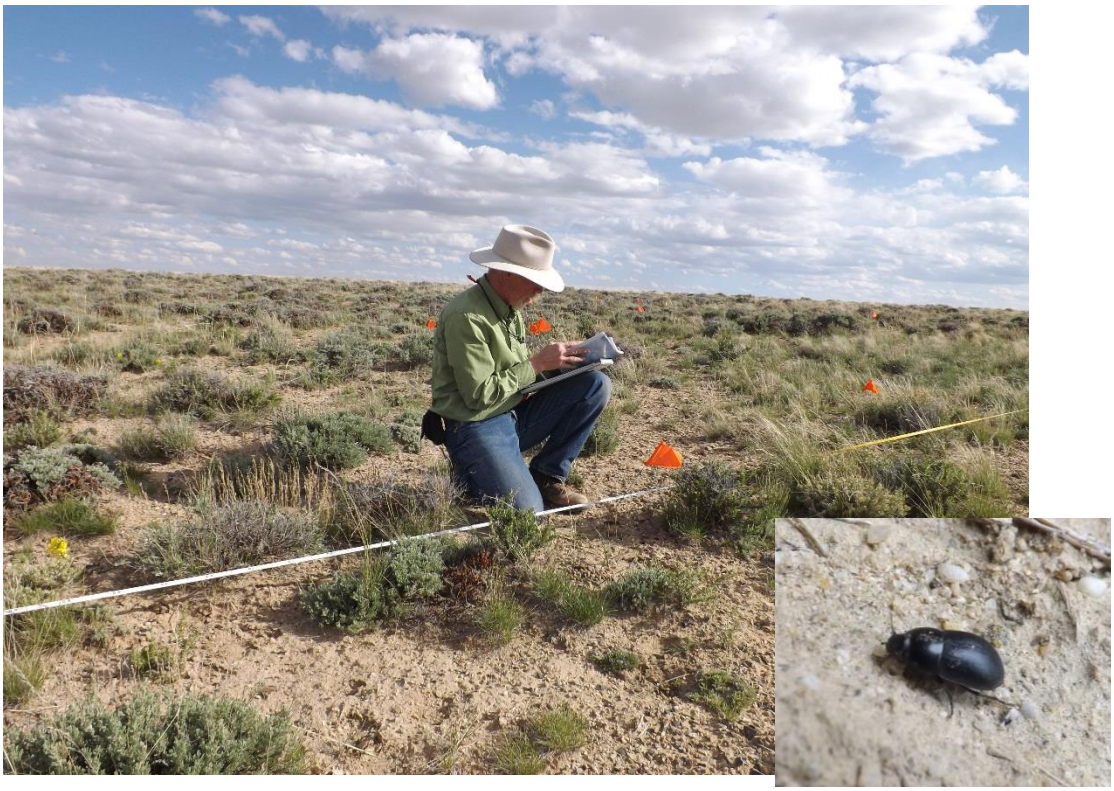
Modeling and mapping the distribution of invertebrate prey used by Greater Sage-grouse during the early brood rearing period: Report of a pilot project



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Introduction

The range-wide decline of Greater Sage-grouse (*Centrocercus urophasianus*; Sage-grouse hereafter) is likely explained by a variety of interacting factors. Research suggests that Sage-grouse population viability largely depends on chick recruitment into the adult cohort, a population constraint that appears to be common for grouse worldwide (Connelly et al. 2011, Hannon and Martin 2006). Mortality of Sage-grouse is highest during the first two weeks of life, with cold weather, predation and lack of food, particularly invertebrate prey, as the primary causes of mortality (Hannon and Martin 2006).

Invertebrate prey is vital to chick survival (Johnson and Boyce 1990; see also discussion and references in Drut *et al.* 1994 and Thompson *et al.* 2006). Hens typically prefer brooding habitat with higher densities of invertebrates (Fischer *et al.* 1996). Additionally, invertebrate availability of Lepidoptera was positively related to brood survival in Nevada and Oregon (Gregg and Crawford 2007). Several studies (e.g., Sveum *et al.* 1998, Connelly and Braun 1997) point to low-quality brood-rearing habitat as a general limit to Sage-grouse populations, and low availability of invertebrate prey may be the primary factor. Furthermore, many proximate causes of chick mortality, such as succumbing to cold weather or predators, may result from poor body condition that is ultimately caused by low availability of invertebrate prey (Beckerton and Middleton 1982).

A large proportion of the diet of Sage-grouse chicks is invertebrates (Patterson 1952, Klebenow and Gray 1968, Johnson and Boyce 1990). Invertebrates provide a rich source of protein for rapidly-growing chicks. Previous studies found that chicks mainly eat ants (Formicidae, Hymenoptera), beetles (Coleoptera), and grasshoppers and crickets (Orthoptera; Patterson 1952, Klebenow and Gray 1968). Patterson (1952) collected Sage-grouse chicks widely within Wyoming and discovered that invertebrates were equally important in chick diets as forbs during the entire first two months of life (June and July). For example, 55% of the diet of one week old chicks was ants. In southeastern Idaho, most sage grouse-chicks (75-100%) ate invertebrates during the first month of life, and ants and beetles were the most common diet items (Klebenow and Gray 1968). Adult Sage-grouse also rely on the same prey taxa. In fact, adults eat invertebrates during May through September each year, and invertebrates account for 12% of their annual diet (Patterson 1952). In central Montana, 15% of Sage-grouse adults ate Hymenoptera, 27% ate Orthoptera, and 3% ate Coleoptera (Wallestad *et al.* 1975).

Throughout most Sage-grouse range, and especially in the high-elevation basins of Wyoming, the egg-laying and brood-rearing seasons are quite cold with frequent snow storms and little plant growth. Thus, protein for Sage-grouse is a limited resource and most of the available protein is invertebrates (Stiven 1961). The egg-laying and brood-rearing seasons are the times when protein requirements of sage grouse hens (producing eggs) and chicks (rapid growth) are at their highest (Beckerton and Middleton 1982). Invertebrates provide much more protein for foraging chicks than plants, even later in the brood-rearing season when primary production increases (Stiven 1961). The need for protein in late spring and early summer by Sage-grouse may be common among vertebrates in the Intermountain region.

Scientists and wildlife managers are well-aware that Sage-grouse need sagebrush and forbs in their diet (e.g., Huwer et al. 2008), and much effort has been committed to researching and mapping those resources. In contrast, the relationships between habitat characteristics and invertebrate prey, especially early in the brood-rearing period, have received little attention. Land managers, wildlife managers, policy makers and project planners/operators currently use a variety of Sage-grouse habitat maps in attempts to integrate Sage-grouse conservation with a suite of other important land uses. However, a major piece of the picture is missing; spatially-explicit models describing the availability of invertebrates vital to Sage-grouse during the early-brood rearing period.

We proposed to model and map the abundance and biomass of invertebrates available for Sage-grouse consumption during the early brood-rearing period as a function of landscape, climate and vegetation in the Greater South Pass Sage-grouse Core Area of Wyoming. Our primary goals are to provide insight into invertebrate availability during a season when invertebrates are a critical resource to Sage-grouse, and to express that knowledge in map form for direct application by conservationists, land and wildlife managers, and resource developers. By developing the information we will fill critical gaps in both ecological knowledge and management effectiveness. Our objective is to investigate relationships between the availability of invertebrate prey needed by Sage-grouse as a function of vegetation during the early brood-rearing season.

This report describes a pilot project that we carried out to develop methods for sampling invertebrate abundance and biomass, and various vegetation features, in sagebrush-dominated vegetation in the Greater South Pass Core Area of Wyoming. We will use the information from this pilot project to design and conduct a larger project in the same area.

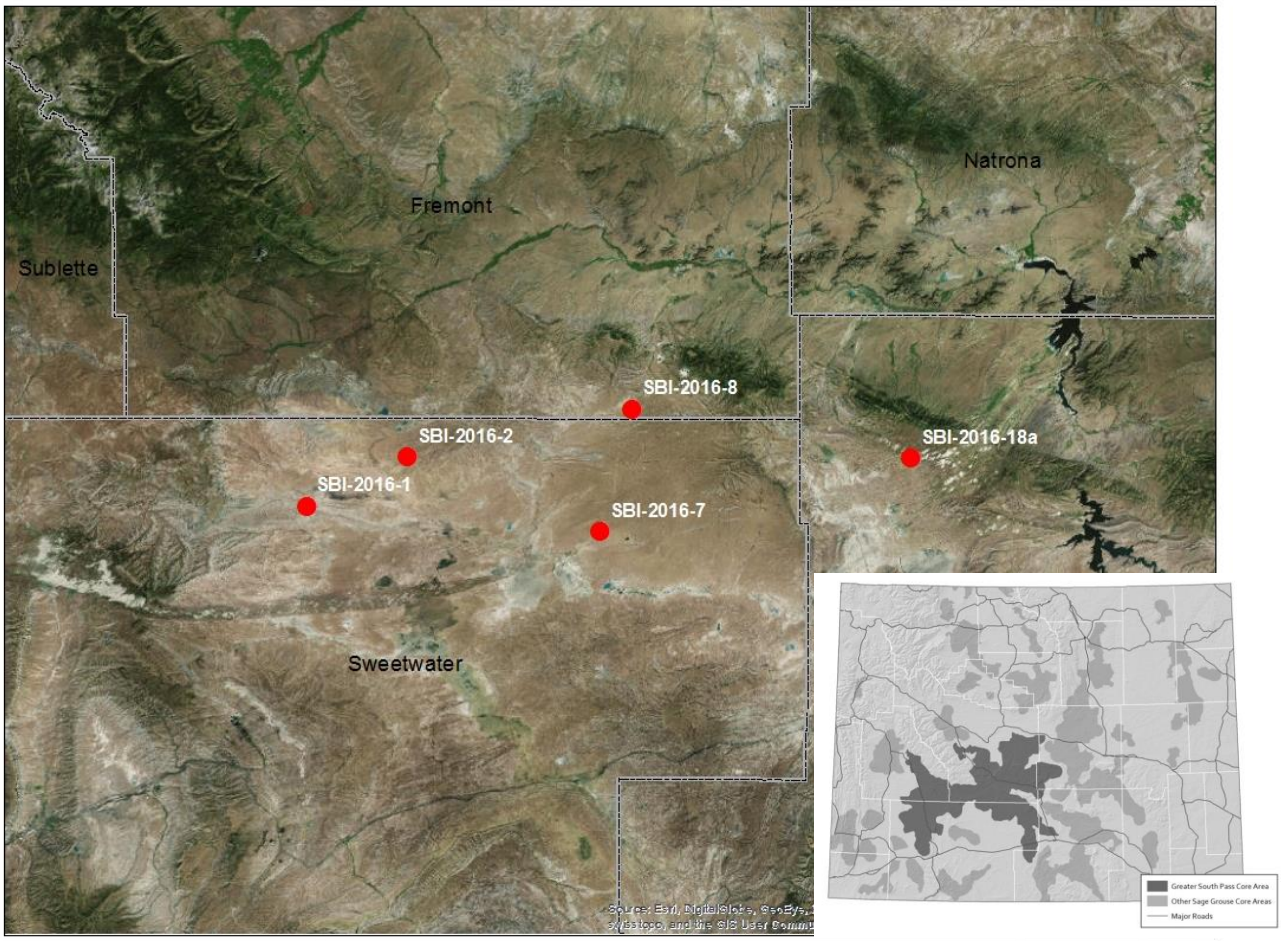

Figure 1. Inset map showing the Wyoming Sage-grouse core areas with the Greater South Pass Core Area where our study occurred in dark gray. The red points indicate the sites where we measured vegetation structure and invertebrate availability.

