

**Associations Between Deer Browse and Aphid Colonization in a
Long-Term Monitoring Study of *Ligusticum porteri***

By: Sloane Rittler

Mentor: Emily Mooney

Program: Independent Research and Course

Abstract

Deer are prolific herbivores that, if left to increase exponentially, could decimate populations of plants and possibly other herbivores. Due to the rapidly increasing abundance of deer, this is a risk that is getting ever closer to becoming a reality. This phenomenon is a concern for herbivores that currently share plant resources with deer species, as well as the plants that deer rely on for food. Many herbivores that are at risk of this competition are insects. Insect populations are already decreasing, but with the addition of increased deer abundance and, thus, increased competition around the corner, it is more important than ever to understand how these organisms interact. This study explores the ecological and trophic relationships between mule deer (*Odocoileus hemionus*) and aphid colonies (*Aphis asclepiadis*) on the plant Osha (*Ligusticum porteri*) and the possibility that deer are seeking out aphid colonized plants as a food source. If this is the case, the insects could be at risk of this resource competition that could eventually have devastating effects on their populations. Mule deer populations can be controlled on the local level, and this study will inform what organisms are being effected by large herbivores and whether population management may be needed for these herbivorous mammals.

Introduction

Mule deer are an abundant and charismatic species native to the Colorado Rockies. These mammals are not uncommon to see in almost all parts of the state, and the natural herbivores have their own unique effects on the Colorado ecosystem through their behavior, range, and diet (Barrett & Stiling, 2007; Waser et al., 2014). Over the last 75 to 150 years deer populations have been flourishing leading to serious overabundance (Côté et al., 2004). This wealth of individuals presents the risk of over-browse, also known as over grazing, which would have major negative effects on plant dwelling insects (Allombert, Stockton, and Martin 2005). Given the already declining global population of insects, potential over-browsing of resources necessary for many insects' survival could result in serious ecological consequences (Wagner et al. 2021).

Aphids are small invertebrates that colonize a host plant, feeding off the phloem or sap of a plant and secrete a sweet waste product called honeydew (Mooney et al., 2016). This secretion is highly sought out by a multitude of organisms including ants and some wasps, making it a common element of the diets of many species, while the aphids themselves are subject to predation by others (Faria et al., 2008). The presence of aphids also attract predators that not only eat aphids but other herbivorous bugs, this means the aphids act as a form of pest control for plants, protecting them against other, more harmful, insects because the predators aphids attract will also eat any other herbivorous bug on the plant (Styrsky & Eubanks, 2007). Modern knowledge shows that “40% of aphid species form mutualisms with ants” (E. Mooney et al., 2023). This behavior can be observed in that these mutualistic ants will protect aphid colonies from potential predators or other threats. These ants can also be observed feeding off the honeydew that the aphids produce. This relationship is still not fully understood, but it is known that ants will directly affect aphid populations by preventing winged alates from flying to new plants and forming new colonies by tearing the wings off these alates (Rice & Eubanks, 2013). It has also been discovered that aphid colonies in the presence of ants produce more honeydew as well as reproduce quicker and more efficiently (Rice & Eubanks, 2013). Given this mutualism between ants and aphids, there is also a chance that an interaction between aphids and deer may manifest itself in what statistically looks like an interaction between deer and ants. Additionally, some deer have been known to consume ants in specific contexts which has changed our view of trophic interactions involving vertebrates we consider herbivores (Awasthi et al., 2024). Furthermore, the range overlap between aphids and deer is significant, and deer often consume the host plants on which aphids form their colonies (Takahashi & Huntly, 2010; Wambolt, 1996). This overlap has caused the two species to have both direct and indirect effects on each other (Badri Ghimire, 2020).

Many studies have been conducted on how aphid colonies respond to deer browsing their host plant but few have been done on the effects herbivorous insects have on larger organisms that share the same food source (Gish et al., 2011; Zhu et al., 2012). This study uses the abundant alpine flower *Ligusticum porteri* (*L. porteri*), commonly known as Osha, as the basis on which this overlap occurs within the

Colorado Rocky Mountains (Kindscher et al., 2019 ; Mooney et al. 2016), allowing the plant to be both browsed by deer and colonized by aphids in conjunction with one another. The study utilized a long history of observational data that includes aphid colony and plant health metrics as well as whether a plant has been browsed. In addition to data collected in previous years, further observations were made in 2024 following the same methods as previous years and new data on deer density was also collected. This study intended to provide a better understanding of the impact the presence of aphids have on deer browsing patterns which, in turn, can provide insight into the possible effects that deer overabundance has on herbivorous insects that share similar food sources.

