

**Impacts of Mule Deer Herbivory on Herbaceous
Vegetation in the Gothic area, with focus on
Aquilegia coerulea.**

Renee Arozqueta
REU 2005
Mary Price & Nick Waser

Abstract

The impacts of growing deer populations upon biodiversity have caused concern for ecologists since it is speculated that certain species of herbs are targeted and over abundantly browsed. This study investigated deer abundance as well as intensity of deer browsing of herbaceous plants inside and outside the fenced protection of the Rocky Mountain Biological Laboratory. *Aquilegia coerulea* was used as a focal species since it has been observed to be very highly browsed. It was found that deer are observed more often inside the fence than out. Overall browsing intensity of all plant species in sites inside and outside the fence was not significantly different; however variation between sites in meadows as opposed to aspen forests was significant. Across all study sites, *Aquilegia coerulea* was on the average browsed 50%. Significant differences were found between *Aquilegia* plants caged to prevent herbivory and those open to browsing; unprotected plants produced one-third of the normal fruit production of protected plants.

Introduction

Increasing white-tail deer populations have become a growing problem in the eastern United States in the second half of the 20th century. Agricultural activities that improve temperate habitats, like replanting after logging, create earlier succession forest with high quality herbaceous ground cover for deer browsing. Reductions in hunting and natural predators have also led to population increases. Finally, warmer winters have increased deer body mass and winter survival (Cote et al, 2004). These human activities indirectly affect plant communities by altering herbivore abundance.

Ecologists are concerned with these recent trends because deer potentially influence ecosystems by altering nutrient cycles, reducing plant cover, affecting forest succession and reducing biodiversity. This is largely due to the fact that deer selectively browse herbaceous plants.

Plants are not defenseless however, they respond to herbivory in two ways, by evolving resistance or tolerance. Resistance refers to the combined attributes of a plant to avoid browsing such as thorns, tough leaves, or chemicals that make the plant unpalatable

or indigestible. Tolerance is how a plant compensates for being browsed. A study done in 1999 by another REU, Katherine Sharaf, looked at tolerance of *Ipomopsis aggregata*. She found that flowering stalks grew back when clipped but with smaller reproductive parts; the subsequent generations of these plants also had smaller flowering parts overall. Another study on tolerance by Belsky (1986) suggested that browsing could actually be beneficial to some plant species if they overcompensated for lost biomass.

It is unclear at this point whether deer populations are increasing or decreasing in the Rocky Mountains and if the impacts of deer browsing are significant. Only two publications studied mule deer populations in Colorado. The first claimed that deer populations are actually decreasing in Colorado. The second was a challenge to the credibility of deer censuses.

In the West, there are several similar conditions that imply that local populations of mule deer might follow the increasing trend of the eastern white-tail deer. For example, avalanches can have the same effect as logging to create an earlier successive forest. Regardless of regional herbivore population trends, local areas can be heavily impacted if they are protected to exclude hunting, predators and/or recreational damage to quality forage. One such area is Gothic Colorado, the site of the Rocky Mountain Biological Laboratory, which has extensive barbed wire fence; the fence mainly keeps out the cattle but it also provides protection from the factors listed above. Observations in the local Gothic area suggest that deer densities have increased in recent years, as has the browsing intensity of specific plant species such as *Aquilegia coerulea*.

In the summer of 2005, I conducted surveys at the Rocky Mountain Biological Laboratory, located in Gothic Colorado to address the following questions.

1. Are deer more common inside or outside the protection of the RMBL fence?
2. Which plant species are more/less resistant to browsing?
 - a. Do plant species differ in resistance, and which species are more susceptible to browsing.
 - b. Does location affect the probability of browsing?
3. What impacts does deer browsing have on *Aquilegia coerulea*, the Colorado Columbine, as a focal species?

Methods and Materials

Question 1: Are deer more common (higher density) inside RMBL protection?