Methods and Study Area

Study Area

We conducted the study in the Greater South Pass Core Area (Figure 1) identified by the State of Wyoming in its policy on management of Sage-grouse (Office of the Governor 2011). The specific areas that we studied within the Greater South Pass Core Area were chosen after examining the range in climate variables, elevation and vegetation types in the area. We selected potential sampling sites in a stratified-random manner within the core area.

Field Methods

Selection of Sampling Sites

We stratified the Greater South Pass Core Area based on the dominant land cover types using the GAP Ecological Systems layer (Davidson *et al.* 2009). About 20 locations were randomly placed on public land using a spatially-balanced method to allocate them proportionally to the area occupied by each of the major land-cover types. One plot comprised a 30 m by 30 m cell corresponding to a cell in the Ecological Systems layer.

Plot Characterization

At each site, we marked out the corners of a plot within which we collected our data. Following the method of Herrick *et al.* (2016), we recorded information to characterize the physical setting of the plot. Within each plot, we laid out parallel transects with a reel tape stretched taut and anchored at each end. We also marked out the corners of three microplots measuring 5 m X 5 m. We recorded the coordinates of the plot, but did not permanently mark the plot, transects, or microplots.

Invertebrate Sampling

We estimated the availability of invertebrates using five different collection methods: shrub samples, litter samples (Figure 2A), ant mound counts (Figure 2B, C), flushing grasshoppers (Figure 2D) and pit fall traps (Figure 2E). Grasshopper and ant mounds were counted in the entire plot, and shrubs, litter and pit fall traps were collected in three microplots (5 m x 5 m) randomly placed in each plot. We counted ant mounds and grasshoppers by walking transects 3 m apart, immediately after marking out the plot (Beever and Herrick 2006). Walking transects flushed grasshoppers for easy counting. To estimate the availability of invertebrates living in shrubs, we selected one shrub in each of two microplots and three shrubs in the remaining microplot to sample. We placed a bag over each sagebrush plant and cut the stem. Ethanol was poured over the shrub, and the black bag was sealed, hung and placed in the sun for at least two hours. We struck the main stem of the sagebrush with a hammer 20 times to dislodge invertebrates and we collected the material in the bottom of the bag for analysis. We measured three dimensions (width, depth and height) of each shrub to estimate area and volume of the canopy (see vegetation measurements for more detail) to investigate relationships between invertebrate availability and shrub characteristics. To measure availability of invertebrates in the litter layer, we collected litter samples from under each sagebrush sampled using a 43 cm x 43 cm frame with 1 mm^2 mesh sewed over the top to inhibit invertebrates from escaping (modified from Ausden and Drake 2006). Finally, we collected invertebrates at one site using pit fall traps left over night for comparison with the other methods. We identified, counted and measured dry mass of all invertebrates in the laboratory.

To estimate the availability of invertebrates, we analyzed pitfall, litter and shrub samples. We considered invertebrates collected using these methods as available for Sage-grouse to eat. Invertebrates were separated from debris and identified to family using a dissecting microscope and

available keys. All invertebrates were counted and weighed to estimate biomass. To calculate abundance in pitfall traps, we counted the number of invertebrates per trap. To estimate invertebrate density in litter, we counted the number of individuals per sample and calculated the density (ind/m^2). For shrub sampling, we calculated the density of invertebrates based on shrub area (width x depth; ind/m^2). We measured dry mass by leaving invertebrates in a drying oven for 24 hours at 40˚C. We left samples in a desiccator for 1 hour before weighing samples on a four-place balance.

Vegetation Characteristics

For collecting data about percent plant canopy cover, percent litter cover, and percent ground cover, we used the point-intercept method at points on each of the transects (Figure 2F). Plant heights were measured at different points along the transects. A plant species list was made from the point-intercept data augmented by a search of the entire plot. We identified plants to species when possible; for those that we could not, we collected specimens for determinations later. The methods of Herrick *et al.* (2016) are the basis for collecting all of these data.

One person did the sampling along the transects and conducted the inventory of plant species in the plot.

1. Percent plant canopy cover was sampled using the point-intercept method, with the sample points 100 cm apart along the transects. At each point, a wire 1.5 mm in diameter (the wire on a pin flag) was lowered to the ground, with the wire held as nearly vertical as possible and allowed to fall to the ground without being guided by the observer. The identities of the plants that the wire touched were recorded in the order they were touched, from highest to lowest.

Each intercepted plant was recorded as alive or dead. Live plants were those that were rooted and had produced live tissue in the year of measurement they included parts of perennial herbaceous plants or of woody plants that supported live canopy, even if the part of the canopy touched by the pin appeared to be dead. Dead plants were those that did not appear to have produced live tissue during the year of measurement. If the same species of plant was intercepted 2 or more times at a point, only one intercept was recorded; and if both live and dead canopies of the same species were intercepted at a point, only the live intercept was recorded.

For sampling plant canopies so tall that the observer could not look down on them, 2 or more wires were taped together and the observer attempted to hold the wire vertically over the point on the tape and to raise it straight up.

2. Percent litter cover was sampled using the same intercept points as were used for plant canopy cover. Herbaceous litter consisted of detached plant parts $\leq$ 5 mm in diameter, and dung. Woody litter consisted of detached plant parts >5 mm in diameter.

3. Percent ground cover was measured with the same intercept points as were used for plant canopy cover and litter. Ground cover was the material that the pin intercepted at the soil surface, and consisted of these seven categories: plant base (living or dead plant material rooted in the soil); cyanobacterial crust; moss; lichen attached to the soil; vagrant lichen; rock (fragments > 5 mm in diameter but not apparently continuous beneath the plot); bedrock (rock that appeared to be continuous beneath the plot); and bare soil (including rock fragments $\leq$ 5 mm in diameter).

Figure 2. A.) Collecting a litter sample under a cut sagebrush. B.) Harvester and C.) Thatching ant mounds were counted in plots as well as D.) grasshoppers flushed from vegetation. E.) We collected invertebrates using pitfall traps in one plot. F.) Vegetation was measured along transects within each plot.

4. Heights of herbaceous and woody plants were measured at points 200 cm apart along each transect and lying 15 cm to one side of the transect. The points lay 15 cm from the the right edge of the tape, looking from the beginning of the transect (the 0 point on the tape) to the end. At each point, a rod was held vertically, and a 15-cm long plastic rule was turned around the rod to describe a cylinder 30 cm in diameter, centered on the point and extending upward from the ground surface. The heights of the tallest herbaceous plant part and of the tallest woody plant part within the cylinder were recorded. The plants did not have to be rooted in the cylinder.

Heights were measured as the perpendicular distance (relative to the Earth's center) from the soil surface at the point (i.e., at the center of the cylinder), regardless of the slope or the unevenness of the ground. Plant parts were not straightened or held upright for the measurements. Heights up to 2 meters tall were recorded to the nearest centimeter; heights taller than 2 meters were recorded to the nearest 30 cm. The identity of each measured plant was recorded, and it was noted as being alive or dead.

5. Shrub volume was calculated from measurements taken on each of the four shrubs that were selected in each microplot for measuring shrub height. Three measurements were made on each shrub: the thickness of the canopy (the distance between the bottom and the top of the canopy), the length the canopy (measured along the longest axis), and the width of the canopy (measured along the axis perpendicular to the longest axis). Volume was calculated as the product of canopy thickness, length, and width.

6. Shrub density was estimated from counts of the numbers of shrubs rooted in each of the microplots. The identity of each shrub was recorded, and each was tallied by 10-cm height interval.

7. Plant species richness. All of the plant species noted during a systematic search of the plot were recorded. The observer started at one corner of the plot, and walked a pattern of parallel lines, with each line parallel to one side of the plot and the lines 3 m to 5 m apart (lines were closer together in plots with denser vegetation). The observer took care to look beneath shrub canopies.

Data Analysis

Invertebrate availability

We calculated the density, biomass and richness of invertebrates collected with each method in each plot using the Program R and the packages plyr, matrix and vegan.

Vegetation Characteristics

1. Percent plant canopy cover

Percent plant canopy cover was estimated as the proportion of the intercept points at which plant canopy was intercepted at any level. For each plot, we estimated three percent-cover values: cover of herbaceous plants, of woody plants, and of all plants. Each estimate was calculated using all of the intercept points in the plot (that is, the points from all the transects in a plot were combined for the calculation).

For each category of canopy cover (total, herbaceous, and woody), we tested for significant differences among the plots in the proportions of points with canopy cover, using a normal approximation of a chi-square contingency test (Zar 2010, section 24.13). This test treats the data as a dichotomous variable and tests the hypotheses:

H_0: The proportions of canopy cover from all 5 plots are the same.
H_A: The proportions of canopy cover from all 5 plots are not the same.

When this test showed a significant difference among the plots, we used a Tukey-type multiple comparison test (Zar 2010, section 24.14a) to see which plots differed significantly from the others. Details of both types of test are given in Appendix 1.

2. Percent litter cover

Percent litter cover was estimated as the proportion of the intercept points in the plot at which plant litter was intercepted at any level. We examined total litter cover, herbaceous litter cover, and woody litter cover separately. As with plant canopy cover, we used a normal approximation of a chi-square contingency test to look for differences among the five plots, and a Tukey-type multiple comparison test to see which plots differed from the others. Details are in Appendix 1.

3. Percent ground cover

Percent ground cover for a given category was estimated as the proportion of the intercept points in the plot at which each type of ground cover was intercepted. Because only bare soil was intercepted at more than a few points, we did not test for statistical differences among the plots.