Methods

Long-term Observational Study

Over the course of the 2024 summer season, I followed the set census procedures for Dr. Emily Mooney's *L. porteri* lab. At each site (Figures 6-9), a 30 meter transect is placed with 10 host plants randomly selected to be censused throughout the summer along the transect. The weekly census followed the same structure to ensure consistency of the data collected. A data sheet was used to track the number of flowering stalks on the plant as well as the average phenological stage of the plant. Additionally, the number of aphids and aphid alates on the flowering stalks were also counted and recorded, we also censused four different specific species of ant (along with any other species of ant) we saw on the flowering stalks: *Formica rufa*, *Formica podzolica*, *Formica fusca*, and *Tapinoma sessile*. We also counted mirid adults and nymphs that were seen on the stalk along with any other insect seen such as beetles, ladybugs, wasps, and so on. Each site experienced varying levels of environmental conditions, including browse by mammalian herbivores (Figure 1), as well as possible frost damage and trampling. The Mooney lab has tracked insect abundance in these 20 sites since 2017, and since 2022 the team has also systematically recorded browsing of flowering stalks. Additional factors recorded at each site included air temperature and snowmelt date, which is standardized as the date when bare ground appears in spring (Mooney et al. 2023).

Pellet Counts

An additional aspect of this study was the collection of deer density data. Density was estimated based on pellet count, this is a standardized and common method for estimating deer density within an area (Anderson & Medin, 1969). Each site had pellets counted on two 2 meter by 30 meter transects to get an estimate of herbivore density for the site. The transects were chosen in the same manner for each site. One transect was measured out parallel to the already chosen plant transect two meters away as to avoid interference with the study plants. Scat within one meter on either side of this transect were counted and recorded to be analyzed later. The scat that was able to be identified on site as Deer, Elk, Moose, Cow, or Carnivore were recorded as such. Anything unidentifiable in the field was recorded under other with a description. If it was able to be identified later from a picture (taken in the field) and a description it was moved into the correct category, otherwise it stayed in the other column. Once the first transect had been completed, using a random number generator from 1 to 30 a point along the transect tape was selected for the second transect to start from. The direction was decided using a random compass angle from 1 to 360. The second transect was counted and recorded the same way the first was.

Data Analysis

All data was analyzed using R (R Core Team, 2023). We did three main analyses to test for associations among deer browse and aphid colonization. The first analysis tested for differences in browse patterns among sites observed on plants in 2022, 2023, and 2024 combined. To conduct this analysis we used the dplyr package in R to manipulate our raw data allowing it to be easier analyzed (Wickham et al., 2023), this was done by organizing observations by plant and site as well as filtering out the raw data from years before 2022. The second analysis highlighted the browse patterns between sites between the three years (2022-2024). This test also utilized dplyr to accomplish the same organization by site and plant, and for this test, by year (Wickham et al., 2023). The ggplot package was used to create all figures (Wickham, 2016), and cowplot was used to make these figures easier to interpret (Wilke, 2024). This test showed the differences in browse occurrences among the three different years. The third analysis used a model-selection approach to determine which factor or combination of factors determined the overall best

predictor of browse a population experienced. To conduct this analysis we used the lmerTest package (Kuznetsova et al., 2017) to construct our model and the car package (Fox & Weisberg, 2019) to obtain our P value. The AICcmodavg package (Mazerolle, 2023) was used to conduct the model selection. In this analysis, the response variable is the number of plants browsed (N) in each site in each study year. Possible explanatory variables included the presence of an aphid colony, the number of ants on a plant, the number of umbels on the plant, and the site the plant belonged to.

