$ 0.2
Annual Grass	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0
Perennial Grass	22.5 $\pm$ 1.2	26.0 $\pm$ 1.5	22.5 $\pm$ 1.6	23.0 $\pm$ 1.1
Rabbitbrush	5.7 $\pm$ 0.8	3.8 $\pm$ 0.5	4.7 $\pm$ 0.5	4.8 $\pm$ 0.8
Sagebrush	10.1 <sup>a</sup> $\pm$ 1.2	5.9 <sup>b</sup> $\pm$ 0.5	7.9 $\pm$ 1.1	8.2 $\pm$ 1.1
Live Shrub	13.7 <sup>a</sup> $\pm$ 1.0	8.6 <sup>b</sup> $\pm$ 0.8	11.4 $\pm$ 1.2	11.0 $\pm$ 1.1
Dead Shrub	5.9 <sup>a</sup> $\pm$ 0.8	3.1 <sup>b</sup> $\pm$ 0.3	4.2 $\pm$ 0.6	4.7 $\pm$ 0.8
Total Shrub	19.6 <sup>a</sup> $\pm$ 1.6	11.7 <sup>b</sup> $\pm$ 0.8	15.5 $\pm$ 1.6	15.7 $\pm$ 1.7
Total Basal	6.9 $\pm$ 0.5	7.7 $\pm$ 0.5	8.1 <sup>a</sup> $\pm$ 0.5	6.5 <sup>b</sup> $\pm$ 0.4
Total Vegetative	45.9 $\pm$ 2.3	41.4 $\pm$ 1.7	46.4 <sup>a</sup> $\pm$ 2.1	40.9 <sup>b</sup> $\pm$ 1.7
<b><i>Height (cm)</i></b>				
Reproductive Grass	22.8 <sup>a</sup> $\pm$ 1.2	27.7 <sup>b</sup> $\pm$ 1.3	23.0 <sup>a</sup> $\pm$ 1.5	27.4 <sup>b</sup> $\pm$ 1.0
Vegetative Grass	12.2 $\pm$ 0.4	13.2 $\pm$ 0.3	13.4 <sup>a</sup> $\pm$ 0.4	11.9 <sup>b</sup> $\pm$ 0.2
Live Shrub*	30.6 $\pm$ 1.1	23.5 $\pm$ 0.8	27.8 $\pm$ 1.5	26.3 $\pm$ 1.1
Total Shrub*	32.1 $\pm$ 0.9	24.5 $\pm$ 0.6	28.5 $\pm$ 1.4	28.1 $\pm$ 1.0
<b><i>Other</i></b>				
Basal Gap (cm)	127.8 <sup>a</sup> $\pm$ 8.0	103.7 <sup>b</sup> $\pm$ 4.8	N/A	115.8 $\pm$ 5.5
Percent Basal Gap	85.8 $\pm$ 0.8	85.0 $\pm$ 1.1	N/A	85.4 $\pm$ 0.7
Species Richness	16.5 $\pm$ 0.8	16.5 $\pm$ 1.0	17.8 <sup>a</sup> $\pm$ 0.9	15.3 <sup>b</sup> $\pm$ 0.7

<sup>a,b</sup>: significant (at 0.05  $\alpha$ -level) differences within rows for season of use and year

\*: Total and live shrub height were significantly taller in spring grazed sites when years were analyzed separately

### *Grazed Sagebrush Sites: Insects*

Caterpillar abundance was different between years ( $F_{1,15} = 9.37$ ,  $p = 0.0079$ ).

Average caterpillar abundance per plot was six individuals in 2007 and only two

individuals in 2008. There were no differences between caterpillar abundance by season of grazing when both years were combined, or when tested individually.

No year effects were tested for other insects because they were only counted during 2007. Grasshopper, scarab beetle, and darkling beetle abundance showed differences between seasons of grazing ( $F_{1,14} = 4.35, 4.97$  and  $4.89, p = 0.0555, 0.0426$  and  $0.0441$ , respectively; abundances were  $\ln+1$  transformed; Table 2.3). Spring grazed areas exhibited a greater abundance of grasshoppers and darkling beetles, while the winter grazed areas had greater, though relatively low, scarab beetle abundance. There were no differences in ant abundance between the spring and winter grazed sites.

**Table 2.3** Ant, grasshopper, darkling and scarab beetle abundance per plot (mean  $\pm$  SE) for 2007 and caterpillar abundance per plot for 2007 & 2008 in sagebrush sites. Brothers, Oregon.

Grazing	Ants	Caterpillars	Darkling Beetles	Grasshoppers	Scarab Beetles
<i>Winter</i>	1850.3 $\pm$ 490.0	3.5 $\pm$ 1.0	16.5 <sup>a</sup> $\pm$ 2.1	19.3 <sup>a</sup> $\pm$ 3.8	0.2 <sup>a</sup> $\pm$ 0.2
<i>Spring</i>	1577.2 $\pm$ 386.3	4.2 $\pm$ 1.3	10.0 <sup>b</sup> $\pm$ 2.6	10.2 <sup>b</sup> $\pm$ 3.6	3.5 <sup>b</sup> $\pm$ 1.5

<sup>a,b</sup> : significant (at 0.05  $\alpha$ -level) differences within columns

### *Rabbitbrush Sites: Vegetation*

Among the 19 measured vegetation characteristics, 10 were different between the two rabbitbrush sites (Table 2.4). Total and live shrub cover were higher in the meadow site ( $F_{1,6} = 6.56, p = 0.0429$  and  $F_{1,6} = 10.48, p = 0.0177$ , respectively). Sagebrush and rabbitbrush cover were also different ( $F_{1,6} = 100.18, p < 0.0001$  and  $F_{1,6} = 18.44, p = 0.0051$ , respectively), with the upland site exhibiting more sagebrush and less rabbitbrush cover. Total vegetation cover ( $F_{1,6} = 65.32, p = 0.0002$ ), plant basal cover ( $F_{1,6} = 32.99, p = 0.0012$ ) and shrub height ( $F_{1,6} = 26.71, p = 0.0021$ ) were all greater in the meadow site. The upland site had greater basal gap size ( $F_{1,6} = 19.95, p = 0.0042$ ) than the meadow site and larger percentage of gap area ( $F_{1,15} = 7.17, p = 0.0367$ ).

The only significant year affect for the rabbitbrush sites was annual forb cover ( $F_{1,7} = 10.93$ ,  $p = 0.0130$ ), with 2007 having more cover than 2008 (2007 =  $6.5\% \pm 1.9$  and 2008 =  $1.8\% \pm 0.6$ ).

Significant interactions between rabbitbrush site and year were apparent for dead shrub cover ( $F_{1,6} = 23.29$ ,  $p = 0.0029$ ), perennial grass cover ( $F_{1,6} = 15.84$ ,  $p = 0.0072$ ), vegetative grass height ( $F_{1,6} = 11.76$ ,  $p = 0.0139$ ), and reproductive grass height ( $F_{1,6} = 19.22$ ,  $p = 0.0046$ ). Dead shrub cover was similar between rabbitbrush sites in 2007 but showed a doubling in cover in the meadow plots in 2008. Live grass height was also similar between sites in 2007, but in 2008 about a 4 cm decrease in height in the upland site was measured. Reproductive grass height in the upland site was taller in 2007 and shorter in 2008 when compared to the meadow site. Within the meadow site, perennial grass cover was lower in 2007 compared to 2008. Conversely, the upland site had greater cover in 2007 compared to 2008.

**Table 2.4** Vegetation parameters (mean  $\pm$  SE / plot) of rabbitbrush sites (2007 & 2008). Shrub category = rabbitbrush and sagebrush combined. Brothers, Oregon.

Variable	Meadow	Upland
<b>Cover (%)</b>		
Annual Forb	$4.8 \pm 2.2$	$3.6 \pm 1.0$
Perennial Forb	$4.3 \pm 1.1$	$2.9 \pm 0.7$
Food Forb	$6.0 \pm 1.3$	$3.8 \pm 1.2$
Annual Grass	$2.8 \pm 1.9$	$0.0 \pm 0.0$
Perennial Grass	$44.0 \pm 7.7$	$15.4 \pm 1.9$
Rabbitbrush	$29.9^a \pm 2.8$	$11.2^b \pm 0.7$
Sagebrush	$0.4^a \pm 0.2$	$5.1^b \pm 0.5$
Live Shrub	$23.9^a \pm 1.9$	$15.1^b \pm 0.7$
Dead Shrub	$6.9 \pm 1.4$	$4.0 \pm 0.8$
Total Shrub	$30.7^a \pm 2.9$	$19.1^b \pm 1.2$
Total Basal	$11.1^a \pm 1.1$	$4.0^b \pm 0.7$
Total Vegetative	$86.6^a \pm 4.1$	$41.0^b \pm 2.3$
<b>Height (cm)</b>		
Reproductive Grass	$23.0 \pm 3.0$	$24.3 \pm 1.1$
Vegetative Grass	$15.5 \pm 0.9$	$12.5 \pm 0.7$
Live Shrub	$42.8^a \pm 2.2$	$29.4^b \pm 2.0$
Total Shrub	$44.3^a \pm 2.2$	$28.2^b \pm 1.4$
<b>Other</b>		
Basal Gap (cm)	$64.0^a \pm 13.3$	$141.3^b \pm 11.0$
Percent Basal Gap	$45.7^a \pm 15.8$	$88.0^b \pm 0.7$
Species Richness	$18.8 \pm 1.6$	$16.0 \pm 0.9$

<sup>a,b</sup>: significant (at 0.05  $\alpha$ -level) differences within rows

### *Rabbitbrush Sites: Insects*

Of the insects counted, only two showed differences between the rabbitbrush sites (Table 2.5). Caterpillar abundance was different between sites ( $F_{1,6} = 16.77$ ,  $p = 0.0063$ ), with meadow plots having, on average, almost four times more caterpillars than upland plots. Unlike the sagebrush sites, caterpillar abundance showed no differences between years in the rabbitbrush dominated areas. Grasshopper abundance was different between meadow and upland plots ( $F_{1,6} = 14.05$ ,  $p = 0.009$ ). Upland plots had, on average, almost three times more grasshoppers per plot than meadow plots.

**Table 2.5** Ant, darkling beetle, grasshopper, and scarab beetle abundance per plot (mean  $\pm$  SE) for 2007 and caterpillar abundance per plot for 2007 & 2008 in rabbitbrush sites. Brothers, Oregon.

Type	Ants	Caterpillars	Darkling Beetles	Grasshoppers	Scarab Beetles
<i>Meadow</i>	3311.7 $\pm$ 1499.5	20.1 <sup>a</sup> $\pm$ 2.7	22.3 $\pm$ 7.6	7.5 <sup>a</sup> $\pm$ 0.6	2.7 $\pm$ 2.1
<i>Upland</i>	1591.3 $\pm$ 216.9	5.0 <sup>b</sup> $\pm$ 0.8	23.3 $\pm$ 0.6	18.8 <sup>b</sup> $\pm$ 2.9	0 $\pm$ 0

<sup>a,b</sup> : significant (at 0.05  $\alpha$ -level) differences within columns

### *Correlations Between Insects and Vegetation*

Pearson's product moment correlations were used to test for relationships between insect abundance, by group (ants, caterpillars, darkling beetles, grasshoppers, and scarab beetles), and vegetation measurements across study sites.

To evaluate caterpillar abundance and vegetation parameters, three different combinations of sites were used to elucidate all possible variations in correlations: 1) all plots, 2) sagebrush plots only, and 3) rabbitbrush plots only. When all sites were combined, the highest coefficients between vegetation parameters and caterpillar abundance were with total vegetative cover (coefficient = 0.78,  $p < 0.0001$ ) and percent basal gap (coefficient = -0.79,  $p < 0.0001$ ) (Table 2.6). In the sagebrush sites, annual grass cover was the only vegetation parameter to exhibit a significant

correlation with caterpillar abundance (coefficient = 0.73,  $p < 0.0001$ ). Rabbitbrush dominated areas presented high correlation coefficients with gap measurements, basal cover, sagebrush cover, total shrub height and total vegetative cover (Table 2.6).

**Table 2.6** Significant (0.05  $\alpha$ -level) Pearson's product moment correlations [ $\geq (\pm 0.6)$ ] between total caterpillar abundance and vegetation variables. 2007 & 2008 combined. Brothers, Oregon.

Variables	All Sites		Sagebrush Sites		Rabbitbrush Sites	
	<i>p-value</i>	<i>Coefficient</i>	<i>p-value</i>	<i>Coefficient</i>	<i>p-value</i>	<i>Coefficient</i>
Annual Grass Cover	NS	-	<0.0001	0.73	NS	-
Mean Basal Gap	NS	-	NS	-	0.0131	0.69
Percent Basal Gap	<0.0001	-0.79	NS	-	0.0241	-0.77
Perennial Grass Cover	<0.0001	0.61	NS	-	NS	-
Plant Basal Cover	NS	-	NS	-	0.0031	0.69
Rabbitbrush Cover	<0.0001	0.64	NS	-	NS	-
Sagebrush Cover	NS	-	NS	-	0.0003	-0.79
Total Shrub Height	<0.0001	0.61	NS	-	0.0139	0.60
Total Vegetation Cover	<0.0001	0.78	NS	-	0.0003	0.79

NS : variables that were tested but not significant

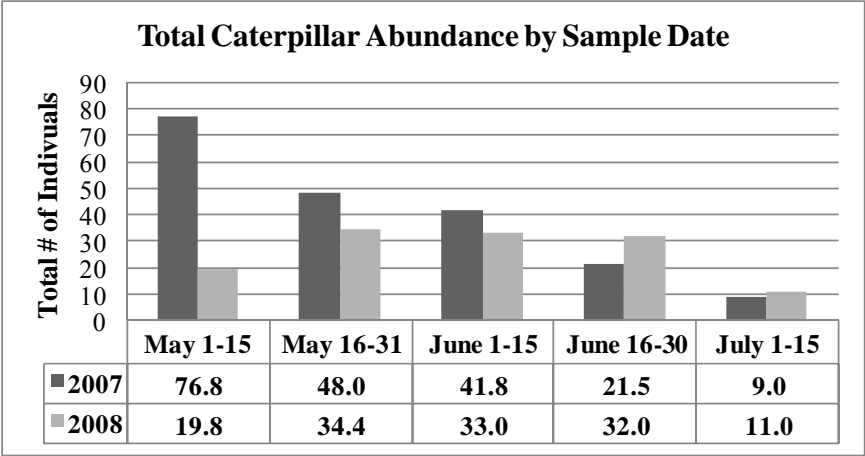
Darkling beetles showed a positive correlation with annual forb and annual grass cover (coefficient = 0.60,  $p = 0.0020$  and coefficient = 0.59,  $p = 0.0023$ , respectively). Grasshoppers, ants, and scarab beetles did not show significant correlations with any vegetation parameters.