4. Height of herbaceous plants

Mean height of the herbaceous plants in a plot was calculated from the values measured at all of the points in the plot (i.e., not from per-transect estimates), with the "AVERAGE" function in Microsoft® Excel® 2013. We also calculated the sample standard deviation for the plot (using the "STDEV.S" function).

5. Height of woody plants

Mean height of the woody plants in a plot was calculated in the same manner used for height of the herbaceous plants.

6. Shrub density

The mean and standard deviation of the shrubs were calculated from the data collected in the three microplots.

Relationship between invertebrates and vegetation

We used Principal Component Analysis (PCA) and model selection to estimate the relationships between invertebrate availability and vegetation characteristics. Before analysis, we identified variables that were highly correlated (>0.8) using Spearman's Rank correlations and we retained one of the highly correlated variables in subsequent analyses. PCA was used to visualize relationships among variables and was done in R using the package factoextra. We used Akaike information criterion with the small sample size correction (AICc) to select the vegetation characteristics that best explained invertebrate density, biomass and richness, ant mound counts and grasshopper density using the package AICcmodavg in R. We used our knowledge of invertebrates, vegetation and the ecosystem to make a priori models including a full model (all vegetation variables included) and a null model (no variables). The model with the smallest AICc value was the model that best explained the invertebrate characteristic.

Results

Plot Setting

We sampled five plots in the South Pass Sage-grouse Core Area of Wyoming (Figure 1) in late May and early June 2016 (Table 1). The plots lay at elevations between 2020 and 2154 meters. Aspect varied among the plots. Most plots were on gentle slopes and one (SBI-2016-18a) was in a swale between sand dunes. Figure 3 shows the variation in the height and density of sagebrush among the plots.

Table 1. Sampling dates, coordinates, and settings of sample plots.

Plot ID	Visit Date (2016)	Latitude (NAD83)	Longitude (NAD83)	Elev. (m)	% Slope	Aspect, degrees (true N)	Landscape Position	Shape Across Slope	Shape Down Slope
SBI-2016-1	05/31	42.11544	108.63403	2121	2	27	Backslope	Linear	Linear
SBI-2016-2	06/01	42.19822	108.40631	2020	3	246	Flat	Concave	Linear
SBI-2016-7	06/02	42.07346	107.97102	2138	12	188	Backslope	Convex	Convex
SBI-2016-8	06/02	42.27764	107.89781	2154	3	72	Alluvial Fan	Concave	Concave
SBI-2016-18a	06/03	42.19580	107.26772	2097	1	270	Swale Between Dunes	Concave	Concave

Invertebrates

We collected 26 families of arthropods in eight orders of insects and arachnids. The invertebrate order Hemiptera (true bugs; 537 individuals/m^2 of plot area) was most dense followed by Hymenoptera (bees, wasps and ants; 143 ind/m^2), Coleoptera (beetles; 143 ind/m^2) and Arachnida (spiders; 70 ind/m^2). The most abundant families of invertebrates were Cicadellidae (leafhoppers; 266 ind/m^2), Formicidae (ants; 119 ind/m^2), Psyllidae (jumping plant louse; 101 ind/m^2) and Rhopalidae (scentless plant bugs; 97 ind/m^2). Invertebrate densities ranged between 69 to 730 individuals/m^2 in our plots when we combined shrub samples, litter samples and grasshopper counts. Arachnids (0.02 g/m^2) had much lower biomass compared to insects. The insect order Hymenoptera (bees, wasps and ants; 7.1 g/m^2) had the highest biomass followed by Coleoptera (beetles; 3.6 g/m^2), Lepidoptera (butterflies and moths; 0.14 g/m^2) and Hemiptera (true bugs; 0.13 g/m^2). The families with the highest biomass were Formicidae (ants; 6.8 g/m^2), Tenebrionidae (darkling beetles; 2.1 g/m^2), Curculionidae (weevils; 0.3 g/m^2) and Carabidae (carabid beetles; 0.2 g/m^2). Invertebrate biomass ranged between <1 g/m^2 to 10 g/m^2.

The density of invertebrates we collected depended on the type of sample. Invertebrates were more abundant in sagebrush (373 ind/m^2) and litter samples (184 ind/m^2) compared to grasshopper counts (<0.1 ind/m^2). Hemiptera were most dense on sagebrush (524 ind/m^2) followed by Arachnida (55 ind/m^2), Hymenoptera (40 ind/m^2) and Coleoptera (38 ind/m^2). Invertebrate density and biomass in litter samples varied among plots with the highest values in the plots with basin big sagebrush (Plot 18a; Figure 4A, B). Hymenoptera (712 ind/m^2) were most dense in litter samples followed by Coleoptera (128 ind/m^2) and Arachnida (25 ind/m^2). We counted between 0 and 4 ant mounds in each plot (0-0.006 mounds/m^2; harvester and thatching ants; Figure 4C), but ant mounds may be home to hundreds to thousands of individuals. Grasshopper density was low in all plots (Figure 4D). We collected 16 invertebrates on average in each pitfall trap, but we cannot calculate the density of invertebrates collected in these traps because a quantitative area was not sampled. Hymenoptera (15 individuals;

primarily Formicidae) were the most abundant invertebrates in pitfall traps followed by Coleoptera (6 individuals) and Diptera (4 individuals).

The biomass of invertebrates we collected depended on the type of sample. Invertebrates had higher biomass in litter (2.6 g/m^2) than in sagebrush samples (1.5 g/m^2). Coleoptera had the highest biomass on sagebrush (2.1 g/m^2) followed by Hymenoptera (0.6 g/m^2) and Hemiptera (0.1 g/m^2). Hymenoptera (10.9 g/m^2) had the highest biomass in litter samples followed by Coleoptera (2.1 g/m^2) and Lepidoptera (0.1 g/m^2).

Figure 3. The five plots that were measured for invertebrate availability and vegetation characteristics.

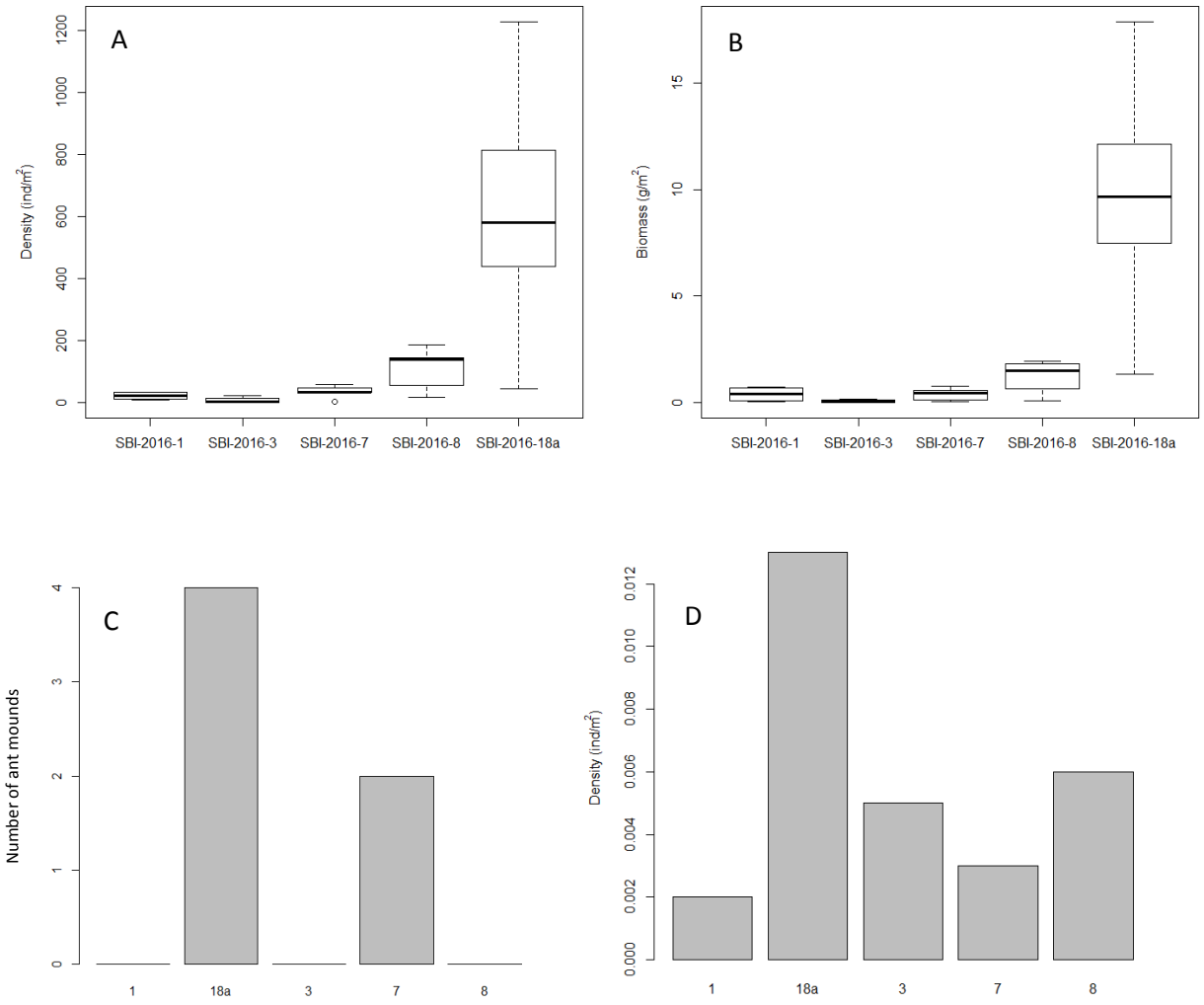

Figure 4. A.) Density and B.) biomass of invertebrates collected in litter samples among plots. C.) The number of ant mounts observed among plots and D.) the density of grasshoppers.

Vegetation

Because this was a pilot project, we tried several different combinations of plot size, number of transects, and lengths of transects (Table 2) to determine how long the sampling would take and how useful the data would be.

Table 2. Dimensions of the plots and numbers of sampling transect, points, and microplots.

Plot ID	Plot Dimensions (m)	# Transects	Transect Length (m)	# Points / Transect	# Intercept Points In Plot	# Height Points In Plot	# Micro-plots[1]
SBI-2016-1	25 x 25	2	25	25	50	17	3
SBI-2016-2	25 x 25	2	25	25	50	27	3
SBI-2016-7	25 x 25	3	25	25 (23)[2]	73	35	3
SBI-2016-8	25 x 25	3	25	25	75	36	3
SBI-2016-18a	15 x 25	3	15	15	45	21	3

Notes:

1. Each microplot measured 5 m x 5 m.
2. In plot SBI-2016-7, two transects had 25 points each and one transect had just 23 points.