<u>Hypothesis 1a)</u>	Deer are more common inside than out	in > out
<u>Hypothesis 1b)</u>	Deer are more common outside than in	in < out
<u>Hypothesis 1c)</u>	Deer are as common inside and out	in = out

To test the hypothesis that foraging activity densities are higher inside RMBL fenced land than in unprotected areas outside the fence, I examined how frequently deer were sighted during standardized dawn and dusk walks, (these are times when deer are mostly likely to be foraging). I selected ten sites in the Gothic area where columbine are found, five within the fence and five outside, and walked a route through these study sites. I reversed the direction of the route every other time to get a more accurate distribution, in other words, to prevent seeing the same places at the same time on every walk. Sites inside and outside the fence included a mix of similar environments, such as

open meadows, and aspen forests habitats to control for deer habitat preference and columbine chemistry.

I kept track of time I spent inside and outside the fence so I could express data as number of deer observed per minute. I also recorded when I entered different habitats. These observations were analyzed with a t-test.

- $H_0: P\{\text{deer/min}\} \text{ inside} = P\{\text{deer/min}\} \text{ out}$
- $H_{a1}: P\{\text{deer/min}\} \text{ inside} \neq P\{\text{deer/min}\} \text{ out}$
- $H_{a2}: P\{\text{deer/min}\} \text{ inside} > P\{\text{deer/min}\} \text{ out}$

Under the null hypothesis, the number of deer seen inside and outside the fence is proportional to the time spent observing inside and outside because essentially the probability of sighting per minute of observation is equal. The first alternative hypothesis says that the probabilities of seeing a deer inside and outside the fence are not equal, this is a two-tailed test meaning either probability could be higher. The second alternative hypothesis states that the probability of seeing a deer inside the fence is higher than seeing one outside. This outcome would support the hypothesis that deer prefer to spend their time in a protected area.

Question 2: Which plant species are more likely to be browsed?

Hypothesis 2a—Species Effect)

Plant species appear to be browsed at the same proportions across sites.

Hypothesis 2b—Site Effect)

Variation in browsing among species is consistent across sites

Hypothesis 2c—Site/Species Interaction)

Relative browsing frequency of species varies across sites.

To test for species and site specific browsing rates, I established three 5 meter transects and surveyed them twice during the season, once in early July and once in early August. The resulting data from these transects serve three purposes: 1) to observe which plant species are heavily browsed and which are avoided overall, 2) to be used in conjunction with survey columbines in assessing variation in browsing intensity across sites and 3) to be correlated with survey columbines with respect to browsing frequency of other species.

Three out of the six survey columbines (discussed below) were randomly chosen by rolling of a die. Transects were drawn with a 5 meter length of string between two stakes. Transects orientation was 140 degrees from the survey plant except when obstacles were presented and then transects were drawn in the opposite direction, 220 degrees.

Each plant that intersected the 5 meter transect was identified and classified as browsed or unbrowsed. A plant was considered browsed if there was visible evidence of herbivory, such as missing flowers or stems that appeared cut short. A plant can be a clump of stalks that intersects a transect with only one leaf; a plant was considered intersecting if a stem crossed the string when viewed from above. I must emphasize that transects did not exclusively look at the impact of browsing by deer alone, but all mammals that could have come by and eaten plants.

From 30 transects, (three at each of ten sites), I compiled a master list of 51 plant species. Numbers of browsed and unbrowsed individual plants were recorded for each

species. Overall frequency, or species abundance, was expressed as the combined total of browsed and unbrowsed plants of a given species. These numbers give an idea of the species composition of plant community in areas where columbine are found. With these data, average percentages of browsing for each species at each site were calculated.

I used Anova to compare sites located inside and outside the fence were done using percentage of browsing deviation as a response variable. A second Anova analysis looked at browsing deviation in different habitats: aspen forests vs. meadows.

Question 3: How is browsing likely to affect the Columbine population?