Results

Site

When analyzing the data regarding site, two different approaches were taken: site to site variation within all years (Figure 2) (20 sites X 10 plants X 3 years = 600 observations) and site to site variation among years (Figure 3) (10 plants X 20 sites = 200 observations each year). The data within all years showed that the 3 Irwin sites received the most browse on average for a location. One of the Gothic sites Sun 3 received the most browse overall compared to all sites. Population was shown to hold strong significance towards the likelihood of a plant being browsed (Figure 2) (F value: 1.6235, P value: 0.00494).

The variation of browse among sites when separated by year varied more, which was expected. The same general patterns shown in the first test stayed relatively constant, but each year saw varying levels of overall browse (Figure 3). 2022 saw the most amount of browse when comparing all three years, and 2023 saw the least. Although some sites in 2023 received a substantial amount of browse, 2024 has less sites overall that showed no browse. The browse within sites in 2024 was also much more variable than the previous two years. While 2023 saw little browse among all sites, 2024 saw some sites with very little and even no browse while other sites had huge amounts of browse, some of which even surpassed or met the 2022 numbers.

This pattern in number of plants browsed within different sites follows a relatively similar pattern to the preliminary tests done before this study (Figure 1). The only difference being higher browse rates

overall compared to that dataset (2019-2023 compared to 2022-2024). This is likely due to the method in which browse was observed before 2022 which had a high chance for missed counts.

Pellet Count

Expectedly, when comparing the number of pellet piles counted at each site with the number of plants at the site that were browsed, a clear correlation was found (Figure 5) (Z value: 2.811, P value: 0.00494). The most pellets were counted at all three Irwin sites (11, 21, 12 pellets respectively) which reflects in the browse data as areas that are most susceptible to browse (Figure 2). The least pellets were counted in sites to high human traffic or with little shelter (most Sun sites and the Washington Gulch sites). Unexpectedly, even though Sun 3 showed significantly higher browse compared to other sites (figure 2), only one pellet pile was seen at that site. Interestingly, Sun 3 did see large amount of browse over all three years, including 2024 (Figure 3).

Model Selection

The use of the AICcmodavg package (Mazerolle, 2023) allowed for the identification of the variable that accounted for browse of plants best. The variables tested include number of ants, number of umbels and ants, number of ants and aphids, number of aphids, number of umbels, and number of umbels and aphids (Table 1). No significant relationship was seen between aphid colonization and browse after running a model selection test with all the data (20 sites X 10 plants X 3 years = 600 observations), but a correlation was seen between number of ants on a plant and the likelihood of that plant being browsed. This relationship was shown to be statistically significant (Figure 4) (Z value: 2.288, P value: 0.0221). The next most likely driver for plant browse was the number of ants on a plant along with the number of umbels on a plant, which usually directly correlates with the size of the plant.

Discussion

Site

Variation in overall plants browsed between sites was to be expected. Each site is subject to its own biotic and abiotic factors that change likelihood of browse overall. What can be seen in the data is that some sites were expected to see more browse than others. This is likely due to proximity to public traffic at each site as deer tend to avoid these areas (Price et al., 2014). This specific aspect of each site is still under analysis but is our leading prediction for the variability between sites. Mule Deer are known to be skittish around people, and while the deer in the area are largely habituated to people due to the presence and safety of the Rocky Mountain Biological Laboratory, it is possible the deer still avoid the more public trails (Price et al., 2014). This would explain why Sun 3 received so much browse as it is on RMBL property and on a trail that is not accessible to the public and only receives a small amount of traffic from the occasional scientist. Average temperature and elevation of each site are also still under analysis, and we suspect these aspects play an additional role in the likelihood of deer browse. We anticipate that deer are seeking out cooler microclimates due to rising temperatures within the area. Mule Deer have been known to move towards areas with cooler average temperatures and higher precipitation in the summer (Nicholson et al., 1997).

Pellet Density

While the relationship between pellet pile density and number of plants within a site browsed was expected to be positive, the confirmation of this eliminates the confounding variable that there is a different herbivore browsing the *L. porteri* in the area. This opens the door for more focused studies on the relationship between Mule Deer patterns and likelihood of browse, instead of having further work on the identification of the type herbivore browse in the area. Previous studies have found that pellet counts provide accurate input into the total overall use a habitat has to deer within a season (Loft & Kie, 1988). This confirms that the deer at each of our sites rely on those specific types of habitats in the summer season, which is supported by our site data as the patterns have stayed similar among years. This allows us to assume that the more populated types of habitats within our sites will be sought out by deer. This supports the identification of future sites for studies on the system to be chosen with relative success based on the type of information being gathered.