Species Composition

All five plots were in sagebrush steppe vegetation. Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) was the dominant sagebrush in four plots, and basin big sagebrush (*A. tridentata* ssp. *tridentata*) dominated the fifth (Table 3).

Grasses generally shared dominance with shrubs (in terms of canopy cover), although the plot with the basin big sagebrush canopy had almost no grass cover. The common grasses among all plots were Sandberg bluegrass (*Poa secunda*), western wheatgrass (*Pascopyrum smithii*), Indian ricegrass (*Achnatherum hymenoides*), and an unidentified bunchgrass (possibly also *A. hymenoides*) in one plot. Forbs were minor components of the vegetation, although they were more common than were grasses beneath the tall basin big sagebrush canopy in plot SBI-2016-18a.

In every plot, the list of plants from the inventory of the entire plot shows that the number of intercept points that we used is insufficient to document species richness. The inventory revealed at least as many additional species in each plot as were found at the intercept points, and in two plots, the number of additional species was over twice the number of species from the intercept points.

Table 3. Plant species in plots. Each cell shows the number of times a species was intercepted at the intercept points in a plot. Empty cells indicate that a species was not found in a plot. "x" indicates that a species was noted during the inventory but was not encountered at the intercept points.

Plots ----->	SBI-2016-1	SBI-2016-2	SBI-2016-7	SBI-2016-8	SBI-2016-18a	All Plots
# intercept points ----->	(n=50)	(n=50)	(n=73)	(n=75)	(n=45)	(n=293)
SHRUBS						
Artemisia pedatifida	1					1
Artemisia tridentata ssp. *tridentata*					25	25
Artemisia tridentata ssp. *wyomingensis*	6	19	8	23	1	57
Atriplex gardneri	x					
Chrysothamnus viscidiflorus	x	3	1		x	4
Ericameria nauseosa		3			x	3
Gutierrezia sarothrae	x		1			1
Krascheninnikovia lanata	x		1			1
Linanthus pungens		x	1	x		1
Picrothamus desertorum	x					
Tetradymia sp.	x					
All Shrubs, Intercepts	7	25	12	23	26	

Table 3 (continued).

Plots ----->	SBI-2016-1	SBI-2016-2	SBI-2016-7	SBI-2016-8	SBI-2016-18a	All Plots
# intercept points ----->	(n=50)	(n=50)	(n=73)	(n=75)	(n=45)	(n=293)
GRAMINOIDS, PERENNIAL						
Achnatherum hymenoides	3		3			6
Achnatherum sp.?		5		13		18
Elymus elymoides	1	x		1	x	2
Elymus lanceolatus var. *lanceolatus*	1					1
Hesperostipa comata					1	1
Pascopyrum smithii		5	1	3		9
Poa cusickii var. *pallida*				1		1
Poa secunda var. *secunda*	8	7		12		27
All Graminoids, Intercepts	13	17	4	30	1	
FORBS, PERENNIAL						
Agoseris sp.				1		1
Antennaria dimporpha?				x		
Antennaria microphylla?		1		x		1
Astragalus purshii	x			x		
Boechera retrofractra	x		x	x	x	
Castilleja sp.				x		
Cryptantha ambigua?			x		1	1
Cryptantha watsonii?		x		1		1
Delphinium bicolor					x	
Dieteria canescens var. *canescens*			x			
Eremogone hookeri	x		x			
Eriogonum caespitosum				x		
Eriogonum ovalifolium var. *ovalifolium*	x		x			
Eriogonum ovalifolium var. *purpureum*				x		
Erysimum capitatum	x				x	
Leptosiphon septentrionalis				x		
Lomatium orientale				x		
Mertensia sp.					x	
Opuntia polyacantha	x		1	x	x	1
Packera sp.		x				
Penstemon angustifolius var. angustifolius	x					
Phlox hoodii	x	x	x	x		
Phlox muscoides			x			
Sedum lanceolatum					x	
Sphaeralcea coccinia			x			
Townsendia sp.	x					
Transberingia bursifolia?					x	
Trifolium gymnocarpon				x		
All Perennial Forbs, Intercepts	0	1	1	2	1	

Table 3 (continued).

Plots ----->	SBI-2016-1	SBI-2016-2	SBI-2016-7	SBI-2016-8	SBI-2016-18a	All Plots
# intercept points ----->	(n=50)	(n=50)	(n=73)	(n=75)	(n=45)	(n=293)
FORBS, ANNUAL						
*Alyssum desertorum**		x		1	x	1
Camissonia pusilla				x		
Collinsia parviflora					x	
Descurainia pinnata var. *nelsonnii*		x			1	1
Draba nemorosa					4	4
Gayophytum decipiens		x		4	x	4
Gymnosteris parvula				x		
Mimulus sucksdorfii				x		
All Annual Forbs, Intercepts	0	0	0	5	5	
# species from intercepts	6	7	8	10	6	37
# additional spp from inventory	15	8	8	16	13	60

* exotic species

Plant Canopy Cover

Plant canopy cover differed substantially among the five plots, from >75% cover in SBI-2016-2, SBI-2016-8, and SBI-2016-18a, to <30% in SBI-2016-7 (Figure 5). Shrub cover exceeded herbaceous-plant cover in three of the plots, especially in SBI-2016-18a, which had an overstory of tall basin big sagebrush (see below).

Comparisons revealed significant differences ($p < 0.05$) among the plots in total canopy cover, herbaceous canopy cover, and woody canopy cover. Pairwise comparisons of plots for total cover showed that plots SBI-2016-1 and SBI-2016-7 had significantly less total canopy cover than did the other three plots. Pairwise comparisons for herbaceous canopy cover showed a complicated pattern of differences: plots SBI-2016-8 and SBI-2016-2 had significantly more herbaceous canopy than plots SBI-2016-7 and SBI-2016-18a; but differences among SBI-2016-1 and other plots, and among SBI-2016-18a and other plots, were complicated. For woody canopy cover, the pairwise comparisons also showed a complicated pattern: woody cover was significantly greater in plots SBI-2016-18a and SBI-2016-2 than in plots SBI-2016-1 and SBI-2016-7, but cover in plot SBI-2016-8 was not significantly different from either of those groups of two plots. These complicated relationships probably resulted from the pairwise test having too little power to discern some differences in this data set. Details about the statistical tests on canopy-cover data are shown in Appendix 1.

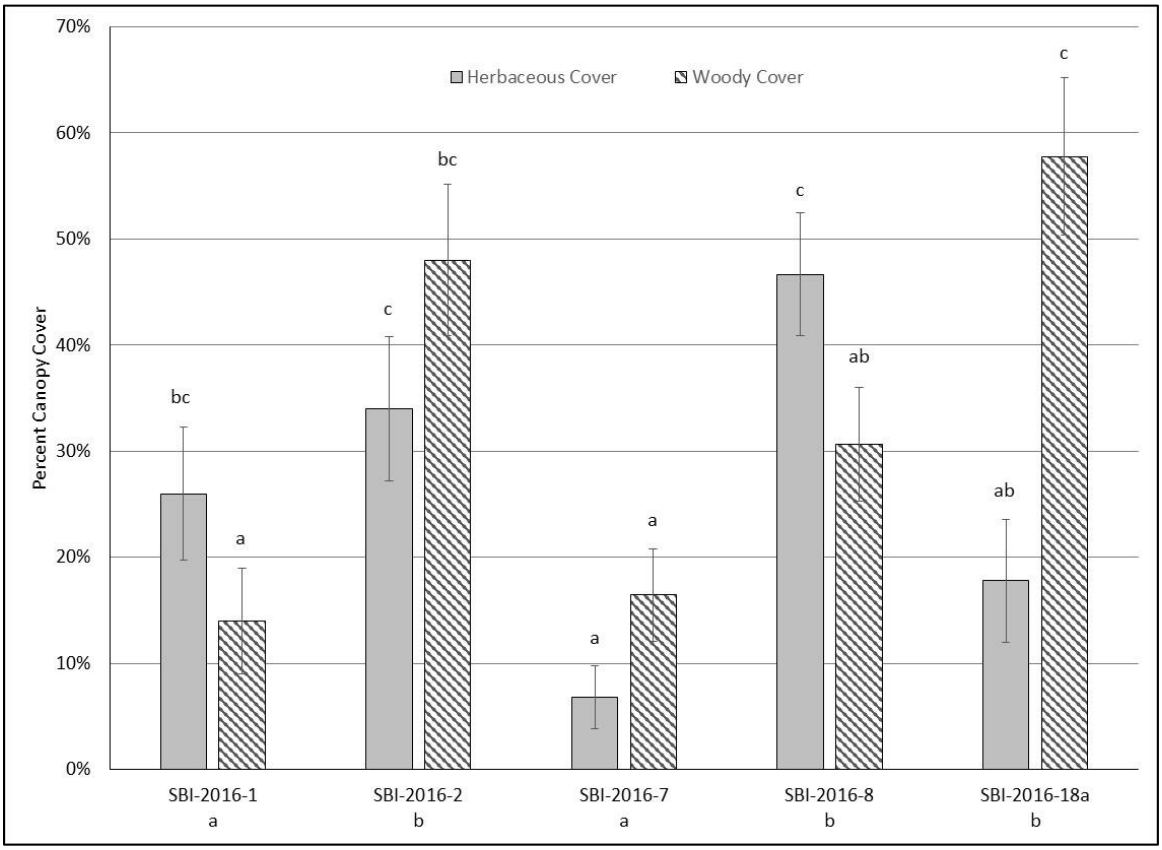

Figure 5. Percent canopy cover of herbaceous plants and woody plants. Bars are percentages of all intercept points in each plot. Error bars are standard deviations. Letters indicate results of pairwise comparisons of plots for herbaceous canopy cover (above herbaceous bars), woody canopy cover (above woody bars), and total canopy cover (beneath plot numbers); plots with different letters differ significantly (p=0.05) in that type of canopy cover.

Shrub Density

Shrub density was estimated from counts of plants in microplots at three of the plots (Figure 6). Estimates ranged from 1.5 to > 2.5 shrubs/m^2, but there appears to be little difference among the three plots. Comparison of the density data with the list of species documented at the intercept points and in the plot inventory (Table 2) shows that counts of shrubs in three microplots per plot failed to document all of the shrub species present.