### *Sample Date*

During the 2007 season, initially a high abundance of caterpillars was seen with a subsequent decline (Figure 2.1). However, in 2008, initial abundance was low followed by a slight increase and then a gradual decline. The first sample session, in May, appears to be the only one that was greatly different ( $> 15$  caterpillars) between years.

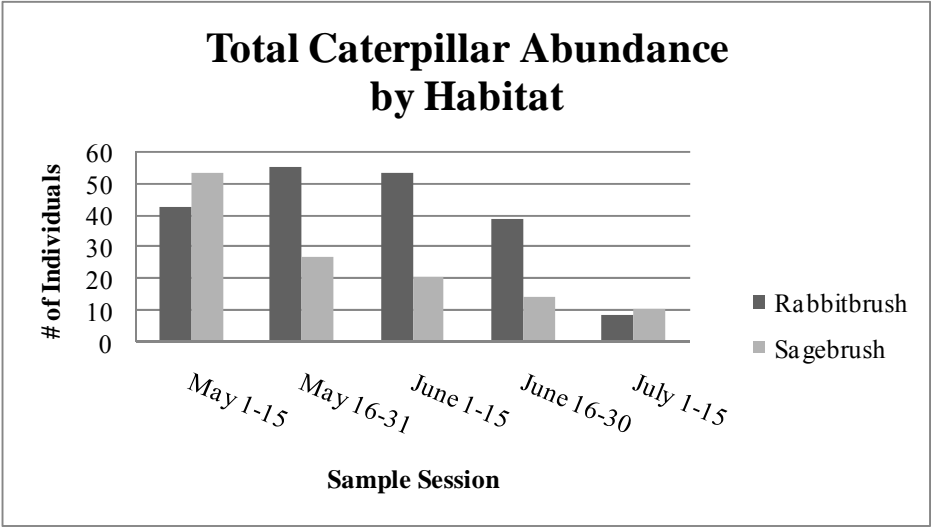


**Figure 2.1** Total caterpillar abundance, for all sites combined, by 2-week sample session for 2007 & 2008. Brothers, Oregon.



When abundance was separated by 2-week sample session between the sagebrush and rabbitbrush sites, it was apparent that the rabbitbrush sites provided a greater abundance of caterpillars longer in the season than the sagebrush sites (Figure 2.2).

**Figure 2.2** Total caterpillar abundance for sagebrush and rabbitbrush sites, 2007 & 2008 combined. Brothers, Oregon.



## Discussion

The elucidation of relationships between insect abundance, plant community characteristics, and management was moderated by annual differences in some insect and vegetation components across the landscape. This study found that certain vegetation characteristics differed between sagebrush sites subjected to spring or winter grazing and also between the two rabbitbrush dominated communities. Within the sagebrush sites, caterpillar abundance was different between years. Additionally, darkling beetle, grasshopper, and scarab beetle abundance differed between spring and winter grazed sagebrush sites. Within the rabbitbrush sites, caterpillars and grasshoppers differed in abundance between rabbitbrush communities. Caterpillar abundance was higher in the meadow site, whereas grasshopper abundance was higher in the upland site. These grasshopper findings are consistent with their biology. Grasshoppers lay their eggs in the soil; therefore, moister soils make eggs more susceptible to disease and fungi (J. Miller pers. comm., 2/09). Grasshoppers are also adapted to exposed situations in open habitats, such as steppes and deserts (Daly et al. 1998).

## *Vegetation Measurements*

Overall, vegetation measurements showed differences between the two sagebrush sites, between the two rabbitbrush sites, and also between 2007 and 2008. Findings in differences between the spring and winter grazed sagebrush sites were consistent with other grazing studies (Blaisdell et al. 1982, Bork et al. 1998, Mueggler 1950). Similar to results reported by Bork et al. (1998), sites under spring grazing management had higher shrub cover than sites under winter grazing management. Growth advantage is shifted to the grasses when there is winter use of shrubs (Scotter 1980). Not surprisingly, perennial grass cover was higher in the winter grazed sites. The higher grass cover is likely, in part, a function of the timing of the grazing;

dormant season grazing can increase or improve perennial grass cover (Bork et al. 1998, Mueggler 1950). However, there was an interaction between shrub height and year, which may have been due to sampling error or shrub recovery from a set-back caused by Aroga moth (*Aroga websteri*) infestations in 2006. When years were analyzed separately, shrubs were taller in the spring grazed sites. One of the biggest differences between seasons of grazing was gap size. Mean basal gap was almost 30 cm greater in the spring grazed sites compared to winter grazed sites. This difference may be due to the fact that a long history of spring grazing would give a competitive advantage to the shrubs because the grasses and forbs are being grazed during the growing season (Austin et al. 1983). Over time, this practice may reduce the basal area and/or density of the bunchgrasses, thus proper livestock stewardship is crucial for successful spring grazing plans.

The rabbitbrush locations had many differences with regards to vegetation measurements. Similar to the sagebrush dominated sites, the most notable difference between the rabbitbrush sites was the basal gap size. At the meadow site, mean gap size was, on average, almost 70 cm less than in the upland site. Although there was a large difference in gap size, this was not surprising due to the nature of the habitat types. The meadow site held water longer in the growing season, so more vegetation would be expected when compared to the drier, upland rabbitbrush site. In addition, there was about 10% more total shrub cover in the meadow site compared to the upland site. Rabbitbrush cover was also greater at the meadow site compared to the upland site; which was probably due to the differences in habitat types and species of rabbitbrush present. The upland site tended to have more of a mixed shrub stand (rabbitbrush and sagebrush), whereas the meadow site was predominately rubber rabbitbrush. Shrub height was also taller at the meadow sites, which was most likely a function of the species of rabbitbrush present. There was an average 45% difference in the total vegetation cover between the meadow (mean = 86%) and upland (mean = 41%) sites.

## *Insects and Vegetation*

Caterpillar abundance in the sagebrush sites showed a year effect, with 2007 having three times more caterpillars, on average, than 2008. This year effect was likely related to weather, foliage quality, and natural enemies influencing each species of caterpillar. Precipitation may have been an especially important factor with 2007 being at 75% of the long-term mean whereas 2008 was only at 56% of the nine month long-term mean.

The meadow site had, on average, almost four times as many caterpillars than the upland site. Also, the rabbitbrush sites had half as many plots as the sagebrush sites and still provided a higher total abundance of caterpillars. Unlike the sagebrush sites, no year effects were apparent, suggesting that the rabbitbrush sites provide enough plant and insect community diversity to buffer some weather effects. The meadow location provides a unique and diverse community in comparison to the upland rabbitbrush and sagebrush sites, so having a higher abundance of caterpillars seems probable. In comparison to the other sites, the higher amount of basal and vegetative cover along with smaller gap sizes in the meadow site may make for a more suitable caterpillar environment.

Other insects were only counted during 2007, but grasshoppers and darkling beetles showed greater numbers in the winter grazed sites compared to spring grazed sites. Overall, the winter grazed locations provided more insects, mainly ants, beetles, and grasshoppers, than spring grazed sites. The rabbitbrush sites provided more ants, caterpillars, and darkling beetles than the sagebrush sites, suggesting that these sites may be good habitat for sage-grouse brood-rearing. Also, grasshoppers were more than twice as abundant in the upland site compared to the meadow site. When comparing the meadow site to the upland rabbitbrush and both sagebrush sites, grasshoppers were less abundant in the meadow area, which subsequently had more vegetation cover. Darkling beetle abundance was similar between rabbitbrush sites but higher than in either sagebrush site, suggesting darkling beetles may have some

affinity for characteristics of the rabbitbrush dominated sites. Ants were most abundant in the meadow location, but also showed the highest variability there. Though not measured, proximity of the pitfall traps to ant mounds may be related to the variability in ant abundance at this site.

Correlations were used to determine what, if any, relationships existed between the measured vegetation characteristics and insect abundances. When sagebrush and rabbitbrush sites were combined, caterpillar abundance showed the strongest positive correlation with total vegetation cover and negative correlation with percent basal gap. Vegetation cover and gap size go relatively hand in hand, so it seems probable that caterpillar abundance would correlate with these factors because as vegetation cover increases there is a larger food source and area of habitat for caterpillars. With more cover and less basal gap, there is less area of the soil surface exposed to the sun, which would likely decrease or at least mediate the heating of the soil surface. Another hypothesis is that the further it is for a caterpillar to move between food plants, the greater the length of exposure to soil surface temperatures and greater the opportunity for it to be found by a predator. Furthermore, the sagebrush and upland rabbitbrush sites contain small ( $< 5$  mm) pumice pieces on the soil surface which the meadow site does not have. This soil property may provide an unsuitable environment or obstacle for caterpillars.

Similar to having all the sites combined, caterpillar abundance at the rabbitbrush sites had the highest correlations with percent basal gap (negative), sagebrush cover (negative), and total vegetation cover (positive). Sagebrush cover on the rabbitbrush sites varied between  $< 1\%$  at the meadow site to around  $5\%$  at the upland site. Caterpillar abundance was highest in the meadow site, which subsequently had the least amount of sagebrush cover. However, this small range in sagebrush cover may not be sufficient to adequately describe a relationship with caterpillars, because when all the sagebrush and rabbitbrush sites were combined there was no correlation with sagebrush cover.

The only correlation between the sagebrush sites and caterpillars was with annual grass cover. This positive correlation is somewhat peculiar because annual

grass (only *Bromus tectorum* L.) cover was < 1% at any of the sagebrush sites, which may mean that a small amount of *B. tectorum* may have a large effect on caterpillar abundance.

Other insect correlations were only tested with rabbitbrush and sagebrush sites combined because separating these out would have dramatically reduced the sample size. As the only insects to show a significant correlation with any measured vegetation characteristics, darkling beetles positively correlated with annual forb and annual grass cover. This relationship was probably driven by the meadow site because it had the most annual forb and annual grass cover as well as the highest abundance of darkling beetles.

### *Sage-grouse Habitat Guidelines*

As an update to Braun et al. (1977), Connelly et al. (2000) proposed guidelines to manage sage-grouse populations and their habitats based on the old guidelines and the latest research and literature. They suggested that productive sage-grouse brood-rearing habitat should encompass more than 40% of their seasonal habitat and have sagebrush heights between 40-80 cm and sagebrush canopy cover between 10-25% with grasses and forbs providing an additional 15% or more canopy cover (Connelly et al. 2000). The Bureau of Land Management (BLM) guidelines for sage-grouse and sagebrush-steppe ecosystems were intended to promote the conservation of sage-grouse and their habitats, specifically in Washington and Oregon (Barrett et al. 2000). BLM guidelines separate brood-rearing habitat into two categories, 1) optimum and 2) sub-optimum. Optimum brood rearing habitat is similar to Connelly's guidelines with sagebrush between 40 cm and 80 cm tall and canopy cover of 10 to 25%. Also, optimum habitat has an herbaceous understory with 15% grass canopy cover and 10% forb canopy cover. Sub-optimum habitat has sagebrush canopy cover around 14% with the understory (grasses and forbs combined) canopy cover of at least 15%.

None of the sites in this study satisfied all of the guidelines. However, all sites met Connelly's suggested grass-forb canopy cover of greater than 15%. The grass cover requirement was met for the BLM's optimum habitat by 92% of the plots; however, only one plot met the optimum habitat forb cover requirement. All sites met the herbaceous cover component for the BLM's sub-optimum brood-rearing habitat. Neither the winter or spring grazed sites met the sagebrush height guidelines; however the spring grazed site, with an average sagebrush cover of 10.1%, met both sets of guidelines for sagebrush cover.

Reference conditions described in the Pumice 8-10 PZ ecological site description (NRCS 2007) would meet the guidelines for herbaceous cover, but would not meet guidelines for sagebrush cover at a landscape level. The winter grazed sagebrush sites appear to resemble the reference conditions described in the Pumice 8-10 PZ ecological site description (NRCS 2007), with grasses dominating and sagebrush co-dominating; therefore, meeting sagebrush cover  $> 10\%$  would not be expected. The spring grazed sites suggest a departure from the reference conditions of the Pumice 8-10 PZ ecological site (NRCS 2007), due to an increase in sagebrush at the expense of the herbaceous components of the community. This departure from the reference state allows these spring grazed sites to meet the low end of the sagebrush cover guideline. These sagebrush sites occur on very pumiceous soils allowing for higher effective moisture for plants. This soil feature is probably why these sites are not dominated by *A. tridentata* ssp. *wyomingensis* Beetle & Young (Wyoming big sagebrush), which would be more typical of this elevation and precipitation zone. However, the *A. tridentata* ssp. *vaseyana* that is established in this location is of very short stature and likely not ecologically capable of meeting the 40-80 cm height requirements of the guidelines.

Not surprisingly, neither rabbitbrush dominated site met the sagebrush cover requirements. The upland rabbitbrush site reflects an area that has experienced historical management practices, like farming and grazing, which have caused a conversion from sagebrush grassland to a rabbitbrush dominated community with grasses being only a minor component. Thus this site has departed from the reference

conditions of the Pumice 8-10 PZ ecological site (NRCS 2007), and will likely never meet the sagebrush cover requirements suggested in the guidelines. The Mountain Swale 12-16 PZ ecological site description (NRCS 2007) reference state would not meet the guideline suggestions for sagebrush or forb cover. This site would be closer to 30 mm of precipitation and production would be towards the low end of the specifications in the ecological site description (~1680 kg/ha). The meadow site currently does not resemble the reference condition as specified in the Mountain Swale 12-16 PZ ecological site description (NRCS 2007). However, the amount of rabbitbrush present indicates that the historical management (farming and/or grazing) has altered community composition and is likely in an alternate state, which would require active restoration to revert back to the reference state. However, even in pristine condition, these mesic meadows are intended to be *L. cinereus* dominated, not sagebrush dominated.

Interestingly, when compared to all the other sites, the meadow site provided the highest abundance of caterpillars. Therefore, having components of a rabbitbrush community within sage-grouse brood-rearing habitat may be beneficial to sage-grouse chicks. This meadow area also provided the most potential hiding cover for sage-grouse, making it a relatively safe area for foraging while providing insects and forbs for sage-grouse chick consumption. Also, though not part of this study, most of the sage-grouse sightings at the study sites occurred at the meadow location.

Nevertheless, these are just guidelines and are up to the discretion of the appropriate land manager. Some sagebrush dominated communities may not be ecologically able to meet the guideline suggestions and still be considered in adequate condition to provide quality habitat for sage-grouse.