Model Selection

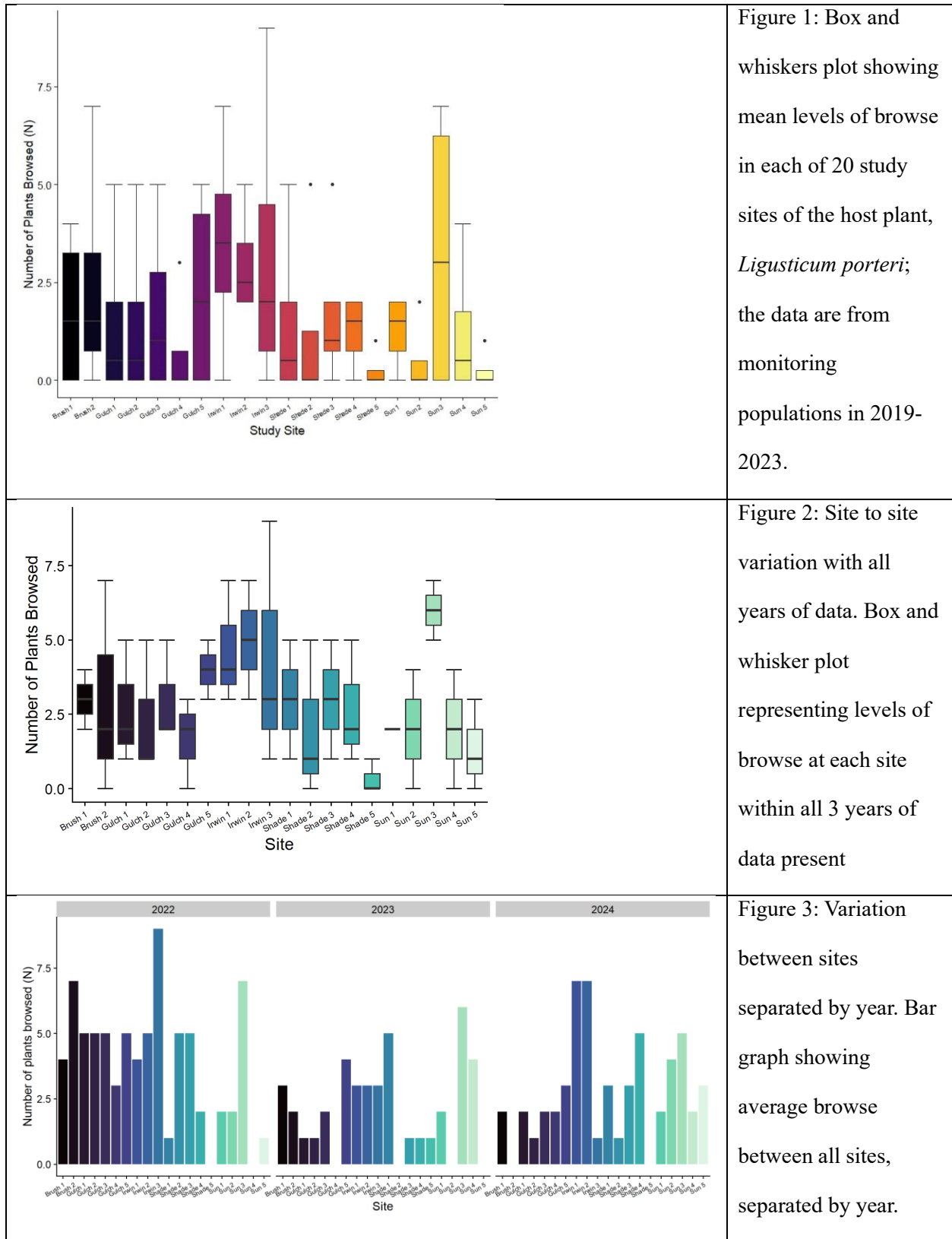
After running our model selection, aphids did not prove to be the leading driver in browse of *L. porteri*. The results show ants *are* the leading driver (according to our data thus far) which provides a very fascinating insight into a connectivity between ants, aphids and deer. It is possible that deer (and possible other larger herbivores) are using ants as a scent or a sight indicator for the presence of aphids on a plant. There is, of course, the likelihood that ants are sought out for other reasons, but further work needs to be done to truly understand what mechanism is at work here. In contrast with our study, a previous study has shown that browse from deer causes *Acacia* trees to produce more nectar which increases the likelihood of a plant eating ant seeking out that tree after it has been browsed (Palmer et al., 2008). This interaction shows deer browse driving ant abundance due to their effect on the chemistry of the trees they eat. Although this study is in contrast with ours, it does prove that these two organisms can have major effects on the dynamics of the other. So, are herbivores using ants as an indicator? Is this a learned behavior? What about plants with ants that are not mutualistic with aphids, does that change the story? These questions are the direction in which future studies can be focused in order to get a better understanding of the mechanisms that are at work within this interaction. This relationship between plant insects, their mutualisms, plants, and larger herbivores is not well understood and opens the doorway for understanding relationships previously thought as unrelated which could change our understanding of an array of trophic interactions (Gish et al., 2017).