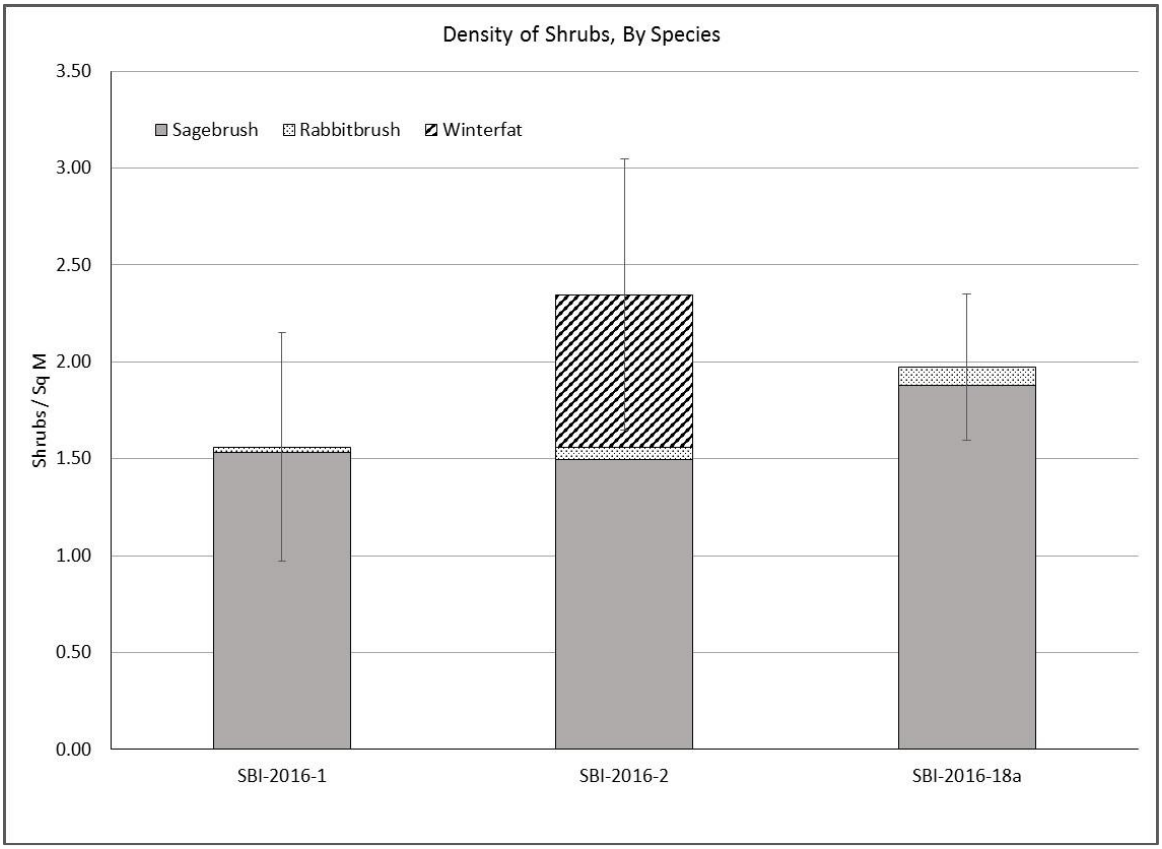

Figure 6. Density of shrubs in plots. Shrub density was not estimated for plots SBI-2016-1 or SBI-2016-7. Each bar is the average from the 3 microplots in the plot. Error bars are standard deviation for all species.

Canopy Height

The vegetation that we sampled was generally short, with the shrubs and herbaceous plants averaging around 20 cm tall (Figure 7). Plot SBI-2016-18a was an exception, where basin big sagebrush formed an overstory 1.2 meters tall.

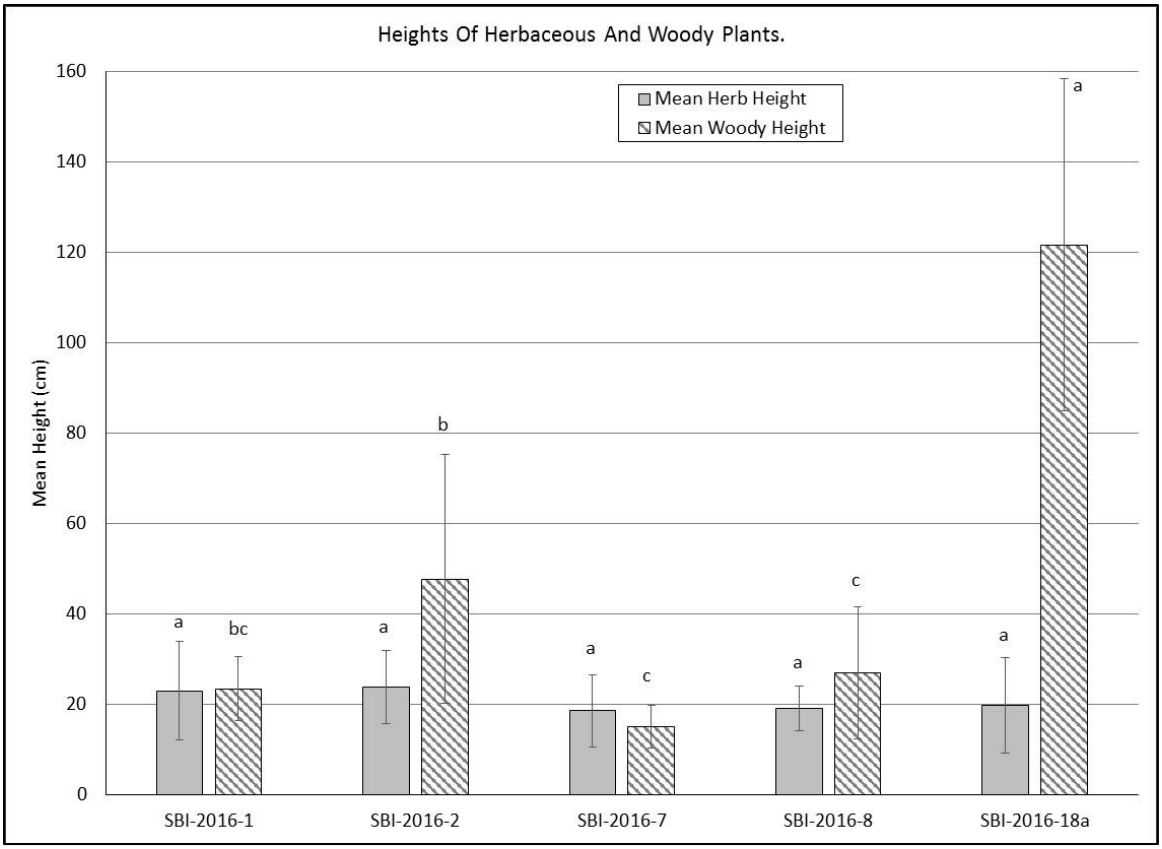

Figure 7. Heights of Herbaceous Plants and Woody Plants Measured Along Transects. Bars are means from the points in each plot. Error bars are standard deviations. Letters indicate results of pairwise comparisons of plots for herbaceous plant height (above herbaceous bars) and woody plant height (above woody bars); plots with different letters differ significantly (p=0.05) in that type of plant height.

One-way analysis of variance showed that woody plant height differed significantly ($p < 0.05$) among the plots, but herbaceous height did not. A comparison of means showed that woody plants were significantly taller ($p < 0.05$) in plot SBI-2016-18a than in the other four plots (Figure 4), that woody plants were significantly taller in plot SBI-2016-2 than in plots SBI-2016-7 and SBI-2016-8, and that plot SBI-2016-1 did not differ significantly from these latter three plots. The complicated pattern of differences among the four plots other than SBI-2016-18a resulted from the comparison of means test lacking sufficient power for this dataset. Details of the statistical analysis are shown in Appendix 1.

Litter Cover

The amount of plant litter cover varied substantially among the plots, from < 20% in SBI-2016-1 to > 90% in SBI-2016-18a (Figure 8). In all plots, the litter was predominantly from herbaceous plants, and it was the herbaceous litter that varied so much among plots. The amount of woody litter was more uniform from plot to plot.

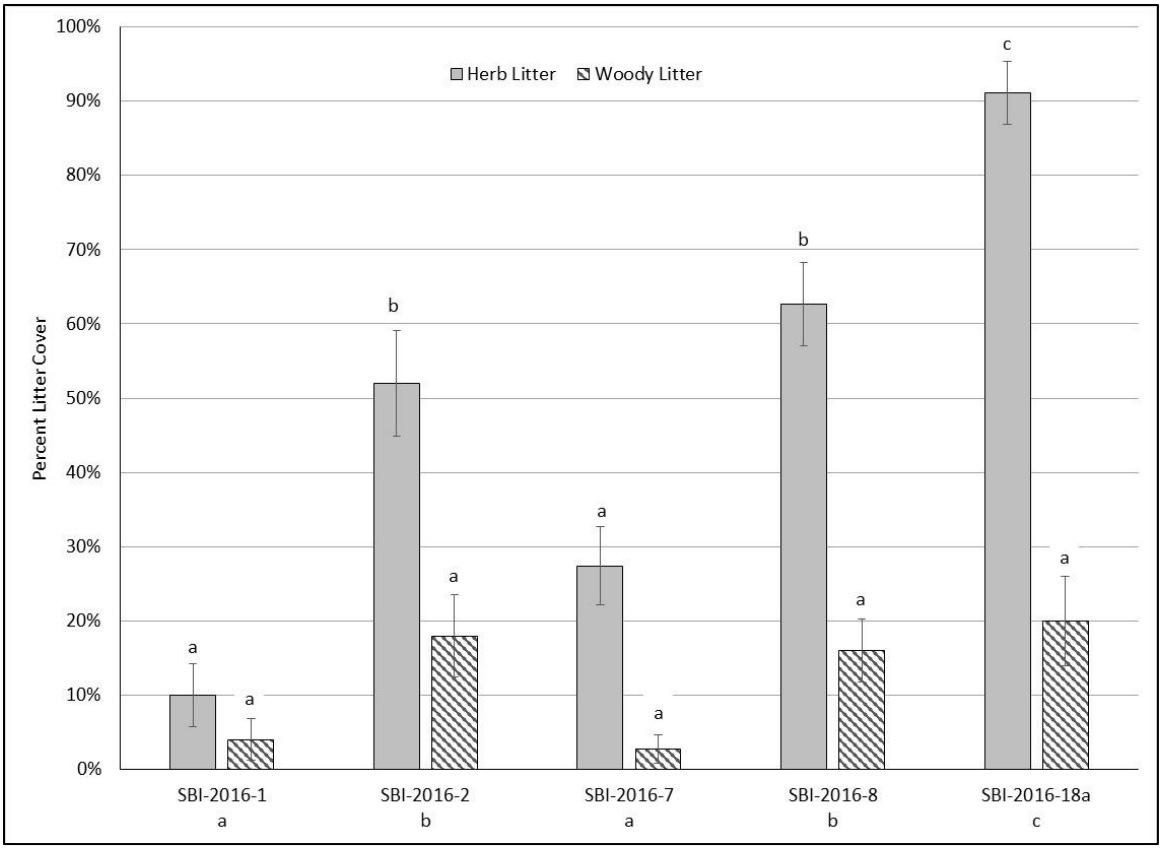

Figure 8. Percent cover of plant litter in plots. Bars are percentages of all intercept points in each plot. Error bars are standard deviations. Letters indicate results of pairwise comparisons of plots for herbaceous litter cover (above herbaceous bars), woody litter cover (above woody bars), and total litter cover (beneath plot numbers); plots with different letters differ significantly (p=0.05) in that type of litter cover.