Hypothesis 3a) The abundance of Columbine is likely to decrease due to overabundant browsing

Hypothesis 3b) The abundance of Columbine is likely to increase due to overcompensation

Hypothesis 3c) The abundance of Columbine will not show dramatic change due to browsing

To test effects of browsing on columbine I surveyed columbine in ten different locations. I took two different approaches; one with focal plants and one with survey plants.

Focal plants:

In two of the ten study sites, three plants were caged to prevent herbivory by large mammals (including deer and marmots), but not to exclude pollinators. Cages were constructed of large wire mesh, (2in x 4in). These three plants were paired with nearby uncaged plants of similar size and stalk number for comparisons. Once a week I visited these plants to take counts of different variables: number of browsed and unbrowsed flowering stalks, number of browsed and unbrowsed leaves, number of expanding (or

new) leaves, number of small, medium, large and aborted buds, number of flowers, number of fruits, and finally number of seeds per fruit.

Survey plants:

I selected ten sites in the Gothic area, five inside the RMBL fence and five outside. In each site, six *Aquilegia coerulea* plants were randomly selected and marked. These survey plants were monitored three times during the season for counts of browsed and unbrowsed flowering stalks.

Results

Question 1:

The data collected from 6 deer surveys support the hypothesis that deer are more abundant inside the protection of the RMBL fence than outside (table 1). More deer were seen overall, and per minute of observation inside the fence. A chi squared test was used to compare observed deer frequencies with expected frequencies calculated from time spent observing: $\chi^2 = 10.896$, $df = 1$, $p < 0.005$

Table 1: Cumulative Results from Deer Surveys

	Inside			Outside		
	Meadow	Forest	Total	Meadow	Forest	Total
# deer observed	9	7	15	3	0	3
# minutes observing	86	56	142	69	107	176
Mean # deer/minute	0.093	0.125	0.091	0.043	0	0.017

Figure 1: Deer Survey Route past 401 study sites



Question 2:

Data from plant transects did not support the hypothesis that deer browse more heavily in sites located inside the fence than outside the fence. There was, however, significant variation among sites in browsing rates. Further analysis revealed that browsing was more intense in meadow habitats than in aspen forests. The browsing deviation from the mean of each study site is illustrated in figure 2.

Site Effects:

Out of the 51 species observed across all transects, there were 16 that occurred with an average frequency over 1.5 individuals per site. Average browsing % ranged from 0 to 50% within these 16 species

Table 2: Average frequencies and browsing % for 16 most abundant species in transects

Species	Frequency/ 5m transect	Browsed frequency %
Lathyrus leucanthus	4.30	0.01937984
Potentilla pulcherrima	4.27	0.11328125
Thalictrum fendleri	2.78	0.01796407
Ligusticum porteri	2.58	0.0516129
Galium septentrionale	1.77	0.02830189
Vicia americana	1.73	0
Helianthella quinquenervis	1.65	0.12121212
Valeriana occidentalis	1.63	0.24489796
Aquilegia coerulea	1.37	0.5
Taraxacum officinale	1.20	0.11111111
Fragaria virginiana	1.05	0
Achillea lanulosa	0.98	0
Erigeron speciosus	0.88	0.0754717
Geranium richardsonii	0.82	0.24489796
Viola nuttallii	0.72	0.09302326
Pseudocymopterus montanus	0.55	0.09090909

Overall average frequency was calculated by averaging 2 census periods of average frequencies per 5 meter transects.

Average browsing % was calculated by dividing total # of browsed individuals in 2 census periods over the total frequency of individuals in a species in 2 censuses.

Site/Location Effects:

Deer frequencies were found to be higher inside the RMBL fence than outside. Contrary to patterns of deer abundance observed during deer surveys, deviation from the mean browsing frequency was not greater inside than outside the fence. Although mean deviations show that browsing was slightly but not significantly higher inside than outside the fence, (Inside = 0.02030, Outside = -0.01172). Anova indicated this difference was not significant (table 3a,b).