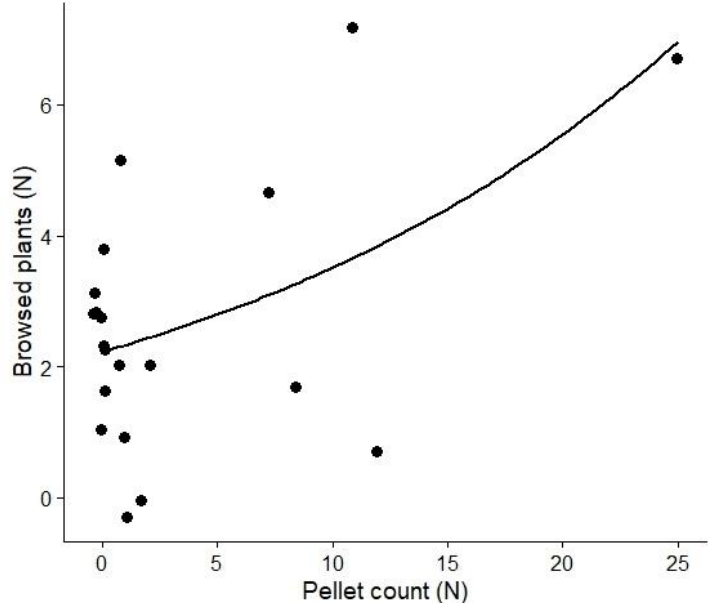
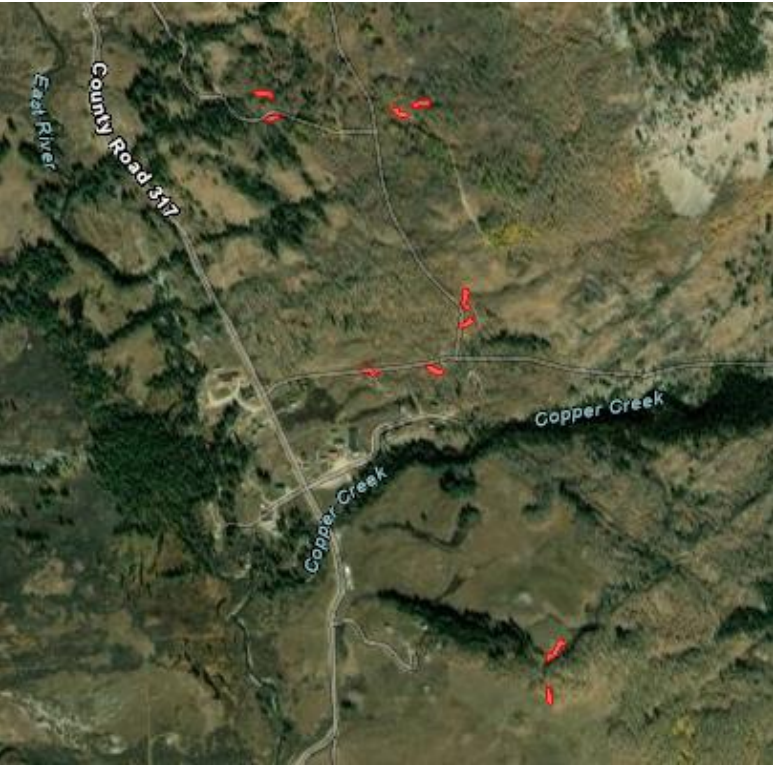
Sources Cited