## **Conclusions and Management Implications**

These results are consistent with other studies (Connelly et al. 2000, Connelly et al. 2004, Schroeder et al. 1999) in that the meadow location provided the greatest



abundance of insects, especially Lepidoptera larva, and the most forb cover. Although this is an *E. nauseosa* dominated meadow, it is surrounded by *A. tridentata* ssp. *vaseyana* communities and *Juniperus occidentalis* Hook. (western juniper) woodlands. This landscape heterogeneity may be required to provide the complex and diverse habitats needed by sage-grouse and sagebrush obligate species. My research suggests that having this community type represented within the landscape may provide high-quality brood-rearing habitat for sage-grouse. However, these results are not promoting the deterioration of mesic upland meadows that are in good condition (*L. cinereus* dominated), but if the area is already dominated by *E. nauseosa* it may be adequate to maintain this type of plant community for sage-grouse brood-rearing. The upland, *C. viscidiflorus* dominated site also had greater forb cover than any of the sagebrush dominated sites. These results suggest that having patches with rabbitbrush dominance may provide good quality foraging habitat for sage-grouse broods within a sagebrush dominated landscape.

Inter-annual variation in caterpillar abundance makes measuring habitat suitability challenging. However, the vegetation components and caterpillar abundance were consistent between years within the rabbitbrush sites, with the exception of annual forb cover. There was variability between years in the sagebrush sites for caterpillar abundance, forb cover, total vegetative cover, grass height, and species richness. Thus, inter-annual variation in vegetation characteristics may influence variation in insect abundance.

When addressing habitat management, it is important to understand the proposed guidelines, but also to be able to adapt them to the area of interest. The current brood-rearing habitat guidelines make no recommendations for insects. As a vital component of sage-grouse chick survival, I propose that inclusions of plant community types (e.g., *E. nauseosa* dominated or mesic, wet sites) that support a diversity and high abundance of forbs and insects should be added to monitoring plans or assessments of current or potential sage-grouse brood-rearing habitat.

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### Chapter 3: Moth Abundance and Diversity in a Mixed Sagebrush-Steppe Community in Central Oregon, USA

#### Abstract

A causative factor in declining greater sage-grouse (*Centrocercus urophasianus*) populations is reduced annual recruitment due to poor habitat quality. Recently, the abundance of Lepidoptera larvae (caterpillars of moths and butterflies) has been positively correlated with sage-grouse brood and chick survival. In turn, the abundance of Lepidoptera is related to climate, nutrient cycling, plant populations, and predator-prey population relationships. This two-year study (2007-2008) focused on understanding the ecology of Lepidoptera in central Oregon sagebrush-steppe communities by elucidating relationships between Lepidoptera and the existing vegetation community characteristics. Identification of species based on caterpillars is difficult; therefore, conducting an inventory of the adults to document Lepidoptera species within the study area was necessary. After categorizing species of macromoths according to their caterpillar foodplant group, the relative importance of plant communities on biodiversity of the moths was assessed. Four sites were chosen in central Oregon for this research. The first two were *Artemisia tridentata* ssp. *vaseyana* (mountain big sagebrush) dominated communities under two different seasons of cattle grazing management, spring and winter. The remaining two sites were split between a *Chrysothamnus viscidiflorus* (yellow rabbitbrush) dominated upland and an *Ericameria nauseosa* (rubber rabbitbrush) dominated meadow. Overall, 222 moth species were collected at the study locations with the rabbitbrush sites having 194 species and *A. tridentata* ssp. *vaseyana* sites having 173 species. The single most abundant Lepidoptera species was *Trichocerapoda oblita*, which was also the most abundant species at each site except the meadow *E. nauseosa* site. Caterpillar foodplant relationships are unknown for three of the top five most abundant Lepidoptera species at this study location. Among the caterpillar foodplant groups, 53 forb feeding species, 20 grass feeding, 31 shrub feeding, 27 tree feeding,

and 91 species with unknown foodplants. Overall moth abundance and species richness was highest during July, August, and September, with relatively few moths being caught in May or June. Moth abundance was highest in the spring grazed *A. tridentata* ssp. *vaseyana* site in both years when compared to the winter grazed site. Also, between the rabbitbrush sites, moth abundance was highest in the upland site, but only during 2008. Moth abundance correlated with several vegetative components within the rabbitbrush sites: 1) negatively with perennial grass cover, total plant basal cover, rabbitbrush cover, shrub and grass height, and total vegetative cover, and 2) positively with basal gap percent and size, as well as sagebrush cover. Multivariate analysis showed that moth species community assemblages grouped by habitat type (spring and winter grazed sagebrush vs. meadow and upland rabbitbrush) and site proximity. Overall, the upland rabbitbrush site exhibited the highest abundance of moths, whereas the meadow site presented the most diverse and unique number of moth species. These data suggest that rabbitbrush communities are an intricate component with the sagebrush-steppe landscape and contribute to the quality of sage-grouse brood-rearing habitat.

## Introduction

Greater sage-grouse (*Centrocercus urophasianus*) have experienced range-wide population declines over the past half century. One of the causative factors in reduced annual recruitment of sage-grouse is poor habitat quality (Crawford and Lutz, 1985). Recently, the abundance of Lepidoptera larvae (caterpillars of moths and butterflies) has been positively linked with sage-grouse brood and chick survival. Years of higher caterpillar availability were associated with observations of higher sage-grouse brood and chick survival (Gregg and Crawford, *in press*).

Species of Lepidoptera function in the dynamics of ecosystems by serving as defoliators, decomposers, prey or hosts to carnivores, and pollinators (Hammond and Miller 1998). The biodiversity of Lepidoptera is thus linked to the dynamics of

ecosystems by influencing nutrient cycling, plant populations, and predator-prey population relationships (Hammond and Miller 1998). More than 11,500 species occur in the United States and Canada (Triplehorn and Johnson 2005); with Oregon alone exhibiting more than 1,600 species (Miller 1995).

Lepidoptera can be split into two categories based on feeding strategies: generalists (polyphagous) and specialists (monophagous). Generalist caterpillars can feed upon any plant among a wide range of plant species and still develop into an adult in the normal period of time (Miller 1995). Specialists are defined as those species that have a restricted range of suitable foodplants and only feed on one species, a few species, or all species within one genus of plants (Miller 1995). Flora considered foodplants for Lepidoptera larva can be categorized into functional groups, such as: 1) conifers, 2) hardwood trees and shrubs, and 3) herbs and grasses (Hammond and Miller 1998). By categorizing species of macromoths according to their caterpillar foodplant (plant(s) which the caterpillars feed upon) group, we can assess the relative importance of plant communities on biodiversity of moths (Miller et al. 2003). In addition, some plant communities with a unique set of species, like meadows in a forest, can be a major factor contributing to the biodiversity within a broad landscape (Miller et al. 2003).

It is important to understand the ecology of Lepidoptera by focusing on their relationships with the existing vegetation because caterpillars have been shown to be beneficial for a number of wildlife species including sage-grouse chick survival (Gregg and Crawford *in press*). Identification of caterpillars is difficult; therefore, it is useful to document Lepidoptera species within an area by conducting an inventory of the adults. The greatest diversity of arthropods is typically found in areas with the greatest diversity of vegetative structure and composition (Gardner et al. 1995). However, little work has been conducted evaluating arthropod populations in sagebrush-steppe communities. Therefore evaluating the relationships between plant community characteristics and Lepidoptera species will provide insight to the role and function of this insect order in the sagebrush-steppe.



The focus of this study was to determine the species and abundance of moths that occur within sagebrush and rabbitbrush dominated sites. Moreover, determining whether moth species assemblages differed between sites representing a variety of conditions inherent in the resident plant communities was of interest. To accomplish these objectives, moth abundance by species and plant community composition and structure were evaluated across four different plant communities. Communities studied were *Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle (mountain big sagebrush) dominated sites under winter and spring grazing management, as well as rabbitbrush (*Chrysothamnus* sp. or *Ericameria* sp.) dominated meadow and upland communities. Furthermore, relationships between measured vegetation characteristics and total moth abundance as well as moth abundance by foodplant functional group (tree, 2) shrub, grass, forb, and unknown), were investigated.

## Site Description

The study area was located in Deschutes and Crook County, in central Oregon, within 16 km of the town of Brothers. Average elevation is 1381 m, ranging from 1352-1421 m. Study sites were located within the John Day and Mazama Ecological provinces (Anderson et al. 1998). The John Day Province is typified by exposed ancient sediments from various geologic events and a stony soil mantle over thick beds of fine sedimentary or tuffaceous materials. The Mazama Province is an area covered by aeolian deposits of pumice and volcanic materials from the Mt. Mazama eruption over 6500 years ago.

Soils in the study area include Luckycreek, Dester, and Stookmoor series (Soil Survey Staff 2009). Soils range from Vitritorrandic Haploxerolls to Vitrandic Argixerolls. Ecological sites include the Pumice 8-10 PZ and Mountain Swale 12-16 PZ (Natural Resources Conservation Service 2007). The potential native plant communities, as described by the Natural Resources Conservation Service (2007), are dominated by *A. tridentata* ssp. *vaseyana* and *Festuca idahoensis* Elmer (Idaho

fescue) or *Leymus cinereus* (Scribn. & Merr.) A. Löve (basin wildrye) and *F. idahoensis*. Current dominant plant associations are: 1) *A. tridentata* ssp. *vaseyana* and *F. idahoensis*, 2) *Chrysothamnus viscidiflorus* (Hook.) Nutt. (yellow rabbitbrush) and *Achnatherum* P. Beauv. (needlegrass), or 3) *Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird (rubber rabbitbrush), *Poa* L. (bluegrass), and *Carex* L. (upland sedges) (Table 3.1). A full species list can be found in Appendix B.

**Table 3.1** Dominant vegetation, soils, and ecological sites of the six research areas. Brothers, Oregon, 2007-2008.

Dominant Shrub Type	Soil Series	Ecological Site
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Dester	Pumice 8-10 PZ
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Dester	Pumice 8-10 PZ
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Stookmoor	Pumice 8-10 PZ
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	Stookmoor	Pumice 8-10 PZ
<i>Ericameria nauseosa</i>	Luckycreek	Mountain Swale 12-16 PZ
<i>Chrysothamnus viscidiflorus</i>	Stookmoor	Pumice 8-10 PZ

Long term (1959-2008) temperature and precipitation data were obtained from the Brothers weather station (43°49'N, 120°36'W, elevation 1414 m; National Climate Data Center 2009). The mean annual temperature is 6.4°C. Maximum and minimum temperatures range from 37.2°C in the summer to -34.4°C in the winter. Mean yearly precipitation is 226 mm, with monthly means ranging between 11 mm and 29 mm. Much of the precipitation comes as snow from November to March. During 2007, the first year of this study, precipitation was 137 mm or 60% of the long-term mean. For the first nine months of 2008, precipitation was 76 mm or 56% of the nine month long-term mean. Thus, both years were characterized by less than average precipitation.

The study area is currently under public (Prineville District, Bureau of Land Management) and private ownership. This area has historically been subjected to a range of disturbances including dry-land farming, sagebrush removal, homesteading, and sheep and cattle grazing. Currently the study area is grazed by cattle on a seasonal basis and also experiences mild levels of public recreational use. The majority of

research sites have been grazed under either a winter (December to March) or spring (April to June) season management plan for over 20 years (J. Swanson, Range Specialist, BLM, pers. comm., 2/09). Grazing treatments were managed under lease agreements and not by a priori criteria used to define treatments for the sites used in this study.

## **Methods**

### *Experimental Design*

A completely randomized design was used to test moth abundance, vegetation, and year differences between the two seasons of cattle grazing on the four locations dominated by *A. tridentata* ssp. *vaseyana*. Additionally, the same measurements were assessed on rabbitbrush (*Ericameria* sp. or *Chrysothamnus* sp.) dominated sites in a dry meadow and an upland location. Sixteen randomly located plots were established in the spring of 2007, half on winter grazed sites and half on spring grazed sites. Eight additional plots were randomly located in the rabbitbrush dominated sites; four each in the meadow and upland plant communities. The location of each plot was established by obtaining randomly generated plot coordinates and a Garmin GPS unit. Plots were established if the correct ecological site, soil, and dominant plant were present at the location; otherwise, the next suitable random coordinate was used. Plots were 30 m x 30 m and at least 100 m from the next nearest plot. Five, 30 m vegetation transects were established in each plot. Transects were systematically located 5 m apart and parallel to one another. Each year a random direction (north/south or east/west) was chosen for transects. Vegetation data among transects were pooled by plot for statistical analyses.

## *Vegetation Assessment*

Plant community composition, by cover, and structure were quantified at similar phenological stages of plants each year following the removal of the cattle. Plant foliar and basal cover and community composition were measured using line-point intercept (Herrick et al. 2005) along five, 30 m transects at each plot for two years. Sampling intervals were determined in 2007 by sampling a 10 m section of a transect every 10 cm and then determining what interval (20 cm, 30 cm, or 40 cm) gave the same ( $\pm < 1\%$ ) cover value for shrubs, forbs, and grasses. Sampling intervals were repeated during 2008. Measuring cover by points is considered the least biased and most objective out of the three (plots, line intercept, and point intercept) cover measures (Bonham 1989). However, a disadvantage of line-point intercept is that species with very low cover values are often not sampled efficiently (Elzinga et al. 1998). Therefore, to account for rare species, a species survey was conducted within each plot after the line-point intercept was completed. Species richness was compiled from the line-point intercept and the species survey.

A vegetation variable called “food forbs” was created. This variable was a sum, of percent cover, of all the known annual and perennial forbs that sage-grouse consume. For this study area the “food forb” variable included: *Achillea millefolium* L., *Agoseris glauca* (Pursh) Raf., *Antennaria dimorpha* (Nutt.) Torr. & A. Gray, *Antennaria rosea* Greene, *Astragalus letiginosus* Douglas ex Hook., *Astragalus peckii* Piper, *Astragalus purshii* Douglas ex Hook., *Castilleja pilosa* (S. Watson) Rydb., *Eriophyllum lanatum* (Pursh) Forbes, *Erigeron linearis* (Hook.) Piper, *Phlox hoodii* Richardson, *Ranunculus glaberrimus* Hook., *Taraxacum officinale* F.H. Wigg., *Trifolium* L., *Gayophytum* A. Juss., and *Microsteris gracilis* (Hook.) Greene.

Plant height and basal gap intercept (Herrick et al. 2005) were used to measure plant community structure. Average vegetative height of shrubs and height of standing dead shrubs were measured, by species, along all transects in both years. The average vegetative and reproductive heights of perennial grasses were also measured.