Total litter cover, herbaceous litter cover, and woody litter cover differed significantly among the plots ($p < 0.05$). For total litter cover and herbaceous litter cover, pairwise comparisons showed that both were significantly greater in plot SBI-2016-18a than in the other plots, and significantly less in plots SBI-2016-1 and SBI-2016-7 than in the other plots (Figure 5). For woody litter cover, though, pairwise comparisons could not find significant differences between pairs of plots; the multiple-comparison test was powerful enough to show a significant difference among all the plots, but the pairwise-comparison test was not powerful enough to find significant differences between pairs of plots.

The details of the statistical tests on litter are shown in Appendix 1.

Ground Cover

Bare soil was by far the predominant type of ground surface in each plot (Figure 9). Lichen, moss, and rock were each recorded in only one plot, and plant bases in three plots. Due to the overwhelming amounts of bare soil in all five plots, no statistical tests were done on differences among plots in ground-cover.

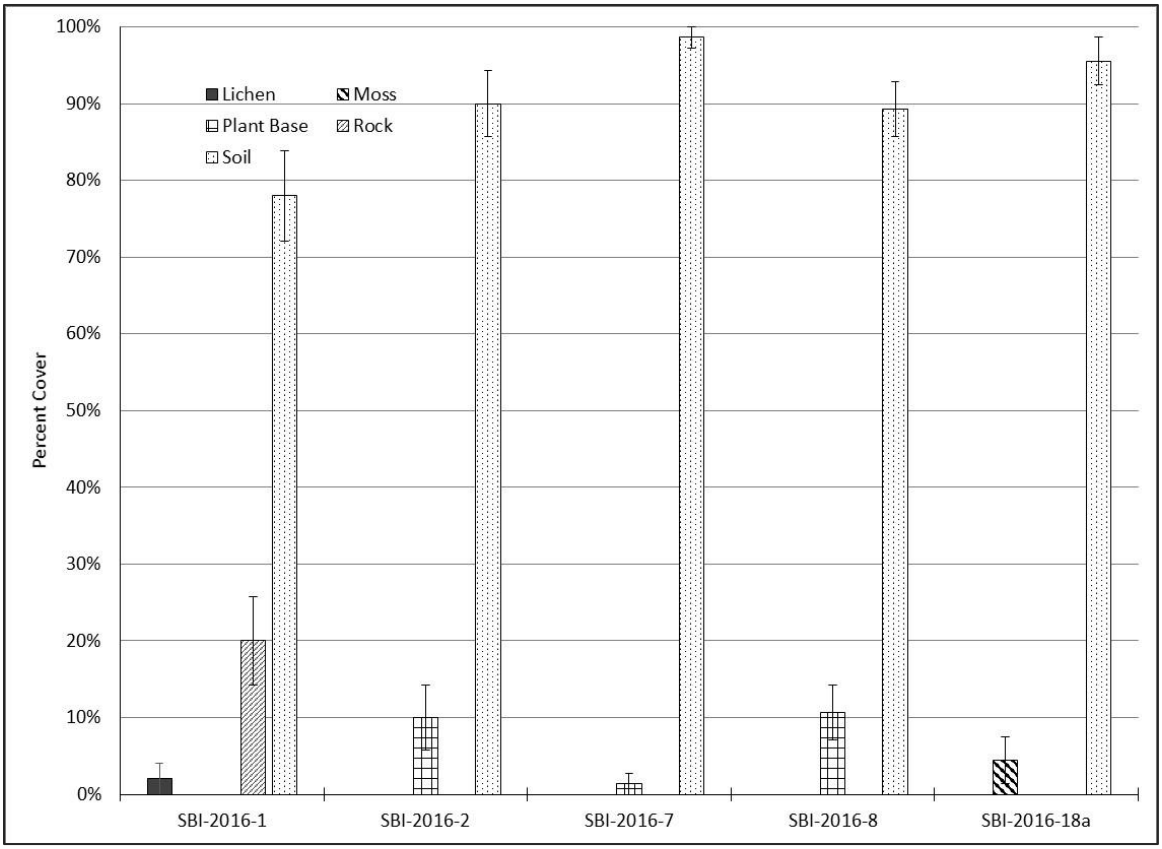

Figure 9. Percent cover by different categories of ground cover. Bars are percentages of all intercept points in each plot. Error bars are standard deviations.

Relationships between invertebrates and vegetation characteristics

Invertebrate availability was strongly (≥0.8) correlated with several vegetation characteristics. Invertebrate density was positively correlated with total canopy cover, woody canopy cover, litter cover, woody litter cover and shrub height. Invertebrate biomass was positively related to shrub area, shrub volume, woody canopy cover, all three litter cover measures and shrub height. Total canopy cover, woody canopy cover, litter cover, woody litter and shrub height were positively correlated with invertebrate richness. The two vegetation characteristics that most strongly correlated with the number of ant mound in a plot were the mass of litter (0.67) and herb canopy cover (-0.78), although none of the vegetation characteristics were strongly correlated with the number of mounds. Finally, grasshopper density was positively correlated with shrub area, shrub volume, woody canopy cover, all measures of litter cover and shrub height.

Most of the variation (68.5%) in our data was explained by dimension 1 using PCA (Figure 10). We removed shrub volume (correlated with shrub area), herbaceous canopy cover (correlated with total canopy cover), and herbaceous and woody litter cover (correlated with total litter cover) from the analysis. Dimension 1 separated plots by shrub height, shrub area, litter mass, woody canopy cover, litter cover and herbaceous height. Dimension 2 explained 31.5% of the variation and separated plots primarily by shrub density, sagebrush density, winterfat density, total canopy cover and plant richness. Invertebrate density, biomass, richness and grasshopper density were strongly associated with dimension 1 whereas the number of ant mounds was associated with dimension 2. Plot 18a fell out on the left side of the plot because of the height of the canopy (basin big sagebrush), and plots 7 and 8

appeared on the right because of the shorter shrub heights and higher densities of rabbitbrush and winterfat.

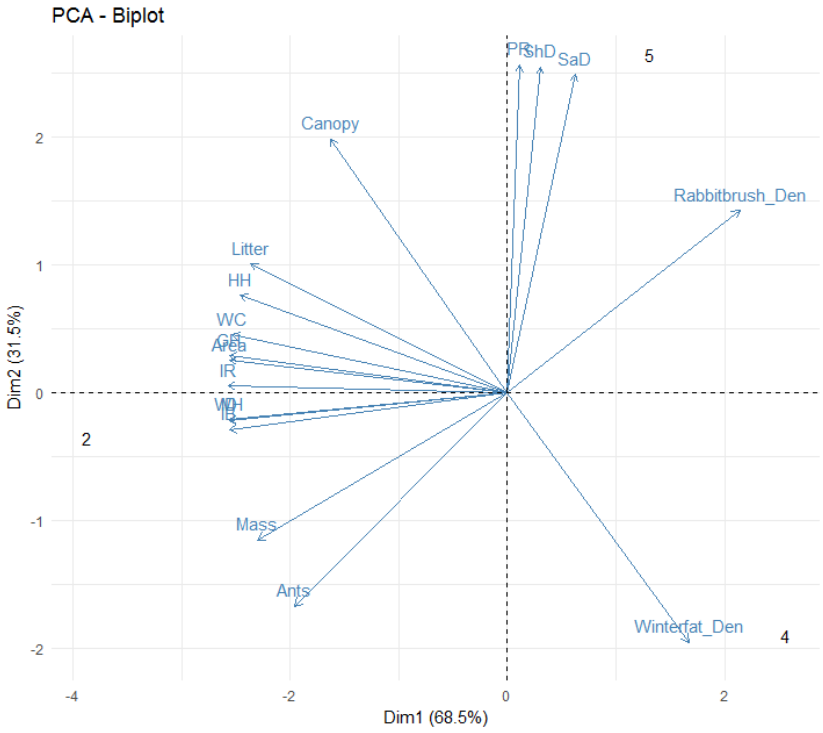

Figure 10. PCA plot showing the relationships between the vegetation and invertebrate metrics measured among plots.

Invertebrate characteristics were best explained using models with multiple variables (Table 4). Invertebrate density and invertebrate biomass were explained by a top model (AICc weight >0.90). The models that explained the most variation in invertebrate density all had a measure of shrub area or volume and litter cover. The best models that explained invertebrate biomass shared the variables shrub area or volume, litter cover and herb height. Shrub area or volume, litter cover and herb height were included in the top models explaining invertebrate richness. The number of ant mounds in plots were best explained by litter cover or mass, canopy cover and herb height. The top models explaining grasshopper density all included the variables shrub area or volume, litter cover and herb height.

Table 4. Top candidate models that explained invertebrate metrics.