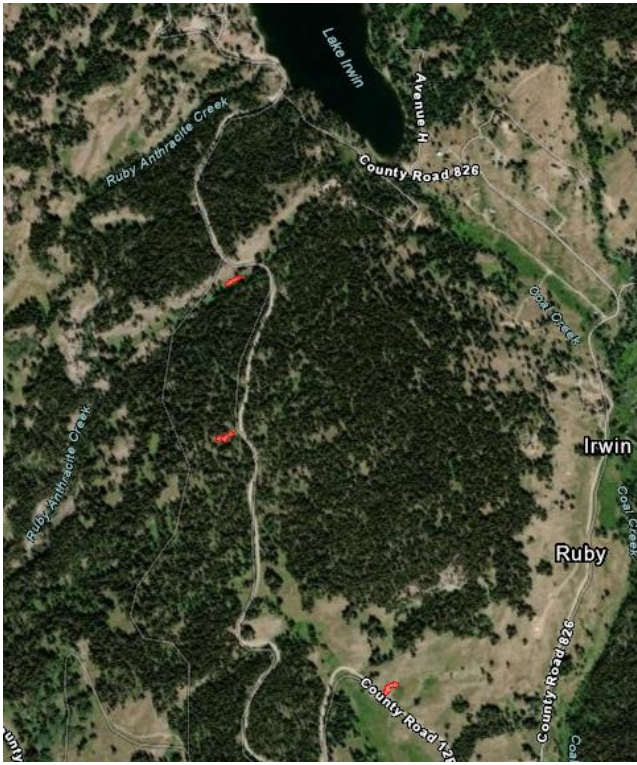
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 A scatter plot showing the relationship between Pellet count (N) on the x-axis and Browsed plants (N) on the y-axis. The x-axis ranges from 0 to 25, and the y-axis ranges from 0 to 6. A positive linear regression line is shown. Data points are scattered around the line, with a notable outlier at approximately (11, 7.5). <table border="1"><thead><tr><th>Pellet count (N)</th><th>Browsed plants (N)</th></tr></thead><tbody><tr><td>0</td><td>1.0</td></tr><tr><td>0</td><td>1.5</td></tr><tr><td>0</td><td>2.0</td></tr><tr><td>0</td><td>2.5</td></tr><tr><td>0</td><td>3.0</td></tr><tr><td>0</td><td>3.8</td></tr><tr><td>1</td><td>1.0</td></tr><tr><td>1</td><td>1.5</td></tr><tr><td>1</td><td>2.0</td></tr><tr><td>1</td><td>2.5</td></tr><tr><td>1</td><td>5.2</td></tr><tr><td>2</td><td>0.0</td></tr><tr><td>2</td><td>0.5</td></tr><tr><td>2</td><td>2.0</td></tr><tr><td>8</td><td>1.7</td></tr><tr><td>8</td><td>4.7</td></tr><tr><td>11</td><td>0.7</td></tr><tr><td>11</td><td>7.5</td></tr><tr><td>25</td><td>6.5</td></tr></tbody></table>	Pellet count (N)	Browsed plants (N)	0	1.0	0	1.5	0	2.0	0	2.5	0	3.0	0	3.8	1	1.0	1	1.5	1	2.0	1	2.5	1	5.2	2	0.0	2	0.5	2	2.0	8	1.7	8	4.7	11	0.7	11	7.5	25	6.5	Figure 5: Number of plants browsed relative to the number of deer pellet piles counted at the plant's site
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 An aerial map showing the location of study sites near the Gothic Townsite. The map includes labels for East River, County Road 317, and Copper Creek. Red arrows point to several sites along the road and creek.	Figure 6: Map of sites near the Gothic Townsite																																								
	Figure 7: Washington Gulch sites map																																								

	
	Figure 8: Irwin Lake Sites Map
	Figure 9: Brush Creek Sites Map