Basal gap intercept of 20 cm or more was measured between perennial plant species during 2008 because it was hypothesized that the distance between perennial plants may influence the abundance of Lepidoptera.

### *Moth Abundance and Diversity*

Moth abundance and diversity were measured using a standard model of ultraviolet black light trap (see Miller et al. 2003). The traps were BioQuip model #2851, with a 22-watt circle light bulb powered by a 12-volt battery. Vapona® strips were placed inside the buckets to kill the moths. Trapping occurred one night per month, between the 7<sup>th</sup> and 12<sup>th</sup>. The exact date was in part determined by moon phase and avoidance of three days prior or post full moon, because moth abundance decreases with fullness of the moon (Yela and Holyoak 1997). Trapping occurred from May through September and all traps were operated on the same night. The traps were collected the following day and all specimens were frozen. Identification and assessment of abundance was completed at the species level for all macromoths and a select group of micromoths.

A temporary enclosure was constructed around each trap during the trapping night to exclude large animals. These enclosures were 3 m x 3 m, with the black light trap centered, and consisted of four t-posts and three strands of half inch electric fencing. The t-posts were permanent during the two years of this study, but the electric fencing was only in place on the trapping nights.

### *Data Analysis*

Moth species richness and abundance were assessed by both presence/absence and relative abundance. Two-way analysis of variance (ANOVA) was used to test for differences in moth abundance and vegetation characteristics between: 1) the winter and spring grazed sagebrush sites by year and 2) the meadow and upland rabbitbrush

sites by year. Correlations between moth abundance and vegetation characteristics were tested using Pearson's product moment correlation. Additionally, correlations were tested between vegetation measurements and foodplant groups: 1) trees, 2) shrubs, 3) grasses, 4) forbs, and 5) unknown. Species that had a known foodplant in more than one group were listed within each group. The unknown group was tested to see if any patterns with vegetation measurements were apparent within the group. For example, if the unknown group had a correlation with grasses, then possibly a sizeable proportion of the unknown species may have a foodplant relationship with grass.

Significant correlations had a  $p$ -value  $< 0.05$  and a coefficient  $\geq (\pm) 0.6$ . All data were tested with and without transformations to determine if transformations were necessary. If necessary, the square root transformation was used for moth abundance and the arcsine square root transformation was used for percent vegetation cover data (Sokal and Rohlf 1995). S-plus 7.0 (S-Plus 2005) was used for correlations, ANOVA, and summary statistics.

To test for differences in the composition of moth species assemblages across the sagebrush and rabbitbrush sites, several multivariate statistical methods were used. Hierarchical cluster analysis, using a Euclidean distance measure and Ward's linkage method, was used to define similar groups of plots with regards to moth species and their abundance. Differences in species composition between groups (from hierarchical cluster analysis) were assessed using rank transformed Multi-response Permutation Procedures (MRPP). Rank transformed MRPP is a nonparametric procedure for testing the hypothesis of no difference in average within-group ranked distances (McCune and Grace 2002). Rank transformed MRPP, using a Euclidean distance measure, was used instead of MRPP because it makes the results more analogous to those from nonmetric multidimensional scaling (NMS) (McCune and Grace 2002). NMS was used to examine how moth species assemblages segregate across the rabbitbrush and sagebrush dominated sites. NMS ordination was run after data transformations, using the slow-and-thorough autopilot setting with the Sorensen distance to calculate the distance matrices. The log transformation and relativization by species maximum were used on the data to reduce coefficients of variation for

species and beta diversity. All multivariate statistical analyses were run using PC-Ord, version 4.35 (McCune and Mefford 1999).

## Results

### *Moths*

Over this two year study, 222 species of moths with a total abundance of 42101 individuals were documented within the study area. A total of 194 species were documented within the two rabbitbrush sites, with 174 species occurring in the meadow site and 128 species occurring in the upland site. The sagebrush sites had a total of 173 species, with 150 species in the spring grazed site and 144 species in the winter grazed site. When comparing the number of unique species (species that only occur in that site) and percent dissimilarity between the rabbitbrush sites and sagebrush sites, it is apparent that the rabbitbrush sites are more uniquely diverse (Table 3.2). Within the rabbitbrush sites, the meadow type had almost three times as many unique species and was 24% more dissimilar when compared to the upland site. Within the sagebrush sites, the number of unique species was similar between sites, as was the percent dissimilarity.

**Table 3.2** Number of Lepidoptera species documented and unique to each site, total moth abundance, and the percent dissimilarity between comparisons. Brothers, Oregon, 2007-2008.

	<b>Sagebrush vs. Rabbitbrush</b>		<b>Rabbitbrush Meadow vs. Upland</b>		<b>Sagebrush Winter vs. Spring</b>	
# of species	173	194	174	128	144	150
Total abundance	27530	14572	4861	9711	11013	16517
# unique species	28	49	66	20	23	29
% dissimilarity	12.61%	22.07%	34.02%	10.31%	13.29%	16.76%

Overall, the five most abundant species were: 1) *Trichocerapoda oblita*, (n = 13089); 2) *Euxoa misturata*, (n = 6244); 3) *Digrammia nubiculata*, (n = 3838); 4) *Plataea trilinearia*, (n = 1178); and 5) *Euxoa satiens*, (n = 1088). Of these five

species, only two have known caterpillar foodplant relationships. The two species with known foodplants are associated with shrubs; *D. nubiculata* feeds on *E. nauseosa* and *P. trilinearia* feeds on species of *Artemisia*. A full moth species list with their respective foodplant group can be found in Appendix C. Although sagebrush sites had twice as many plots as the rabbitbrush sites, *T. oblita* was still most abundant in the sagebrush sites ( $n = 10376$ ) with the spring grazed plots having nearly double the number compared to winter grazed plots. In the meadow site, only 22 *T. oblita* individuals were caught compared to 2691 individuals in the upland site. Also, *E. misturata* was more abundant in the sagebrush sites ( $n = 3651$ ), with spring grazed plots having almost 600 more individuals than winter grazed plots. The two most abundant species were least abundant in the meadow site. The most abundant moth species occurring at each site was as follows: 1) spring grazed sagebrush = *T. oblita* ( $n = 6605$ ), 2) winter grazed sagebrush = *T. oblita* ( $n = 3771$ ), 3) upland rabbitbrush = *T. oblita* ( $n = 2691$ ), and 4) meadow = *Digrammia curvata* ( $n = 488$ ). Thus, the most abundant species overall, *T. oblita*, was the most abundant species at all sites except the meadow.

Moth species richness in each foodplant group was 53 forb feeders, 20 grass feeders, 31 shrub feeders, 27 tree feeders, and 91 unknown (Table 3.3). The total number of moth species in each foodplant group is similar between the sagebrush and rabbitbrush sites. However, the rabbitbrush sites had more moth species with unknown foodplant relationships than the sagebrush sites. When comparing the spring and winter grazed sagebrush sites with the two rabbitbrush sites, the meadow site had the most unknown, forb feeding, and tree feeding foodplant species. The upland rabbitbrush site had the least unknown and forb feeding foodplant species.



**Table 3.3** Number of moth species documented in each foodplant group by site. Brothers, Oregon, 2007-2008.

Foodplant	Sagebrush			Rabbitbrush			Overall
	Total	Winter	Spring	Total	Meadow	Upland	
Forb	42	36	35	47	43	30	53
Grass	19	16	16	18	16	14	20
Shrub	24	21	23	27	22	22	31
Tree	17	11	14	21	19	10	27
Unknown	70	59	62	81	75	51	91

Moth abundance was different between the spring and winter grazed sites ( $F_{1,14} = 4.67$ ,  $p = 0.0485$ ; data were square root transformed) and also between years ( $F_{1,15} = 29.83$ ,  $p < 0.0001$ ). Spring grazed sites exhibited greater moth abundance than winter grazed sites and more moths occurred in 2008 (Table 3.4).

**Table 3.4** Differences in moth abundance per plot (mean  $\pm$  SE) by season of grazing (spring/winter) and year (2007/2008). Brothers, Oregon.

Spring	Winter	2007	2008
1031.3 <sup>a</sup> $\pm$ 150.3	687.6 <sup>b</sup> $\pm$ 63.6	622.9 <sup>a</sup> $\pm$ 57.1	1096.0 <sup>b</sup> $\pm$ 140.8

<sup>a,b</sup>: significant (at 0.05  $\alpha$ -level) differences within season of use and year

Within the rabbitbrush sites, moth abundance showed an interaction between sites and year ( $F_{1,6} = 14.08$ ,  $p = 0.0095$ ). When years were analyzed separately, 2007 showed no difference in moth abundance between the two rabbitbrush sites. However, in 2008 moth abundance was higher ( $F_{1,6} = 54.92$ ,  $p = 0.0003$ ) in the upland rabbitbrush site compared to the meadow site (Table 3.5).

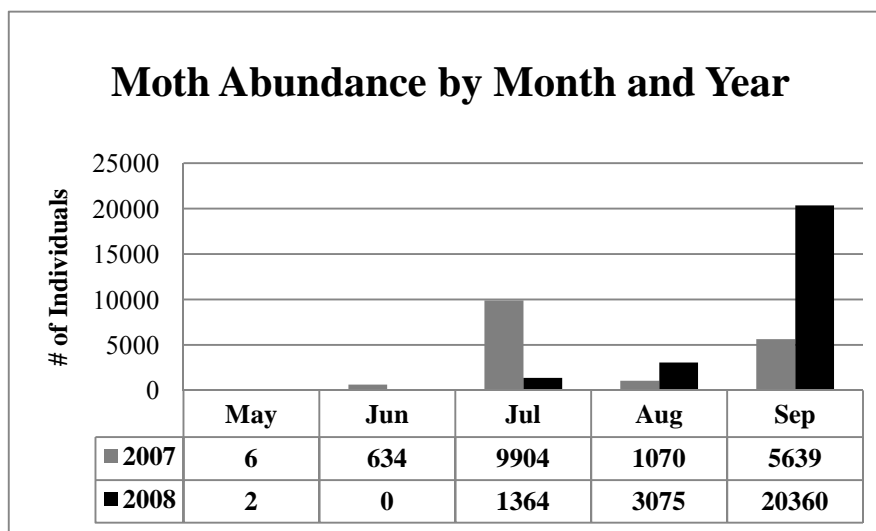
**Table 3.5** Moth abundance per plot (mean  $\pm$  SE) by rabbitbrush site (meadow/upland) for each year (2007/2008). Brothers, Oregon.

2007		2008	
Meadow	Upland	Meadow	Upland
823.2 $\pm$ 57.2	998.2 $\pm$ 117.0	387.5 <sup>a</sup> $\pm$ 34.6	1428.7 <sup>b</sup> $\pm$ 136.2

<sup>a,b</sup>: significant (at 0.05  $\alpha$ -level) differences within years

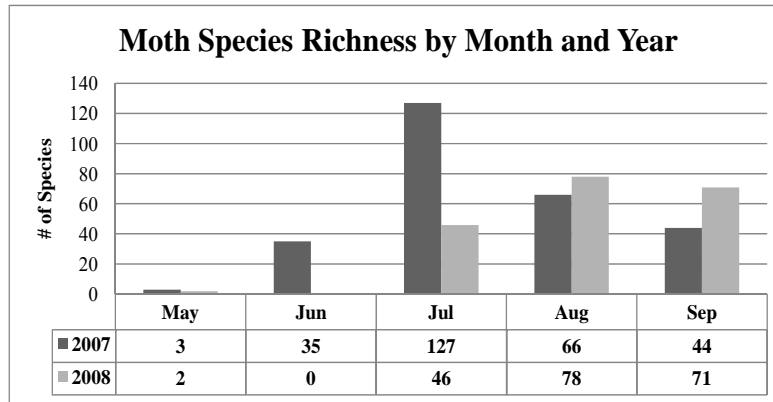
There was considerable variability in moth abundance from May through September in both years, as seen in Figure 3.1. May and June of both years did not provide a high abundance of moths; however more moths were documented in 2007. During 2007, the highest moth abundances occurred in July and September. During 2008, September moth abundances ranged between 4-15 times higher than July-August in 2007 or 2008.

**Figure 3.1** Total moth abundance by month for all sites combined, for 2007 & 2008. Brothers, Oregon.



Moth species richness varied by month of capture and between years. Few moth species were caught during May and June. July through September showed varied species richness with July of 2007 having the most species represented.

**Figure 3.2** Total moth species richness by month, for all sites combined, for 2007 & 2008. Brothers, Oregon.



## *Vegetation*

### Sagebrush Sites

Six of the 19 vegetation measurements were different between the spring and winter grazed sagebrush sites (Table 3.6). Sites under spring grazing management had higher total ( $F_{1,14} = 9.78, p = 0.0074$ ), live ( $F_{1,14} = 8.15, p = 0.0127$ ), and dead shrub cover ( $F_{1,14} = 5.93, p = 0.0288$ ) than winter grazed sites. Sagebrush cover was higher (data were arcsine square root transformed;  $F_{1,14} = 5.17, p = 0.0391$ ) in the spring grazed sites. Mean plant basal gap was only measured in 2008, but differed between seasons of grazing ( $F_{1,14} = 6.63, p = 0.0220$ ). Spring grazed plots had an average gap size of  $127.8 \pm 8.0$  cm compared to an average gap size of  $103.7 \pm 4.8$  cm for winter grazed plots. Reproductive grass height was different ( $F_{1,14} = 8.06, p = 0.0131$ ) with grasses growing taller under winter grazing management.

**Table 3.6** Vegetation parameters (mean  $\pm$  SE / plot) of sagebrush sites by season of grazing (spring/winter) and year (2007/2008). Shrub category = rabbitbrush and sagebrush combined. Brothers, Oregon.