Top Models	AICc	ΔAICc	AICc Weight
Invertebrate Density			
Shrub area+litter mass+canopy cover+woody cover+litter cover+herb height	-311.02	0	0.93
Shrub area+litter cover+woody height+herb height+plant richness	-304.03	6.99	0.03
Shrub volume+litter cover+plant richness+woody cover	-303.58	7.44	0.20
Invertebrate Biomass			
Shrub volume+canopy cover+woody cover+litter cover+herb height	-361.95	0	0.95
Shrub area+litter cover+woody height+herb height+plant richness	-355.40	6.55	0.04
Invertebrate Richness			
Shrub area+litter cover+woody height+herb height+plant richness	-345.94	0	0.87
Shrub volume+canopy cover+woody cover+litter cover+herb height	-341.11	4.83	0.08
Shrub area+litter mass+canopy cover+litter cover+herb height	-340.23	5.71	0.05
Number of Ant Mounds			
Shrub area+Litter mass+canopy cover+litter cover+herb height	-357.50	0	0.54
Shrub volume+canopy cover+woody cover+litter cover+herb height	-357.02	0.48	0.42
Litter+canopy cover+litter mass+herb height	-352.21	5.29	0.04
Grasshopper Density			
Shrub area+canopy cover+woody canopy+litter cover+herb height	-427.12	0	0.58
Shrub volume+canopy cover+ woody cover+litter cover+ height	-425.02	2.09	0.20
Shrub area+litter cover+shrub height+herb height+plant richness	-424.07	3.05	0.13

Discussion

Invertebrates may be limiting to Sage-grouse chicks, especially during the first two weeks of life. Our intent was to measure vegetation characteristics so that we can identify the relationships between vegetation and the supply of invertebrate food to Sage-grouse during the early chick rearing period (first two weeks of June). Our results suggest that larger shrub area or volume on average, higher litter cover and taller herb height are vegetation characteristics that had higher invertebrate densities and biomass. Sage-grouse chicks eat invertebrates that are on or near the ground, such as ants, beetles and grasshoppers. Larger shrubs and taller herbaceous plants would provide more litter (food) and cover (protection) for these invertebrates.

Our study was a pilot project to investigate which methods best assessed invertebrates and vegetation during the early brood rearing season. We tried several invertebrate and vegetation sampling techniques and we discovered what methods worked best in the field and which measures may be most critical for analysis. Future projects will sample shrubs and litter for invertebrates and count ant mounts and grasshoppers in the entire plot. We may also count ant mounds using satellite imagery to account for a larger area around the plots. Although pitfall traps are a great way to capture ground-dwelling invertebrates they are not quantitative measures and they are less efficient as we must return to plots to collect them. Furthermore, Sage-grouse do not feed at night and pitfall traps would be left over night to collect invertebrates which may not represent what is available to chicks.

This pilot project leaves us with questions about how to sample the vegetation. If a vegetation characteristic is to be useful in predicting availability of invertebrates, we must be able to demonstrate significant differences among plots for that vegetation characteristic. With the method and intensity of sampling that we used, we were able to demonstrate differences among plots for some characteristics; but, in some cases, we were unable to demonstrate which individual plots differed from other plots. For example, analysis of variance showed that woody plant height differed significantly among the five

plots, but the pairwise comparisons of means were unable to clearly show which plots had taller woody plants than others. Similarly, for woody litter cover, the normal approximation of the chi-square test showed that the amount of woody cover differed among the five plots, but the pairwise comparisons could not show unequivocally which plots had more woody litter than other plots.

This result might argue for using the intensive sampling methods to collect more data from each plot. Doing this would require either having more than one person sample the vegetation (to speed up sampling), or finding a different, faster, but still intensive method. While more-intensive sampling might be necessary for developing a tool that identifies areas with good invertebrate availability, it would make the application of that tool more costly. A predictive tool that requires expensive vegetation sampling is unlikely to be widely used. Moreover, such a tool might be impossible to use when the vegetation features are being measured from satellite imagery or aerial photographs.

We sampled five plots for our pilot project. We collected data in areas that differed in the species and size of sagebrush among other variables, but our data does not represent all the variation present on the landscape. Our preliminary results should be used with caution as five plots is not enough to understand what vegetation features drive invertebrate availability. Beyond the small sample size, we recognize that annual variation in invertebrate availability likely depends on spring conditions where a warm, moist spring may have far more invertebrates available compared to a cold, dry spring. We do feel that our pilot study begins to unravel some of the relationships between vegetation and invertebrates, and we plan to further develop these ideas in a larger project. Future studies will exclude areas with basin big sagebrush as Sage-grouse do not use such habitats and the differences in shrub height dominated some of the relationships.

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Appendix 1. Details of statistical analyses of plant canopy-cover, plant height, and litter cover data.

A. Plant Canopy Cover

1. Total canopy cover

a. Test for differences among plots in total canopy cover (normal approximation of chi-square contingency test)

H_0 = The proportion of points with canopy cover is the same in all 5 plots.
H_A = The proportion of points with canopy cover is not the same in all 5 plots.

Plot	n = # points in plot	X = # points w/ canopy	$[(X - n\bar{p})^2]/(n\bar{p}\bar{q})]$
SBI-2016-1	50	20	2.357
SBI-2016-2	50	34	5.882
SBI-2016-7	73	17	22.194
SBI-2016-8	75	49	6.292
SBI-2016-18a	45	29	3.326
		χ^2 =	40.051

$\bar{p}$ = mean proportion = 0.509; $\bar{q} = 1 - \bar{p} = 0.491$
k = # of plots = 5; ν = k-1 = 4
Critical $\chi^2_{0.05,4} = 14.860$

χ^2 > critical χ^2, so **reject H_0**. The proportion of points with any canopy cover is not the same in all 5 plots.

b. Test for differences between plots (Tukey-like multiple comparison test).

Test requires an arcsin transformation of each proportion, p′:

$p' = \frac{1}{2}\{(\arcsin [X/(n+1)]^{1/2}) + (\arcsin [(X+1)/(n+1)]^{1/2})\}$

Plots arranged by transformed proportion:

	SBI-2016-7	SBI-2016-1	SBI-2016-18a	SBI-2016-8	SBI-2016-2
X = # points w/ canopy	17	20	29	49	34
n = # points in plot	73	50	45	75	50
p′	29.095	39.345	60.005	61.326	64.438

Test uses **q** statistic = (p'B - p'A)/SE

$SE = \{ [410.35/(nA+0.5)] + [410.35/(nB+0.5)] \}^{1/2}$

Comparison, B vs. A	p'B - p'A	SE	q = (p'B - p'A)/SE	N = nA + nB	$q_{0.05,N,5}$
2 vs. 7*	35.343	3.703	9.546*	123	3.917
2 vs. 1*	25.093	4.031	6.225*	100	3.937
2 vs. 18a	4.433	4.141	1.071	95	3.947
8 vs. 7*	32.231	3.319	9.710*	148	3.858
8 vs. 1*	21.981	3.683	5.969*	125	3.917
7 vs. 1	10.250	3.703	2.768	123	3.917
7 vs. 18a*	30.910	3.821	8.089*	118	3.917
18a vs. 1*	20.660	4.141	4.990*	95	3.947

* q > critical q: significantly different

2. Herbaceous canopy cover

a. Test for differences among plots in herbaceous canopy cover (normal approximation of chi-square contingency test)

H_0 = The proportion of points with canopy cover is the same in all 5 plots.
H_A = The proportion of points with canopy cover is not the same in all 5 plots.

Plot	n = # points in plot	X = # points w/ canopy	$[(X - n\bar{p})^2]/(n\bar{p}\bar{q})]$
SBI-2016-1	50	13	0.0099
SBI-2016-2	50	17	1.3936
SBI-2016-7	73	5	14.6090
SBI-2016-8	75	35	15.4276
SBI-2016-18a	45	8	1.8016
		χ^2 =	33.2416

$\bar{p}$ = mean proportion = 0.266; $\bar{q} = 1 - \bar{p} = 0.734$
k = # of plots = 5; ν = k-1 = 4
Critical $\chi^2_{0.05,4} = 14.860$

χ^2 > critical χ^2, so **reject H_0**. The proportion of points with herbaceous canopy cover is not the same in all 5 plots.

b. Test for differences between plots (Tukey-like multiple comparison test).

Test requires an arcsin transformation of each proportion, p′:

$p' = ½\{(\arcsin [X/(n+1)]^{1/2}) + (\arcsin [(X+1)/(n+1)]^{1/2})\}$

Plots arranged by transformed proportion:

	SBI-2016-7	SBI-2016-18a	SBI-2016-1	SBI-2016-2	SBI-2016-8
X	5	8	13	17	35
n	73	45	50	50	75
p'	15.805	25.450	30.960	35.856	43.114

Test uses **q** statistic = (p'B - p'A)/SE

SE = { [410.35/(nA+0.5)] + [410.35/(nB+0.5)] }$^{1/2}$

Comparison, B vs. A	p'B - p'A	SE	q = (p'B - p'A)/SE	N = nA + nB	$q_{0.05,N,5}$
8 vs. 7*	27.309	3.319	8.227*	148	3.858
8 vs. 2	7.258	3.683	1.971	125	3.917
8 vs. 1	12.154	3.683	3.300	125	3.917
8 vs. 18a*	17.664	3.802	4.646*	120	3.917
2 vs. 7*	20.051	3.703	5.415*	123	3.917
2 vs. 1	4.896	4.031	1.215	100	3.937
2 vs. 18a	10.406	4.141	2.513	95	3.947
1 vs. 7*	15.155	3.703	4.093*	123	3.917
1 vs. 18a	5.510	3.957	1.393	104	3.937
18a vs. 7	9.645	3.821	2.524	118	3.917

* q > critical q: significantly different

3. Woody canopy cover

a. Test for differences among plots in woody canopy cover (normal approximation of chi-square contingency test)

H_0 = The proportion of points with canopy cover is the same in all 5 plots.
H_A = The proportion of points with canopy cover is not the same in all 5 plots.

Plot	n = # points in plot	X = # points w/ canopy	$[(X - n\bar{p})^2]/(n\bar{p}\bar{q})]$
SBI-2016-1	50	7	7.027
SBI-2016-2	50	24	6.397
SBI-2016-7	73	12	7.586
SBI-2016-8	75	23	0.019
SBI-2016-18a	45	26	14.537
		χ^2 =	35.565

$\bar{p}$ = mean proportion = 0.314; $\bar{q}$ = 1 - $\bar{p}$ = 0.686

k = # of plots = 5; ν = k-1 = 4
Critical $\chi^2_{0.05,4}$ = 14.860

χ^2 > critical χ^2, so **reject H_0**. The proportion of points with woody canopy cover is not the same in all 5 plots.

b. Test for differences between plots (Tukey-like multiple comparison test).

Test requires an arcsin transformation of each proportion, p′:

$$p' = \tfrac{1}{2}\{(\arcsin [X/(n+1)]^{1/2}) + (\arcsin [(X+1)/(n+1)]^{1/2})\}$$

Plots arranged by transformed proportion:

	SBI-2016-1	SBI-2016-7	SBI-2016-8	SBI-2016-2	SBI-2016-18a
X	7	12	23	24	26
n	50	73	75	50	45
p'	22.539	24.263	33.783	43.876	49.378

Test uses **q** statistic = (p'B - p'A)/SE

$$SE = \{ [410.35/(nA+0.5)] + [410.35/(nB+0.5)] \}^{1/2}$$

Comparison, B vs A	p'B - p'A	SE	q = (p'B - p'A)/SE	N = nA + nB	$q_{0.05,N,5}$
18a vs. 1*	26.839	4.141	6.482*	95	3.947
18a vs. 7*	25.114	3.621	6.936*	127	3.917
18a vs. 8*	15.594	3.802	4.102*	120	3.917
18a vs. 2	5.501	4.141	1.329	95	3.947
2 vs. 8	10.093	3.683	2.741	125	3.917
2 vs. 7*	19.613	3.703	5.297*	123	3.917
2 vs. 1*	21.337	4.031	5.293*	100	3.937
8 vs. 1	11.244	3.683	3.053	125	3.917

* q > critical q: significantly different

B. Plant Height

Each analysis was a general linear model, single-factor analysis of variance, performed in Minitab® 16.2.4. Plot ID was the single, fixed factor, with 5 levels.