Table 3a: Analysis of Variance of Habitat and Location: Browsing Deviation Response

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	9	0.5114500	0.056828	2.4717
Error	198	4.5522694	0.022991	Prob > F
C. Total	207	5.2016670		0.0108

Table 3b: Effect Tests

Source	DF	Sum of Squares	F Ratio	Prob > F
Habitat (Meadow vs. Forests)	1	0.25732909	11.1925	0.0155
Location (In vs. Out)	1	0.05536828	2.4082	0.1717
Habitat*Location	1	0.01125150	0.4894	0.5104

Although fence effect (location) was not significant, habitat effect was, indicating that different habitats, either aspen forests or open meadows have different mean browsing deviations (see figure 3). Mean browsing deviation was significantly higher in meadows than in forests, (Meadow = 0.061, Forest = -0.026) also see figure 2, table 3.

Patterns of browsing seen in *Aquilegia coerulea* were positively correlated with overall browsing patterns across species, (figure 2 and 3). This means *Aquilegia* was browsed just as much, if not more in 5 out of 10 cases, than all the species in the same site.

($R^2 = 0.3287$, $t = 1.979$, $df = 8$, $p = 0.0423$, 1 tailed)

Figure 2: Mean browsing deviations across sites (bars) and survey Aquilegia (points).

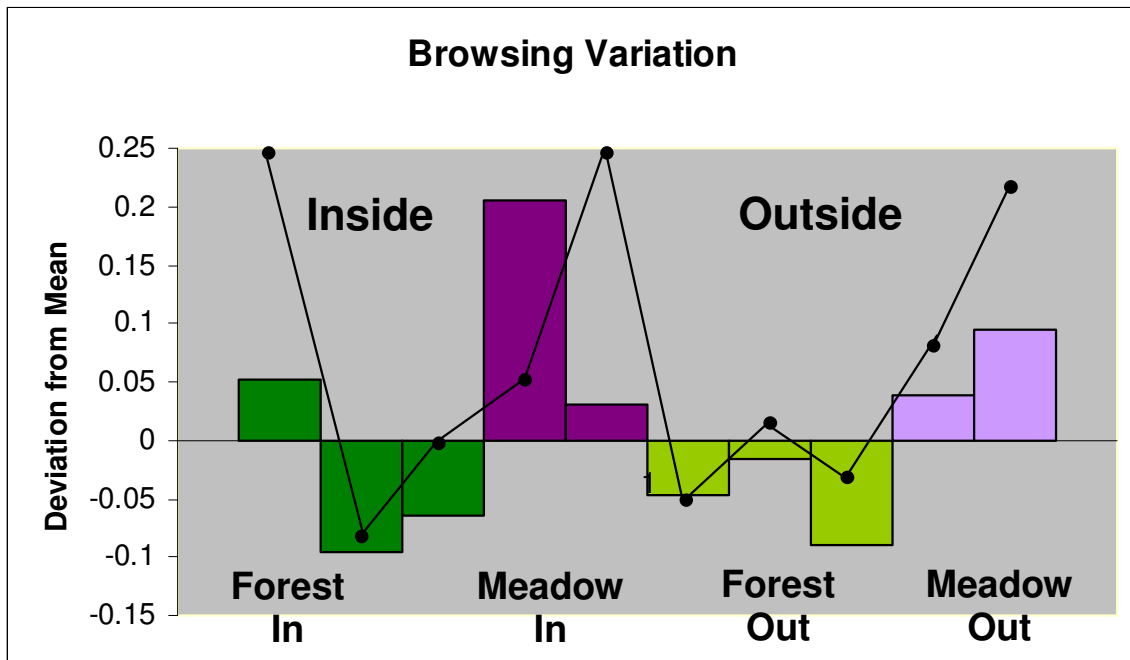
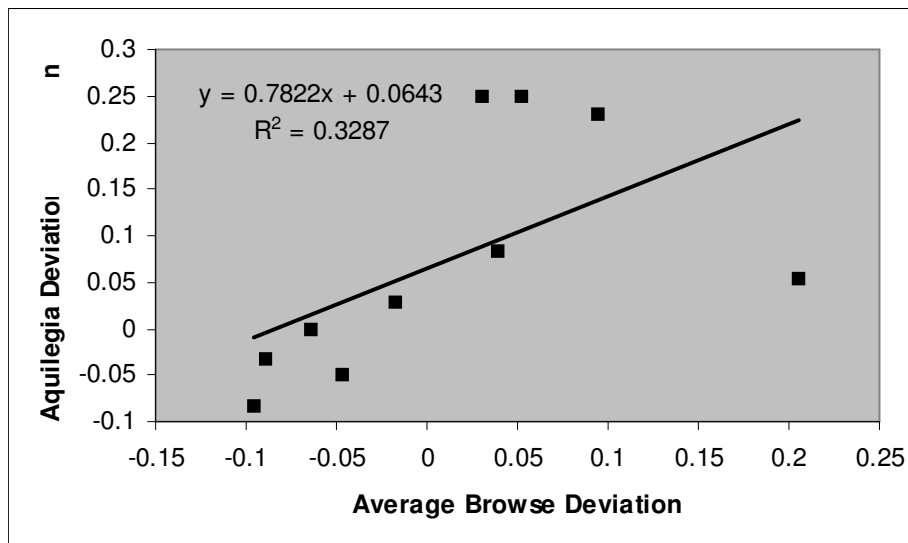