<b>Variable</b>	<b>Spring</b>	<b>Winter</b>	<b>2007</b>	<b>2008</b>
<b><i>Cover (%)</i></b>				
Annual Forb	1.4 $\pm$ 0.4	1.4 $\pm$ 0.4	2.4 <sup>a</sup> $\pm$ 0.4	0.4 <sup>b</sup> $\pm$ 0.1
Perennial Forb	2.5 $\pm$ 0.3	2.3 $\pm$ 0.3	3.0 <sup>a</sup> $\pm$ 0.3	1.9 <sup>b</sup> $\pm$ 0.3
Food Forb	2.9 $\pm$ 0.5	2.4 $\pm$ 0.5	4.1 <sup>a</sup> $\pm$ 0.4	1.2 <sup>b</sup> $\pm$ 0.2
Annual Grass	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0	0.1 $\pm$ 0.1	0.0 $\pm$ 0.0
Perennial Grass	22.5 $\pm$ 1.2	26.0 $\pm$ 1.5	22.5 $\pm$ 1.6	23.0 $\pm$ 1.1
Rabbitbrush	5.7 $\pm$ 0.8	3.8 $\pm$ 0.5	4.7 $\pm$ 0.5	4.8 $\pm$ 0.8
Sagebrush	10.1 <sup>a</sup> $\pm$ 1.2	5.9 <sup>b</sup> $\pm$ 0.5	7.9 $\pm$ 1.1	8.2 $\pm$ 1.1
Live Shrub	13.7 <sup>a</sup> $\pm$ 1.0	8.6 <sup>b</sup> $\pm$ 0.8	11.4 $\pm$ 1.2	11.0 $\pm$ 1.1
Dead Shrub	5.9 <sup>a</sup> $\pm$ 0.8	3.1 <sup>b</sup> $\pm$ 0.3	4.2 $\pm$ 0.6	4.7 $\pm$ 0.8
Total Shrub	19.6 <sup>a</sup> $\pm$ 1.6	11.7 <sup>b</sup> $\pm$ 0.8	15.5 $\pm$ 1.6	15.7 $\pm$ 1.7
Total Basal	6.9 $\pm$ 0.5	7.7 $\pm$ 0.5	8.1 <sup>a</sup> $\pm$ 0.5	6.5 <sup>b</sup> $\pm$ 0.4
Total Vegetative	45.9 $\pm$ 2.3	41.4 $\pm$ 1.7	46.4 <sup>a</sup> $\pm$ 2.1	40.9 <sup>b</sup> $\pm$ 1.7
<b><i>Height (cm)</i></b>				
Reproductive Grass	22.8 <sup>a</sup> $\pm$ 1.2	27.7 <sup>b</sup> $\pm$ 1.3	23.0 <sup>a</sup> $\pm$ 1.5	27.4 <sup>b</sup> $\pm$ 1.0
Vegetative Grass	12.2 $\pm$ 0.4	13.2 $\pm$ 0.3	13.4 <sup>a</sup> $\pm$ 0.4	11.9 <sup>b</sup> $\pm$ 0.2
Live Shrub*	30.6 $\pm$ 1.1	23.5 $\pm$ 0.8	27.8 $\pm$ 1.5	26.3 $\pm$ 1.1
Total Shrub*	32.1 $\pm$ 0.9	24.5 $\pm$ 0.6	28.5 $\pm$ 1.4	28.1 $\pm$ 1.0
<b><i>Other</i></b>				
Basal Gap (cm)	127.8 <sup>a</sup> $\pm$ 8.0	103.7 <sup>b</sup> $\pm$ 4.8	N/A	115.8 $\pm$ 5.5
Percent Basal Gap	85.8 $\pm$ 0.8	85.0 $\pm$ 1.1	N/A	85.4 $\pm$ 0.7
Species Richness	16.5 $\pm$ 0.8	16.5 $\pm$ 1.0	17.8 <sup>a</sup> $\pm$ 0.9	15.3 <sup>b</sup> $\pm$ 0.7

<sup>a,b</sup>: significant (at 0.05  $\alpha$ -level) differences within rows for season of use and year

\*: Total and live shrub height were significantly taller in spring grazed sites when years were analyzed separately

Among the measured vegetation parameters, 8 of 17 variables showed significant differences between years in the sagebrush sites (Table 3.6). Within these differences, all but reproductive grass height had higher values in 2007. Year effects were apparent for all forb cover groups: 1) annual forbs,  $F_{1,15} = 25.64$ ,  $p = 0.0001$ , 2) perennial forbs,  $F_{1,15} = 21.59$ ,  $p = 0.0003$ , and 3) food forbs,  $F_{1,15} = 75.25$ ,  $p < 0.0001$ . Total vegetative cover and plant basal cover were also different ( $F_{1,15} = 5.76$ ,  $p =$

0.0298 and  $F_{1,15} = 19.46$ ,  $p = 0.0005$ , respectively). Reproductive and vegetative grass height were different between years ( $F_{1,15} = 9.36$ ,  $p = 0.0079$  and  $F_{1,15} = 36.55$ ,  $p < 0.0001$ , respectively). With respect to years, vegetative grass heights were greater in 2007, whereas 2008 had greater reproductive grass heights. Species richness was also different ( $F_{1,15} = 7.73$ ,  $p = 0.0139$ ) between years, with 2007 having, on average, three more species present than 2008.

Total and live shrub height showed significant interactions between season of grazing and year ( $F_{1,14} = 14.02$ ,  $p = 0.0022$  and  $F_{1,14} = 16.99$  and  $p = 0.0010$ , respectively). Therefore, each year was analyzed separately. For 2007 and 2008, total shrub height (2007:  $F_{1,14} = 52.15$ ,  $p < 0.0001$ ; 2008:  $F_{1,14} = 11.29$ ,  $p = 0.0047$ ) and live shrub height (2007:  $F_{1,14} = 38.10$  and  $p < 0.0001$ ; 2008:  $F_{1,14} = 4.98$  and  $p = 0.0426$ ) were taller in the spring grazed plots.

## Rabbitbrush Sites

Among the 19 measured vegetation variables, 10 showed significant differences between the two rabbitbrush sites (Table 3.7). Total and live shrub cover were higher in the meadow site ( $F_{1,6} = 6.56$ ,  $p = 0.0429$  and  $F_{1,6} = 10.48$ ,  $p = 0.0177$ , respectively). Sagebrush and rabbitbrush cover were also different ( $F_{1,6} = 100.18$ ,  $p < 0.0001$  and  $F_{1,6} = 18.44$ ,  $p = 0.0051$ , respectively), with the upland site exhibiting more sagebrush and less rabbitbrush cover. Total vegetation cover ( $F_{1,6} = 65.32$ ,  $p = 0.0002$ ), plant basal cover ( $F_{1,6} = 32.99$ ,  $p = 0.0012$ ) and shrub height ( $F_{1,6} = 26.71$ ,  $p = 0.0021$ ) were all greater in the meadow site. The upland site had greater basal gap sizes ( $F_{1,6} = 19.95$ ,  $p = 0.0042$ ) than the meadow site and larger percentage of gap area ( $F_{1,15} = 7.17$ ,  $p = 0.0367$ ).

Annual forb cover was the only vegetation variable significantly different between years ( $F_{1,7} = 10.93$ ,  $p = 0.0130$ ), with 2007 having more cover (2007 = 6.5%  $\pm$  1.9 and 2008 = 1.8%  $\pm$  0.6).

Significant interactions between rabbitbrush sites and year were apparent for dead shrub cover ( $F_{1,6} = 23.29$ ,  $p = 0.0029$ ), perennial grass cover ( $F_{1,6} = 15.84$ ,  $p = 0.0072$ ), vegetative grass height ( $F_{1,6} = 11.76$ ,  $p = 0.0139$ ), and reproductive grass height ( $F_{1,6} = 19.22$ ,  $p = 0.0046$ ). Dead shrub cover was similar between meadow and upland sites during 2007 but showed a doubling in cover in the meadow plots during 2008. Live grass height was also similar between sites in 2007, but 2008 displayed a large decrease in height in the upland site. Reproductive grass height was taller in the upland site in 2007 and then shorter in 2008 when compared to the meadow site. Within the meadow site, perennial grass cover was lower in 2007 compared to 2008.

Conversely, the upland site had greater cover in 2007 compared to 2008.

**Table 3.7** Vegetation parameters (mean  $\pm$  SE / plot) of rabbitbrush sites (2007 and 2008). Shrub category = rabbitbrush and sagebrush combined. Brothers, Oregon.

Variable	Meadow	Upland
<b>Cover (%)</b>		
Annual Forb	4.8 $\pm$ 2.2	3.6 $\pm$ 1.0
Perennial Forb	4.3 $\pm$ 1.1	2.9 $\pm$ 0.7
Food Forb	6.0 $\pm$ 1.3	3.8 $\pm$ 1.2
Annual Grass	2.8 $\pm$ 1.9	0.0 $\pm$ 0.0
Perennial Grass	44.0 $\pm$ 7.7	15.4 $\pm$ 1.9
Rabbitbrush	29.9 <sup>a</sup> $\pm$ 2.8	11.2 <sup>b</sup> $\pm$ 0.7
Sagebrush	0.4 <sup>a</sup> $\pm$ 0.2	5.1 <sup>b</sup> $\pm$ 0.5
Live Shrub	23.9 <sup>a</sup> $\pm$ 1.9	15.1 <sup>b</sup> $\pm$ 0.7
Dead Shrub	6.9 $\pm$ 1.4	4.0 $\pm$ 0.8
Total Shrub	30.7 <sup>a</sup> $\pm$ 2.9	19.1 <sup>b</sup> $\pm$ 1.2
Total Basal	11.1 <sup>a</sup> $\pm$ 1.1	4.0 <sup>b</sup> $\pm$ 0.7
Total Vegetative	86.6 <sup>a</sup> $\pm$ 4.1	41.0 <sup>b</sup> $\pm$ 2.3
<b>Height (cm)</b>		
Reproductive Grass	23.0 $\pm$ 3.0	24.3 $\pm$ 1.1
Vegetative Grass	15.5 $\pm$ 0.9	12.5 $\pm$ 0.7
Live Shrub	42.8 <sup>a</sup> $\pm$ 2.2	29.4 <sup>b</sup> $\pm$ 2.0
Total Shrub	44.3 <sup>a</sup> $\pm$ 2.2	28.2 <sup>b</sup> $\pm$ 1.4
<b>Other</b>		
Basal Gap (cm)	64.0 <sup>a</sup> $\pm$ 13.3	141.3 <sup>b</sup> $\pm$ 11.0
Percent Basal Gap	45.7 <sup>a</sup> $\pm$ 15.8	88.0 <sup>b</sup> $\pm$ 0.7
Species Richness	18.8 $\pm$ 1.6	16.0 $\pm$ 0.9

<sup>a,b</sup>: significant (at 0.05  $\alpha$ -level) differences within rows

### *Correlations Between Moth Abundance and Vegetation*

Pearson's product moment correlations were used to test for relationships between total moth abundance and vegetation measurements, by sites and by foodplant groups. To evaluate total moth abundance and vegetation measurements,

three combinations of sites were used to elucidate possible variations in correlations:

1) sagebrush sites, 2) rabbitbrush sites, and 3) sagebrush and rabbitbrush sites combined.

No significant correlations between total moth abundance and vegetation variables were apparent within the sagebrush sites or when sagebrush and rabbitbrush sites were combined. Rabbitbrush sites, however, showed positive and negative correlations with vegetation measurements (Table 3.8). The highest correlation between rabbitbrush sites was with mean basal gap (coefficient = 0.82,  $p = 0.0129$ ). Total vegetation cover (coefficient = -0.81,  $p = 0.0001$ ) and plant basal cover (coefficient = -0.80,  $p = 0.0002$ ) were also highly correlated with moth abundance. Thus, as distance between plants increased and vegetation cover decreased, moth abundance

increased. Percent basal gap (coefficient = 0.73,  $p = 0.0409$ ) and sagebrush cover (coefficient = 0.70,  $p = 0.0027$ ) were also very highly correlated with moth abundance. Overall, higher moth abundance was associated with

**Table 3.8** Significant (0.05  $\alpha$ -level) Pearson's product moment correlations [ $\geq (\pm 0.6)$ ] between total moth abundance and vegetation parameters at rabbitbrush sites and tree foodplant group. 2007 & 2008, combined. Brothers, Oregon.

	Rabbitbrush Sites		Foodplant = Tree	
	<i>p-value</i>	<i>Coefficient</i>	<i>p-value</i>	<i>Coefficient</i>
Live Shrub Cover	NS	-	0.0014	0.61
Live Shrub Height	NS	-	0.0013	0.62
Mean Basal Gap	0.0129	0.82	NS	-
Percent Basal Gap	0.0409	0.73	NS	-
Perennial Grass Cover	0.0049	-0.66	NS	-
Plant Basal Cover	0.0002	-0.80	NS	-
Rabbitbrush Cover	0.0084	-0.63	0.0003	0.67
Sagebrush Cover	0.0027	0.70	NS	-
Shrub Height	0.0078	-0.64	0.0005	0.65
Total Vegetative Cover	0.0001	-0.81	0.0013	0.62
Vegetative Grass Height	0.0104	-0.62	NS	-

NS: variables that were tested but not significant

increased sagebrush cover, larger basal gaps between plants, and a higher overall percentage of gap area within the plant community. Moth abundance declined as perennial grass cover and vegetative grass height increased, as well as when plant basal cover, rabbitbrush cover, shrub height, and total vegetative cover increased.

For caterpillar foodplant correlations, the tree feeding group was the only group to have significant correlations with any vegetation measurements. All correlations were positive, with rabbitbrush cover (coefficient = 0.67,  $p = 0.0003$ ) and shrub height (coefficient = 0.65,  $p = 0.0005$ ) presenting the highest coefficients (Table 3.8). Other variables correlated with the tree feeding foodplant group were live shrub cover, live shrub height, and total vegetative cover.

### *Moth Community Assemblages*

Patterns in moth community assemblages in rabbitbrush and sagebrush dominated sites were evaluated using NMS on transformed moth community data. Once plots were ordinated in moth species space, a vegetation overlay (seen as vectors in ordination) was used to determine how vegetation variables were associated with the plots. Distinct groupings of plots were apparent in moth species space ordinations. The meadow site separates from all the other sites. An additional NMS analysis was conducted with the meadow plots excluded to provide further information for groupings and vegetation drivers of the remaining sites.

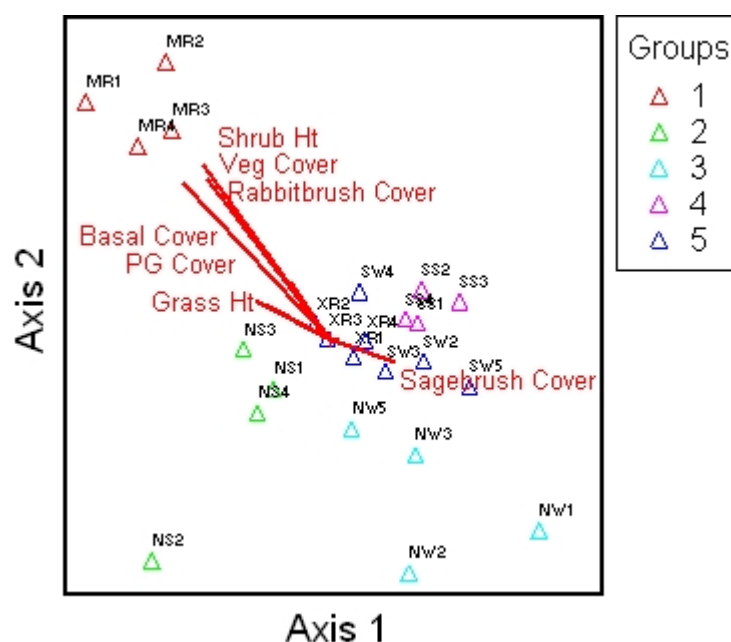
Agglomerative cluster analysis is used when groups are sought from multivariate ecological data (McCune and Grace 2002), thus hierarchical cluster analysis (Euclidean distance and Wards linkage method) was used to determine which plots grouped together when all sites were combined and when the meadow site was excluded. Groups were delineated based on the least amount of chaining and the most amount of information explained while retaining ecological meaning. When both rabbitbrush and sagebrush sites were included, five groups were chosen (chaining = 11.76%). When the meadow site was excluded, three groups were chosen (chaining = 10.74%).