1. Herbaceous Plant Height

a. Test For Differences In Height Among Plots

H_0 = Mean herbaceous plant height is the same in all 5 plots.
H_A = Mean herbaceous plant height is not the same in all 5 plots.

Plot_ID	N	Mean Height	SE Mean	StDev	Variance
SBI-2016a-1	16	22.94	2.75	10.99	120.73
SBI-2016b-2	26	23.65	1.59	8.09	65.44
SBI-2016c-7	33	18.45	1.37	7.89	62.26
SBI-2016d-8	36	19.000	0.838	5.026	25.257
SBI-2016e-18a	19	19.63	2.42	10.54	111.02

General Linear Model, herbaceous plant height vs. plot ID

Factor	Type	Levels
Plot_ID	fixed	5

Analysis of Variance for HerbHeight, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Plot_ID	4	584.85	584.85	146.21	2.20	0.073
Error	125	8321.42	8321.42	66.57		
Total	129	8906.28				

S = 8.15913 R-Sq = 6.57% R-Sq(adj) = 3.58%

$p > 0.05$. Do not reject H_0: Mean herbaceous plant height is the same in all 5 plots.

b. No pairwise comparisons between plots were performed

2. Woody Plant Height

a. Test For Differences In Height Among Plots

Plot_ID	N	N*	Mean Height	SE Mean	StDev	Variance
SBI-2016a-1	8	0	23.38	2.49	7.05	49.70
SBI-2016b-2	25	0	47.64	5.50	27.48	755.16
SBI-2016c-7	27	0	15.037	0.907	4.711	22.191
SBI-2016d-8	32	0	26.81	2.58	14.62	213.71
SBI-2016e-18a	19	0	121.58	8.44	36.80	1353.92

General Linear Model: WoodyHeight versus Plot_ID

Analysis of Variance for WoodyHeight, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Plot_ID	4	150146	150146	37537	79.51	0.000
Error	106	50044	50044	472		
Total	110	200190				

S = 21.7282 R-Sq = 75.00% R-Sq(adj) = 74.06%

$p < 0.05$. Reject H_0: Mean herbaceous plant height is not the same in all 5 plots.

b. Pairwise comparisons between plots

```
Bonferroni method and Tukey method with 95.0% confidence give the same result:

Plot_ID          N    Mean  Grouping
SBI-2016e-18a   19  121.58    A
SBI-2016b-2     25   47.64     B
SBI-2016d-8     32   26.81      C
SBI-2016a-1      8   23.37     BC
SBI-2016c-7     27   15.04      C
Means that do not share a letter are significantly different.
```

C. Litter Cover

1. Total Litter Cover

a. Test for differences among plots in total litter cover (normal approximation of chi-square contingency test)

H_0 = The proportion of points with any litter is the same in all 5 plots.
H_A = The proportion of points with any litter is not the same in all 5 plots.

Plot	n = # points in plot	X = # points w/ litter	$[(X - n\bar{p})^2]/(n\bar{p}\bar{q})]$
SBI-2016-1	50	7	29.815
SBI-2016-2	50	34	4.781
SBI-2016-7	73	22	14.720
SBI-2016-8	75	49	4.908
SBI-2016-18a	45	42	30.003
		χ^2 =	84.227

$\bar{p}$ = mean proportion = 0.509; $\bar{q}$ = 1 - $\bar{p}$ = 0.491
k = # of plots = 5; ν = k-1 = 4
Critical $\chi^2_{0.05,4}$ = 14.860

χ^2 > critical χ^2, so **reject H_0**. The proportion of points with any litter is not the same in all 5 plots.

b. Test for differences between plots (Tukey-like multiple comparison test).

Test requires an arcsin transformation of each proportion, p′:

$p' = \frac{1}{2}\{(\arcsin [X/(n+1)]^{1/2}) + (\arcsin [(X+1)/(n+1)]^{1/2})\}$

Plots arranged by transformed proportion:

	SBI-2016-1	SBI-2016-7	SBI-2016-8	SBI-2016-2	SBI-2016-18a
X = # points w/ canopy	7	22	49	34	42
n = # points in plot	50	73	75	50	45
p′	22.539	33.463	53.809	55.336	74.027

Test uses **q** statistic = (p'B - p'A)/SE

$SE = \{ [410.35/(nA+0.5)] + [410.35/(nB+0.5)] \}^{1/2}$

Comparison, B vs. A	p'B - p'A	SE	q = (p'B - p'A)/SE	N = nA + nB	$q_{0.05,N,5}$
18a vs. 1*	51.488	4.141	12.435*	95	3.856
18a vs. 7*	40.564	3.821	10.616*	118	3.917
18a vs. 8*	20.218	3.802	5.318*	120	3.917
18a vs. 2*	18.691	4.141	4.514*	95	3.856
2 vs. 1*	32.797	4.031	8.136*	100	3.947
2 vs. 7*	21.873	3.703	5.908*	123	3.917
2 vs. 8	1.527	3.683	0.415	125	3.917
8 vs. 1*	31.270	3.683	8.492*	125	3.917
8 vs. 7*	20.346	3.319	6.130*	148	3.91
7 vs. 1	10.924	3.703	2.950	123	3.917

* q > critical q: significantly different

2. Herbaceous Litter Cover

a. Test for differences among plots in herbaceous litter cover (normal approximation of chi-square contingency test)

H_0 = The proportion of points with herbaceous litter is the same in all 5 plots.
H_A = The proportion of points with herbaceous litter is not the same in all 5 plots.

Plot	n = # points in plot	X = # points w/ litter	$[(X - n\bar{p})^2]/(n\bar{p}\bar{q})]$
SBI-2016-1	50	5	28.109
SBI-2016-2	50	26	0.417
SBI-2016-7	73	20	11.761
SBI-2016-8	75	47	6.974
SBI-2016-18a	45	41	34.419
		χ^2 =	81.680

$\bar{p}$ = mean proportion = 0.509; $\bar{q} = 1 - \bar{p} = 0.491$

k = # of plots = 5; ν = k-1 = 4
Critical $\chi^2_{0.05,4}$ = 14.860

χ^2 > critical χ^2, so **reject H_0**. The proportion of points with herbaceous litter is not the same in all 5 plots.

b. Test for differences between plots (Tukey-like multiple comparison test).

Test requires an arcsin transformation of each proportion, p′:

$$p' = \tfrac{1}{2}\{(\arcsin [X/(n+1)]^{1/2}) + (\arcsin [(X+1)/(n+1)]^{1/2})\}$$

Plots arranged by transformed proportion:

	SBI-2016-1	SBI-2016-7	SBI-2016-2	SBI-2016-8	SBI-2016-18a
X = # points w/ canopy	5	20	26	47	41
n = # points in plot	50	73	50	75	45
p′	19.153	31.756	46.124	52.239	71.800

Test uses **q** statistic = (p'B - p'A)/SE

$$SE = \{ [410.35/(nA+0.5)] + [410.35/(nB+0.5)] \}^{1/2}$$

Comparison, B vs. A	p'B - p'A	SE	q = (p'B - p'A)/SE	N = nA + nB	$q_{0.05,N,5}$
18a vs. 1*	52.646	4.141	12.715*	95	3.856
8 vs. 1*	33.086	3.683	8.985*	125	3.917
2 vs. 1*	26.971	4.031	6.690*	100	3.947
7 vs. 1	12.603	3.703	3.404	123	3.917
18a vs. 8*	19.560	3.802	5.145*	120	3.917
18a vs. 2*	25.676	4.141	6.201*	95	3.856
18a vs. 7*	40.043	3.821	10.479*	118	3.917
8 vs. 2	6.115	3.683	1.661	125	3.917
8 vs. 7*	20.483	3.319	6.171*	148	3.9
8 vs. 1*	33.086	3.319	9.968*	148	3.9

* q > critical q: significantly different

3. Woody Litter Cover

a. Test for differences among plots in woody litter cover (normal approximation of chi-square contingency test)

H_0 = The proportion of points with woody litter is the same in all 5 plots.
H_A = The proportion of points with woody litter is not the same in all 5 plots.

Plot	n = # points in plot	X = # points w/ litter	$[(X - n\bar{p})^2]/(n\bar{p}\bar{q})]$
SBI-2016-1	50	2	2.819
SBI-2016-2	50	9	1.994
SBI-2016-7	73	2	5.592
SBI-2016-8	75	12	1.413
SBI-2016-18a	45	9	3.092
		χ^2 =	14.910

$\bar{p}$ = mean proportion = 0.509; $\bar{q}$ = 1 - $\bar{p}$ = 0.491
k = # of plots = 5; ν = k-1 = 4
Critical $\chi^2_{0.05,4}$ = 14.860

χ^2 > critical χ^2, so **reject H_0**. The proportion of points with woody litter is not the same in all 5 plots.

b. Test for differences between plots (Tukey-like multiple comparison test).

Test requires an arcsin transformation of each proportion, p′:

$$p' = \tfrac{1}{2}\{(\arcsin [X/(n+1)]^{1/2}) + (\arcsin [(X+1)/(n+1)]^{1/2})\}$$

Plots arranged by transformed proportion:

	SBI-2016-1	SBI-2016-7	SBI-2016-18a	SBI-2016-8	SBI-2016-2
X = # points w/ canopy	2	2	9	12	9
n = # points in plot	50	50	45	75	50
p′	12.729	12.729	27.022	23.922	25.562

Test uses **q** statistic = (p'B - p'A)/SE

$$SE = \{ [410.35/(nA+0.5)] + [410.35/(nB+0.5)] \}^{1/2}$$

Comparison, B vs. A	p'B - p'A	SE	q = (p'B - p'A)/SE	N = nA + nB	$q_{0.05,N,5}$
2 vs. 1	12.833	4.031	3.183	100	3.856

Because the two most-different plots were not statistically different, no comparisons were made on the other plots.