Rank transformed MRPP was used to test for differences between groups determined from the cluster analysis. An  $A = 1$  means that all items within the groups are identical; however an  $A < 0.1$  is common in community ecology, with an  $A < 0.3$



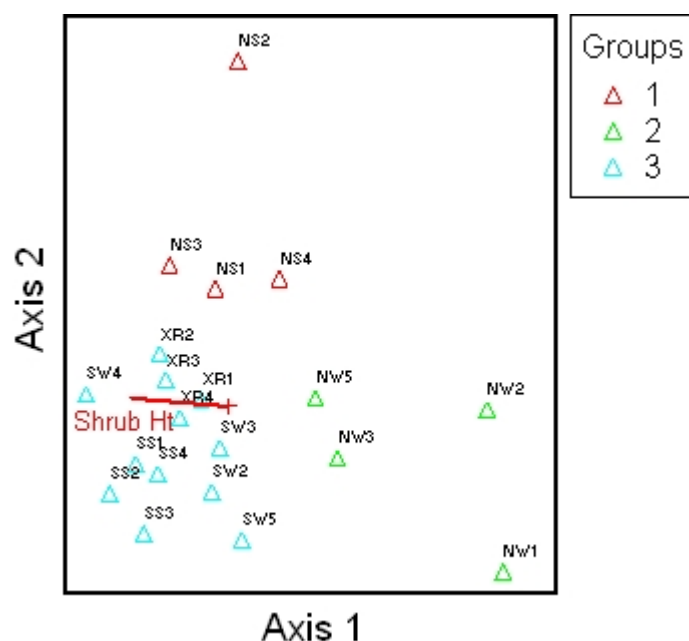
being fairly high (McCune and Grace 2002). When both rabbitbrush and sagebrush sites were combined, the five tested groups were significantly different from one another ( $T = -7.92$ ,  $A = 0.32$ , and  $p < 0.0001$ ). When the meadow site was excluded, the groups were again different ( $T = -11.36$ ,  $A = 0.45$ , and  $p < 0.0001$ ). Hence, the plots within each group were more similar to each other than with other groups or plots.

**Figure 3.3** NMS joint-plot of rabbitbrush and sagebrush plots in moth species space (2007 & 2008) with vegetation overlay. Groups were determined from hierarchical cluster analysis. Brothers, Oregon.



When sagebrush and rabbitbrush sites were combined, the majority of the vegetation variables were most strongly associated with the moth assemblages in meadow plots (Figure 3.3). Shrub height, total vegetative cover, and rabbitbrush cover were the vegetation variables most strongly associated with the moth species occurring in the meadow plots. However, sagebrush cover was strongly associated with the moth assemblages in winter grazed sagebrush plots, spring grazed sagebrush plots, and upland rabbitbrush plots.

**Figure 3.4** NMS joint-plot of upland rabbitbrush and sagebrush plots in moth species space (2007 & 2008) with vegetation overlay. Groups were determined from hierarchical cluster analysis. Brothers, Oregon.



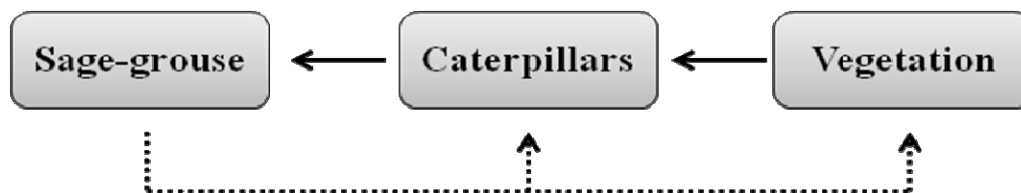
When the meadow plots were removed and the remaining plots re-ordinated, again there were different groupings of plots (Figure 3.4). The three groups seemed to be separated two ways: 1) the 12 plots on the south side of Highway 20 clustered together, and 2) the remaining eight plots separated into spring and winter grazed plots. These groupings seem to be more related to the proximity of the plots than with any overarching habitat characteristic. When the meadow plots were excluded from the ordination, sagebrush cover was no longer a driver of moth species assemblages. This is because when the meadow plots are removed, sagebrush cover is relatively similar between all remaining plots, which then allows other vegetation variables to be evaluated. Shrub height was the only vegetation variable to associate with the remaining sites (Figure 3.4). Shrub height was strongly associated with the moth species assemblages in half of the spring and winter grazed sagebrush plots (NS and NW in Figure 3.4) as well as the upland rabbitbrush plots (XR in Figure 3.4). These

plots were closer in proximity to one another than the other eight sagebrush plots (SS and SW in Figure 3.4).

## Discussion

Diet and nutrition are vital to the health and survival of all animals. The species of prey chosen by predators may ultimately determine good versus poor fitness. In particular, greater sage-grouse are a species of interest and concern due to range wide population declines. Research to better understand the connections between sage-grouse and their habitat components, like insects and vegetation, is critical to their persistence (Figure 3.5). Historically, most studies have shown ants and beetles as the most common insects consumed by sage-grouse chicks. However, recent research positively correlates Lepidoptera larval abundance with sage-grouse chick and brood survival (Gregg and Crawford *in press*). The observation that caterpillars are critical in the life of sage-grouse and other animal species prompts a previously unaddressed avenue of research regarding Lepidoptera biodiversity, caterpillar foodplants, and taxonomy. The Lepidoptera are a diverse group and identification of caterpillars is challenging. However, caterpillars become moths and butterflies, which are the life stage needed for species level identification. Therefore, the purpose of this study was to investigate the adult moth species, their abundance, and their relationships with plant community characteristics within a sagebrush-steppe community, which included areas dominated by *A. tridentata* ssp. *vaseyana*, *C. viscidiflorus*, or *E. nauseosa*. In addition to relating total moth abundance to vegetation components, moth abundance by foodplant group was also evaluated to enhance the ecological understanding of the relationships with plant communities. This research adds to the body of knowledge focused on improving sage-grouse brood-rearing habitat management.

**Figure 3.5** Trophic cascade diagram for sage-grouse, caterpillar, and vegetation interactions. Solid lines are direct effects/energy flow, dashed lines are indirect effects.



The development of a species list based on adults within an area is useful because the species names provide a link to the literature and serve to focus attention on the taxa of local importance. The moth species assemblage is major component of the fauna and provides a critical connection in the dynamics of trophic relationships between vegetation (1° producers), Lepidoptera (1° consumers), and sage-grouse (2° consumers). Plant species richness has been related to insect diversity (Panzer and Schwartz 1998, Southwood et al. 1979), suggesting that diverse plant communities could be used as a surrogate for diverse insect communities. Results of this study, especially the meadow location, corroborate this relationship between insect and plant community biodiversity.

Relationships between moth abundance, caterpillar foodplant groups, and plant communities were mediated by annual variation and plant community differences in rabbitbrush and sagebrush dominated sites. Within the research area, two different plant communities were studied. An *A. tridentata* ssp. *vaseyana* community was chosen to represent what is assumed to be suitable sage-grouse habitat. The rabbitbrush dominated communities were chosen because they were represented within the sagebrush dominated areas and are known to contain a diverse insect community (J. Miller, pers. comm., 9/06). Overall, on a per plot basis, rabbitbrush sites exhibited higher moth abundance than the sagebrush sites. Also, when compared to sagebrush sites, rabbitbrush sites exhibited higher Lepidoptera species richness and a greater number of unique species. Thus, potential sage-grouse diet choice and availability should be high in rabbitbrush dominated communities.

Rangelands are a major resource for livestock grazing. An understanding of the connections between seasonal grazing management, vegetation components, and Lepidoptera are necessary for addressing future research and planning regarding the multiple uses of sage-grouse habitat. Therefore, comparisons between the spring and winter grazed areas, within the same ecological site, were made because initial observations of the area presented what appeared to be two structurally and compositionally different plant communities. Results from the vegetation measurements validated this observation. Though not necessarily attributed to the grazing practices, when compared to the winter grazed site, the spring grazed sagebrush site had more sagebrush cover, more live and dead shrub cover, more total shrub cover, as well as shorter heights of grass in the seed stage, taller shrub heights, and larger basal gaps. Refer to Chapter 2 for a comprehensive discussion on vegetation differences between the spring and winter grazed sagebrush sites. These differences, whatever the cause, in plant community structure and composition may be influencing the number and abundance of moth species present in sagebrush dominated areas. Sagebrush sites under spring grazing management had greater moth abundance and more unique moth species than winter grazed sites.

Within the research area, two rabbitbrush dominated communities were present: 1) meadow, dominated by *E. nauseosa*, and 2) upland, dominated by *C. viscidiflorus*. Both communities, in part, resulted from historical farming practices. The upland site resides within a larger landscape dominated by *A. tridentata* ssp. *vaseyana* and *A. arbuscula* Nutt. ssp. *longiloba* (Osterh.) L.M. Shultz (early sage). The meadow site is located in a valley bottom surrounded by *A. tridentata* ssp. *vaseyana* communities and *Juniperus occidentalis* Hook. (western juniper) woodlands. The meadow site presented a structurally diverse community. These plant community differences were validated with the vegetation measurements. When compared to the upland site, the meadow site had less sagebrush cover, more rabbitbrush cover, more total shrub cover, more basal and vegetative cover, taller shrub heights, and smaller basal gaps. When compared to all other sites, the meadow site exhibited the highest species richness for Lepidoptera and a greater number of unique species, as well as the

most forb feeding, tree feeding, and unknown foodplant species. Consistent with other research (Gardner et al. 1995), the meadow location had a diverse moth and plant community. Based on moth abundance data, the upland rabbitbrush site was the more productive site during this study; although, the variability between years was high. The two rabbitbrush sites were the only sites to have significant correlations between vegetation measurements and moth abundances. The differences in vegetation and landscape position resulted in a more diverse moth community in the meadow site, but greater moth abundance in the upland rabbitbrush site. These differences may also be attributed to species' foodplant relationship with the two rabbitbrush species.

The pattern in moth abundance and species richness varied throughout the year. Relatively few moths were collected during May and June. Although July through September proved to be better sampling months for abundance, the variation between years was high. Although not the focus of this study, differences in abundance may also be due to caterpillar survival in the prior year which would be affected by disease, predators, and quality of foliage. Some variation may be explained by temperature and weather. Yela and Holyoak (1997) reported that moth abundance in light traps increased with temperature and cloud cover. Cloud cover decreases the ambient light from the moon, making the light traps more visible. Thunder, rain, and lightening have been reported as affecting moth abundance in a catch (Makra et al. *unknown*). Consistent with the findings of Summerville and Crist (2005), species richness was higher in the later months, as opposed to May and June. Seasonal variation is likely related to differences in adult emergence times, which are evolved responses to changes in foodplant presence, palatability, or detectability (Niemelä and Haukioja 1982).

From the species with known caterpillar foodplant relationships, species richness was greatest in the forb-feeding guild. Among the 222 species, only three have foodplants in more than one group (ex: forb and grass feeding). Overall, both sagebrush and rabbitbrush sites were dominated by species in the forb-feeding and shrub-feeding guilds. The grass-feeding species were evenly distributed across sites. The number of species in the shrub-feeding guild was higher in the rabbitbrush sites,

but equal when compared between the four habitats (spring and winter grazed sagebrush, upland and meadow rabbitbrush). The number of tree-feeding species was highest in the meadow site. In addition, 91 species had an unknown foodplant relationship, with 81 species in the rabbitbrush sites and 70 species in the sagebrush sites. This means that 41% of the identified species at the study sites have undiscovered foodplant relationships.

Lepidoptera foodplant relationships were assessed with vegetation measurements to incorporate species ecology, as a caterpillar, with the plant communities. The tree feeding guild was the only foodplant group to correlate with any of the vegetation measurements. These species increased in abundance as live shrub cover, shrub height, rabbitbrush cover, and total vegetative cover increased. These relationships are most likely related to the 19 tree feeding species present at the meadow site, which subsequently was the site nearest to juniper woodland habitat and home sites.

## **Conclusions**

This research broadened the understanding of biotic attributes and their relationships to each other within sage-grouse brood-rearing habitat. Bio-inventory and monitoring of species within an ecosystem is critical to the conservation of habitat biodiversity (Kim 1993), be that of sage-grouse, sagebrush obligates, or other sagebrush-steppe associated species. Therefore, understanding the biotic components and their interactions within a habitat will benefit sage-grouse populations. In addition, some species of Lepidoptera have been identified as sensitive to minor changes in the structure of grassland habitats (Erhardt and Thomas 1989). Thus, incorporating Lepidoptera species sensitive to change within sage-grouse habitat monitoring plans may provide an early indicator of plant community change.

Lepidoptera species were not evenly distributed across the study area. The meadow site provided the greatest diversity of Lepidoptera compared to all the sites.

When comparing the two rabbitbrush dominated sites, the upland site produced the greatest abundance of moths. Assuming that the moths were caught in the same habitat they occupied as a larva, we would conclude that the upland site offered far more caterpillars than the meadow site. The results from the first study (Chapter 2) indicated the meadow site had more caterpillars than the upland site. However, high abundance in the larval form does not translate to high abundance in the adult form. There are several reasons for this: 1) high mortality in the larval and pupal stage of Lepidoptera is common, 2) adults may not be attracted to the black light, and 3) abundant adults may have spent their entire larval stage in a plant canopy or in the soil, meaning they would not have been caught in a pitfall trap. As for *A. tridentata* ssp. *vaseyana* dominated communities, sites under spring grazing management provided a higher abundance of moths than winter grazed areas. However, in the sagebrush sites, the difference in abundance between years was equal to the difference between sites under different seasons of grazing.

Future research should focus on determining the species of Lepidoptera larva that are being consumed by sage-grouse chicks. Once known, the caterpillar foodplant relationship should be ascertained, which would in turn allow land managers to focus efforts on maintaining, enhancing, or incorporating the plant species with brood-rearing habitat management plans.



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## Chapter 4: General Conclusions

Insects are an essential component of quality sage-grouse brood-rearing habitat. Lepidoptera larval (caterpillars of moths and butterflies) abundance has been positively linked with sage-grouse brood and chick survival and juvenile recruitment (Gregg and Crawford *in press*). Therefore, it is important to understand the relationships between Lepidoptera and plant community characteristics as well as their ecological function within brood-rearing habitats. The objective of this study was to investigate the relationships between plant community structure and composition and insects, with an emphasis on Lepidoptera, in sagebrush-steppe communities in central Oregon. Insects of interest were determined a priori and included taxa that have been found in sage-grouse chick diets: ants, grasshoppers, darkling beetles, and scarab beetles, with a specific focus on caterpillars. In addition, the species and abundance of adult moths within these sites were determined.

The study area encompassed four sites located within two ecological sites (Pumice 8-10 PZ and Mountain Swale 12-16 PZ) and characterized by three different dominant shrub species. Two sites were in *Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle (mountain big sagebrush) plant communities, managed under spring and winter cattle grazing for the last two or more decades. Although grazing was not applied as a treatment, significant differences in plant community characteristics and insect abundance between the winter and spring grazed areas were detected. The remaining two sites were a *Chrysothamnus viscidiflorus* (Hook.) Nutt. (yellow rabbitbrush) dominated upland and an *Ericameria nauseosa* (Pall. ex Pursh) G.L. Nesom & Baird (rubber rabbitbrush) dominated meadow. Significant differences were detected in plant community characteristics and insect abundance between the two rabbitbrush sites.

After two years of quantifying insect abundance and vegetation attributes some relationships between insects and plant community structure and composition were identified. Additionally, an inventory of the Lepidoptera species present within the

study area was assembled. Although there were consistent results between the studies with regards to Lepidoptera, there were also important differences. In both studies, the rabbitbrush sites provided the highest abundance of Lepidoptera, both in the larval and adult form. However, the meadow site provided the most caterpillars, whereas the upland site exhibited the highest abundance of adult moths. The discrepancies between these results and the two life stages are related to several factors. The first reason for these differences is that pitfall trapping targets insects crawling on the ground, therefore, caterpillars that are located in plant canopies were not sampled. Although alternative methods of sampling caterpillars, such as utilizing beating sheets or by hand picking caterpillars off plants may have generated a larger abundance value, the focus of this study was to quantify the insects within the food availability area for sage-grouse chicks. Secondly, black light trapping for the adult Lepidoptera targets all moths, not just the moths that were ground and litter dwellers as caterpillars. Thus, the two sampling methods are not equal in the sampling efforts for these species. Therefore, the high abundance of adults in the upland rabbitbrush site may be from species that spend their life cycle in a plant canopy and would not have been caught in a pitfall trap during the larval stage. Overall, the composition of Lepidoptera within the meadow site suggests it to be best habitat for sage-grouse broods because of the high number of caterpillars caught, even though the adult abundance was not as high as the upland rabbitbrush site.

From the perspective of sage-grouse brood-rearing habitat, the most important research is yet to be conducted. The species of litter and ground dwelling Lepidoptera, which are available for sage-grouse chicks, need to be identified. Once known, these species can be further examined to learn the caterpillar foodplant relationships and relative abundance within given habitats. This would provide additional information to land managers for incorporation into decisions regarding sage-grouse brood-rearing habitat.

## Improvements

As with most endeavors in life, hindsight is generally better than the first vision. After reflecting upon this research, I would suggest the following:

- A) Due to the nature of the data collected, variability was high with regards to insect abundance. Multiple years of sampling will be required to better elucidate the patterns and trends within the insects of interest. Sampling for multiple years would capture the range in variability between years and elucidate the long-term trend.
- B) Black light trapping in remote locations grazed by livestock proved to be logistically challenging. Two alternative solutions may help mediate livestock impacts: 1) permanent exclosures or 2) no exclosure. The first solution has higher costs and the risk of attracting livestock to the area. The second solution may eliminate the exclosure attractant problem but leaves black light equipment exposed to animals. Additionally, the use of an automatic on/off photovoltaic power switch on the black light would reduce the amount of time spent servicing traps and enhance the feasibility of sampling at the landscape scale.
- C) Ant abundance often exceeded 1000 individuals in a sample; therefore counting individuals during both years was not a viable option. A volumetric method for assessing ant abundance is suggested.
- D) Moth abundance is affected by temperature and weather, therefore, collecting temperature and precipitation data at each site would be helpful when relating insect abundance to time of year. Degree-day models would provide scheduling guidelines for researchers and managers to efficiently allocate their efforts to predict dates for the initiation of trap deployment.

## **Future Research**

Suggestions for future research include collecting and rearing litter and ground dwelling Lepidoptera species found within sage-grouse brood-rearing habitat. Rearing caterpillars to the adult stage would allow researchers to identify the species and facilitate the determination of foodplant relationships. This research would benefit future Lepidoptera studies and management within sage-grouse habitats.

The identification of Lepidoptera species consumed by sage-grouse chicks is also needed to understand if consumption is based on availability only or if some selectivity is employed. If selective, chicks may be consuming more than just ground and litter dwelling Lepidoptera species; therefore, knowing the species consumed by chicks may shift the emphasis of Lepidoptera research.

Additionally, foodplant relationships for the most abundant Lepidoptera species in the sagebrush-steppe need to be determined. Caterpillars are a high quality food source for other animals and insects besides sage-grouse. For that reason, incorporating caterpillar habitat requirements into restoration efforts or monitoring plans may improve habitat quality for a variety of wildlife.

Also, other studies have related invertebrate biomass to vegetation characteristics (Hagen et al. 2005 and Jamison et al. 2002). Therefore, a measure of insect biomass, by type (ex: grasshoppers, darkling beetles, etc.), may be beneficial to further elucidate the relationships between insects as prey species and the quality of the habitat.

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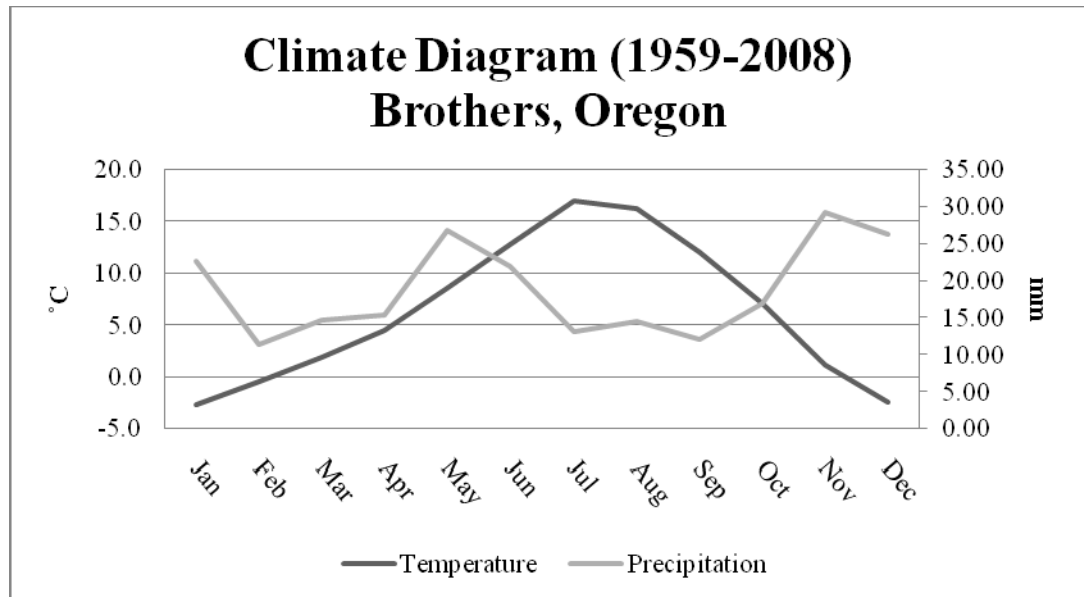
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## **APPENDICES**

## Appendix A: Climate Diagram for Brothers, Oregon

Climate diagram for long-term (1959-2008) weather data from the Brothers, Oregon weather station.



## Appendix B: Plant Species List

Plant species list for research sites and occurrence within each site.

Scientific Name	Common Name	Meadow	Upland	Spring	Winter
<b>Shrubs</b>					
<i>Artemisia arbuscula</i>	low sage	x		x	
<i>Artemisia arbuscula</i> ssp. <i>longiloba</i>	early sage			x	x
<i>Artemisia tridentata</i> ssp. <i>tridentata</i>	basin big sagebrush	x			
<i>Artemisia tridentata</i> ssp. <i>vaseyana</i>	mountain big sagebrush	x	x	x	x
<i>Chrysothamnus humilis</i>	Truckee rabbitbrush		x	x	x
<i>Chrysothamnus viscidiflorus</i>	yellow rabbitbrush	x	x	x	x
<i>Ericameria nauseosus</i>	rubber rabbitbrush	x	x	x	
<i>Purshia tridentata</i>	antelope bitterbrush			x	
<b>Grasses and Grass-like</b>					
<i>Acnatherum occidentale</i>	western needlegrass		x	x	x
<i>Acnatherum thurberianum</i>	Thurber's needlegrass		x	x	x
<i>Agropyron cristatum</i>	crested wheatgrass	x			
<i>Bromus tectorum</i>	cheatgrass	x	x	x	
<i>Carex douglasii</i>	Douglas' sedge	x			
<i>Carex rossii</i>	Ross's sedge		x	x	x
<i>Carex</i> sp.	sedge	x		x	x
<i>Distichlis spicata</i>	saltgrass	x			
<i>Elymus elymoides</i>	squirreltail	x	x	x	x
<i>Festuca idahoensis</i>	Idaho fescue	x	x	x	x
<i>Hesperostipa comota</i>	needle-and-thread grass			x	
<i>Juncus</i> sp.	rush	x			
<i>Koeleria macrantha</i>	prairie Junegrass	x		x	x
<i>Leymus cinereus</i>	basin wildrye	x			
<i>Muhlenbergia richardsonis</i>	mat muhly	x			
<i>Pascopyrum smithii</i>	western wheatgrass	x	x	x	x
<i>Poa cusickii</i>	Cusick's bluegrass	x			
<i>Poa nevadensis</i>	Nevada bluegrass	x			
<i>Poa pratensis</i>	Kentucky bluegrass	x			
<i>Poa sandbergii</i>	Sandberg's bluegrass	x			x
<b>Perennial Forbs</b>					
<i>Achillea millefolium</i>	western yarrow	x			x
<i>Agoseris glauca</i>	pale agoseris		x	x	x
<i>Antennaria dimorpha</i>	low pussytoes			x	x
<i>Antennaria rosea</i>	rosy pussytoes			x	x
<i>Arabis hirsuta</i>	hairy rockcress		x	x	x

<i>Astragalus filipes</i>	basalt milkvetch	x			
<i>Astragalus letiginosus</i>	freckled milkvetch	x			x
<i>Astragalus peckii</i>	Peck's milkvetch				x
<i>Astragalus purshii</i>	woollypod milkvetch		x	x	x
<i>Cardaria pubescens</i>	hairy whitetop	x			
<i>Castilleja pilosa</i>	parrothead Indian paintbrush	x			x
<i>Cirsium scariosum</i>	meadow thistle	x			
<i>Erigeron linearis</i>	desert yellow fleabane				x
<i>Erigeron pumilus</i>	shaggy fleabane	x			
<i>Eriogonum heracleoides</i>	parsnip-flower buckwheat			x	
<i>Eriogonum ovalifolium</i>	cushion buckwheat		x	x	x
<i>Eriogonum umbellatum</i>	sulphur-flower buckwheat		x	x	x
<i>Eriophyllum lanatum</i>	common woolly sunflower		x		x
<i>Erysimum capitatum</i>	sand-dune wallflower		x		
<i>Lepidium latifolium</i>	broadleaved pepperweed	x			
<i>Linanthus pungens</i>	granite prickly phlox		x	x	x
<i>Linum perenne</i>	blue flax	x			
<i>Lomatium sp.</i>	desert parsley			x	
<i>Lupinus caudatus</i>	tailcup lupine	x			x
<i>Machaeranthera canescens</i>	hoary tansyaster		x		
<i>Packera cana</i>	woolly groundsel	x	x	x	x
<i>Phlox hoodii</i>	spiny phlox			x	x
<i>Potentilla gracilis</i>	slender cinquefoil	x			
<i>Pyrrocoma lanceolata</i>	lanceleaf goldenweed	x			
<i>Ranunculus glaberrimus</i>	sagebrush buttercup	x			
<i>Sisyrinchium idahoense</i>	Idaho blue-eyed grass	x			
<i>Symphyotrichum ascendens</i>	western aster	x			
<i>Taraxacum officinale</i>	common dandelion	x			
<i>Townsendia florifer</i>	showy Townsend daisy		x	x	
<i>Tragopogon dubius</i>	yellow salsify				
<i>Trifolium sp.</i>	clover	x			
<i>Vicia sp.</i>	vetch	x			
<b>Annual Forbs</b>					
<i>Alyssum alyssoides</i>	pale madwort	x			
<i>Chamerion sp.</i>	fireweed	x			x
<i>Collinsia parviflora</i>	maiden blue eyed Mary	x	x	x	x
<i>Cryptantha circumscissa</i>	cushion cryptantha		x	x	
<i>Descurainia pinnata</i>	western tansymustard	x	x	x	x
<i>Gayophytum sp.</i>	groundsmoke	x	x	x	x
<i>Lupinus sp.</i>	annual lupine				x
<i>Microsteris gracilis</i>	slender phlox	x	x	x	x
<i>Mimulus nanus</i>	dwarf purple monkeyflower			x	

## Appendix C: Moth Species List

Moth species list with their respective caterpillar foodplant group, total abundance, and abundance within each site, for 2007 and 2008 combined.

Species	Foodplant	Abundance				
		Total	Meadow	Upland	Spring	Winter
<i>Abagrotis discoidalis</i>	shrub	7		3	3	1
<i>Abagrotis duanca</i>	shrub	32	3	7	8	14
<i>Abagrotis forbesi</i>	tree	17	5	4	4	4
<i>Abagrotis glenni</i>	tree	25	2	3	17	3
<i>Abagrotis nanalis</i>	shrub	7	1		4	2
<i>Abagrotis placida</i>	tree	7	2	1	4	
<i>Abagrotis scopeops</i>	unknown	1	1			
<i>Abagrotis variata</i>	tree	1				1
<i>Abagrotis vittifrons</i>	unknown	200	106	41	36	17
<i>Agonopterix alstroemeriana</i>	forb	254	65	30	71	88
<i>Agonopterix</i> sp.	N/A	3	1			2
<i>Agriphila attenuata</i>	unknown	169	50	22	45	52
<i>Agroperina lateritia</i>	grass	1				1
<i>Agrotis ipsilon</i>	forb	6	1	1	2	2
<i>Agrotis venerabilis</i>	forb/grass	49	31	4	4	10
<i>Aletia oxygala</i>	grass	1	1			
<i>Amorbia cuneana</i>	shrub	1		1		
<i>Anomogyna infimatis</i>	forb	11	9	2		
<i>Apamea acera</i>	unknown	5		3	1	1
<i>Apamea alia</i>	grass	1			1	
<i>Apamea amputatrix</i>	grass	12	3	1	3	5
<i>Apamea castanea</i>	grass	14	1	4	5	4
<i>Apamea centralis</i>	unknown	1				1
<i>Apamea cuculliformis</i>	grass	2		1	1	
<i>Apamea inordinata</i>	unknown	2				2
<i>Apamea occidens</i>	grass	253	34	36	90	93
<i>Apamea spaldingi</i>	unknown	11	2	2	3	4
<i>Archips argyrospila</i>	tree	2	2			
<i>Aseptis characta</i>	shrub	282	45	38	143	56
<i>Aseptis fumosa</i>	shrub	1		1		
<i>Autographa californica</i>	forb	2	1	1		
<i>Caenurgina erechtea</i>	forb	1	1			
<i>Chesiadodes cinerea</i>	shrub	986	196	116	372	302
<i>Cheteoscelis bistrifaria</i>	forb	85	22	12	36	15
<i>Chlorochlamys triangularis</i>	shrub	7	3		4	
<i>Chlorosea banksaria</i>	shrub	2	1	1		
<i>Choristoneura occidentalis</i>	tree	1		1		
<i>Choristoneura rosaceana</i>	tree	1	1			

<i>Chortodes rufostrigata</i>	unknown	2	2			
<i>Chrysoteuchia topiaria</i>	grass	23	18	1	1	3
<i>Coloradia pandora</i>	tree	92	17	21	27	27
<i>Copablepharon canariana</i>	unknown	62	60		1	1
<i>Copablepharon spiritum</i>	unknown	1				1
<i>Copablepharon viridisparisa</i>	forb	241	7	56	94	84
<i>Copicucullia antipoda</i>	forb	191	51	37	63	40
<i>Copicucullia eulepis</i>	forb	1			1	
<i>Copicucullia eurekae</i>	unknown	475	4	173	143	155
<i>Crambidia casta</i>	lichen	1		1		
<i>Crambus leachellus</i>	grass	51	10	17	18	6
<i>Crambus plumbifimbriellus</i>	unknown	4	1			3
<i>Crassivesica bocha</i>	forb	48	41		5	2
<i>Crymodes devastator</i>	forb	79	44	15	12	8
<i>Crymodes longula</i>	unknown	2	2			
<i>Cryphia cuerva</i>	unknown	4		1	3	
<i>Cucullia intermedia</i>	tree	1	1			
<i>Cucullia pulla</i>	shrub	16	7	1	2	6
<i>Cucullia similis</i>	unknown	1	1			
<i>Dicestra crotchii</i>	unknown	1			1	
<i>Dicestra trifolii</i>	forb	2			1	1
<i>Digrammia californiaria</i>	forb	14		1	9	4
<i>Digrammia curvata</i>	shrub	886	488	117	166	115
<i>Digrammia modocata</i>	tree	100	62	3	29	6
<i>Digrammia nubiculata</i>	shrub	3838	372	1249	1128	1089
<i>Digrammia sexpunctata</i>	shrub	42	3	4	19	16
<i>Drasteria mirifica</i>	forb	9	2	2	1	4
<i>Eana argentana</i>	unknown	581	54	5	208	314
<i>Egira crucialis</i>	tree	8	8			
<i>Egira hiemalis</i>	tree	1			1	
<i>Epidemas cinerea</i>	unknown	1		1		
<i>Ethmia monticola</i>	unknown	2	1		1	
<i>Euchromius ocellus</i>	grass	4	3			1
<i>Eucosma aurilineana</i>	unknown	69	1	31	25	12
<i>Eucosma bolanderana</i>	unknown	3	1		2	
<i>Eucosma canariana</i>	unknown	1	1			
<i>Eucosma caniceps</i>	unknown	3			2	1
<i>Eucosma crambitana</i>	unknown	44	11	15	14	4
<i>Eucosma mediotriata</i>	unknown	27			8	19
<i>Eucosma ridingsana</i>	tree	16	9	2	2	3
<i>Eucosma snyderana</i>	unknown	95	2	54	28	11
<i>Eucosma</i> sp. <i>Nr. caniceps</i>	unknown	84	84			
<i>Eudrepanulatrix rectifascia</i>	shrub	1	1			
<i>Eupithecia nevadata</i>	shrub	2			1	1
<i>Eupithecia placidata</i>	tree	2	1			1
<i>Euxoa aequalis</i>	unknown	64	48	1	11	4
<i>Euxoa albipennis</i>	forb	67	31	12	18	6



<i>Euxoa atomaris</i>	tree	28	5	6	13	4
<i>Euxoa auripennis</i>	unknown	3	2		1	
<i>Euxoa auxiliaris</i>	forb	4		2		2
<i>Euxoa bicollaris</i>	unknown	6	4			2
<i>Euxoa biformata</i>	unknown	40	1	10	16	13
<i>Euxoa brevipennis</i>	forb	147	3	60	29	55
<i>Euxoa brunneigera</i>	unknown	7	3	1		3
<i>Euxoa castanea</i>	unknown	1	1			
<i>Euxoa catenula</i>	forb	135	15	27	42	51
<i>Euxoa choris</i>	unknown	47	11	10	12	14
<i>Euxoa cicatricosa</i>	unknown	92	1	26	40	25
<i>Euxoa cinereopallida</i>	unknown	19	2		14	3
<i>Euxoa citricolor</i>	unknown	1			1	
<i>Euxoa dargo</i>	grass	21	2	5	11	3
<i>Euxoa declarata</i>	forb	15	11	1	2	1
<i>Euxoa difformis</i>	unknown	2	2			
<i>Euxoa edictalis</i>	unknown	16		1	9	6
<i>Euxoa furvida</i>	unknown	638	223	99	161	155
<i>Euxoa hollemanni</i>	unknown	22	9	3	6	4
<i>Euxoa idahoensis</i>	unknown	210	60	37	53	60
<i>Euxoa infracta</i>	grass	6	3	1	1	1
<i>Euxoa intrita</i>	forb	2	1			1
<i>Euxoa laetificans</i>	forb	126	116	2	5	3
<i>Euxoa messoria</i>	forb	48	18	14	7	9
<i>Euxoa misturata</i>	unknown	6244	167	2426	2110	1541
<i>Euxoa mitis</i>	unknown	317	144	53	85	35
<i>Euxoa moerens</i>	forb	158	28	41	51	38
<i>Euxoa murdocki</i>	unknown	30	18	3	6	3
<i>Euxoa nevada</i>	unknown	132	16	43	55	18
<i>Euxoa oblongistigma</i>	unknown	44	13	10	15	6
<i>Euxoa ochrogaster</i>	forb	42	5	13	8	16
<i>Euxoa olivalis</i>	unknown	36	11	3	14	8
<i>Euxoa olivia</i>	forb	5	1	1	1	2
<i>Euxoa perexcellens</i>	forb	1				1
<i>Euxoa plagigera</i>	unknown	28	14	5	5	4
<i>Euxoa pluralis</i>	unknown	803	53	173	337	240
<i>Euxoa punctigera</i>	forb	9	6		2	1
<i>Euxoa quadridentata</i>	grass	464	192	77	78	117
<i>Euxoa recula</i>	forb	984	5	211	471	297
<i>Euxoa satiens</i>	unknown	1088	428	201	316	143
<i>Euxoa satis</i>	unknown	138	57	11	35	35
<i>Euxoa septentrionalis</i>	unknown	19	9		6	4
<i>Euxoa silens</i>	unknown	4	2	2		
<i>Euxoa simona</i>	unknown	295	26	78	126	65
<i>Euxoa tessellata</i>	forb	88	31	17	18	22
<i>Euxoa tristicula</i>	forb	1			1	
<i>Feltia jaculifera</i>	forb	13	10	1	1	1

<i>Fumibotys fumalis</i>	forb	25	4	9	7	5
<i>Givira</i> sp.	N/A	17	6	1	8	2
<i>Glaucina spaldingata</i>	unknown	10	4		5	1
<i>Grammia nevadensis</i>	forb/shrub	119	37	9	52	21
<i>Hesperumia sulphuraria</i>	shrub	29	1	6	9	13
<i>Homorhodes furfurata</i>	tree	1	1			
<i>Hulstina imitatrix</i>	unknown	43		9	15	19
<i>Hyalophora euryalus</i>	tree	4	2		2	
<i>Hydraecia medialis</i>	forb	4	4			
<i>Hyles lineata</i>	forb	3		2		1
<i>Jocara trahalis</i>	unknown	8	5		1	2
<i>Lacinipolia pensilis</i>	forb/shrub/tree	3	3			
<i>Lacinipolia rectilinea</i>	unknown	1	1			
<i>Lacinipolia stricta</i>	forb	107	34		73	
<i>Lacinipolia vicina</i>	forb	2	1		1	
<i>Leucania farcta</i>	grass	2	1		1	
<i>Leucoma salicis</i>	tree	1	1			
<i>Lithophane longior</i>	tree	3	2		1	
<i>Loxostege commixtalis</i>	forb	34	17	6	3	8
<i>Loxostege stricticalis</i>	forb	1	1			
<i>Macaria adonis</i>	tree	1			1	
<i>Malacosoma californicum</i>	tree	109	34	17	25	33
<i>Marmopteryx marmorata</i>	unknown	9	1	2	4	2
<i>Microtheoris ophionalis</i>	unknown	10	4	2		4
<i>Narraga stalactaria</i>	unknown	2	1			1
<i>Nephelodes demaculata</i>	unknown	11	10	1		
<i>Noctua pronuba</i>	forb	19		3	8	8
<i>Oligia tonsa</i>	unknown	44	8	8	12	16
<i>Oligia violacea</i>	unknown	7	4		3	
<i>Oncocnemis laticollis</i>	unknown	10	1		9	
<i>Oncocnemis umbrifascia</i>	forb	1	1			
<i>Onocnemis sagittata</i>	unknown	3			2	1
<i>Orthosia pulchella</i>	shrub	1		1		
<i>Parabagrotis exertistigma</i>	grass	825	52	255	327	191
<i>Parabagrotis insularis</i>	unknown	90	14	25	27	24
<i>Parabagrotis sulinaris</i>	grass	3		1	1	1
<i>Pediasia dorsipunctella</i>	grass	28	20	3	3	2
<i>Pediasia trisecta</i>	grass	24	23			1
<i>Peridroma saucia</i>	forb	1				1
<i>Perizoma custodiata</i>	shrub	1			1	
<i>Phaneta bucephaloides</i>	shrub	544	30	137	236	141
<i>Pima fulvirugella</i>	unknown	89	34	14	21	20
<i>Plataea newspecies</i>	shrub	53	1	1	37	14
<i>Plataea trilinearia</i>	shrub	1178	162	214	463	339
<i>Platyperigea camina</i>	unknown	37	1	10	16	10
<i>Platyperigea montana</i>	forb	2	2			
<i>Polia noverca</i>	forb	1	1			

<i>Polia nugatis</i>	shrub	315	31	46	188	50
<i>Prochloridea modesta</i>	unknown	1	1			
<i>Prochoerodes amplicineraria</i>	unknown	99	55	5	33	6
<i>Prorella opinata</i>	unknown	1	1			
<i>Protagrotis obscura</i>	grass	56	41	4	9	2
<i>Protogygia enalaga</i>	unknown	2	2			
<i>Protogygia milleri</i>	unknown	19		3	8	8
<i>Protoperigea posticata</i>	unknown	1	1			
<i>Protorthodes curtica</i>	forb	2	2			
<i>Pseudanarta crocea</i>	unknown	307	102	71	98	36
<i>Pseudorthosia variabilis</i>	forb	2	1			1
<i>Pyrausta fodinalis</i>	forb	2	1			1
<i>Pyrausta semirubralis</i>	unknown	1	1			
<i>Pyrausta subsequalis</i>	forb	9	7		2	
<i>Pyrausta unifascialis</i>	forb	22	1	4	6	11
<i>Reabotis immaculalis</i>	unknown	23	6	5	7	5
<i>Rhizagrotis albalis</i>	unknown	1			1	
<i>Sabulodes edwardsata</i>	tree	1				1
<i>Sarata</i> sp.	N/A	98	65	7	19	7
<i>Schinia albafascia</i>	unknown	21	21			
<i>Schinia separata</i>	shrub	96	1	15	59	21
<i>Schinia unimacula</i>	shrub	57	26	6	22	3
<i>Schinia walsinghami</i>	shrub	186		22	140	24
<i>Scopula luteolata</i>	unknown	12	11	1		
<i>Setagrotis atrifrons</i>	shrub	1				1
<i>Setagrotis planifrons</i>	tree	1		1		
<i>Setagrotis radiatus</i>	unknown	8	1	2	5	
<i>Smerinthus cerisyi</i>	tree	3	3			
<i>Spaelotis bicava</i>	unknown	141	17	24	62	38
<i>Speranza colata</i>	shrub	118	30	12	61	15
<i>Speranza quadrilinearia</i>	shrub	1	1			
<i>Sphinx perelegans</i>	tree	3			3	
<i>Sphinx sequoiae</i>	tree	8			7	1
<i>Spodoptera praefica</i>	forb	1			1	
<i>Stannoctenis pearsalli</i>	unknown	2			2	
<i>Tarachidia tortricina</i>	unknown	2	2			
<i>Tholera americana</i>	unknown	812	89	58	308	357
<i>Trichocerapoda oblita</i>	unknown	13089	22	2691	6605	3771
<i>Trichocerapoda strigata</i>	unknown	700	7	156	413	124
<i>Trichoclea u-scripta</i>	unknown	51	13	12	17	9
<i>Triocnemis saporis</i>	forb	1	1			
<i>Xylena brucei</i>	shrub	1			1	
<i>Xylena nupera</i>	shrub	1	1			