Figure 3: Correlation between survey Aquilegia and browsing patterns across species



Question 3: How is browsing likely to affect the Columbine population?

In the first census of focal plants, a small fraction of leaf stems were browsed, but because this number did not increase throughout the season I decided to stop counting leaf stems at the third census and focus on flowering stalks. Early season herbivory to leaf stems could be caused by deer or small mammals. Flowering stalks were observed to be browsed by deer.

During my surveys I saw different scenarios of browsing that should be mentioned for better interpretation of data. Sometimes the flowering stalks of a plant would be completely browsed, leaving no flowers to produce fruits. Other times, only terminal flowers and buds would be eaten, leaving lateral stems to flower. Flowering stalks that showed this kind of damage were counted as browsed when calculating percentages of browse flowering stalks. Only 2% of uncaged flowering stalks remained completely unbrowsed at the end of the season, however a few of the plants shown to be 100% browsed still produced fruits laterally. Treatment showed a significant effect on flowering stalks browsed. ($F_{(1,8)} = 174.9094$, $P < .0001$)

By the last census, there were significant differences between the fruit and seed production of caged and uncaged *Aquilegia* focal plants (table 4).

Table 4: Mean differences in *Aquilegia* measures of fitness

	Caged Plants	Uncaged Plants
Average Fruits per plant	18.500	5.333
Average Carpels per plant	96	34
Average Seeds per plant	2563.67	990.17

Uncaged plants produced 28.8% of the fruits as caged plants, 36.2% of total carpels and 38.6% of seeds.

Seeds and correlated Carpel Size (Area)

The seeds per plant averages were estimated from a regression of seeds vs. a measure of carpel size (figure 4 and table 5). The formula for the regression (seeds = 3.1459049 + 0.430004 Area) was used with average areas of caged and uncaged carpels. (Caged = 55.86 mm², Uncaged = 60.16 mm²). Although average size of carpels of uncaged plants was larger than caged, there was no significant treatment effect on carpel size. The regression in figure 4 is for all focal plants. Specific regression formulas for caged and uncaged plants were different but not significantly.

All focal plants: seeds = 3.15 + 0.43 * Area

Caged: seeds = 4.14 + 0.41 * Area

Uncaged: seeds = -6.65 + 0.61 * Area

Figure 4: Bivariate Fit of Seeds per Carpel by Carpel Area for Focal Plants

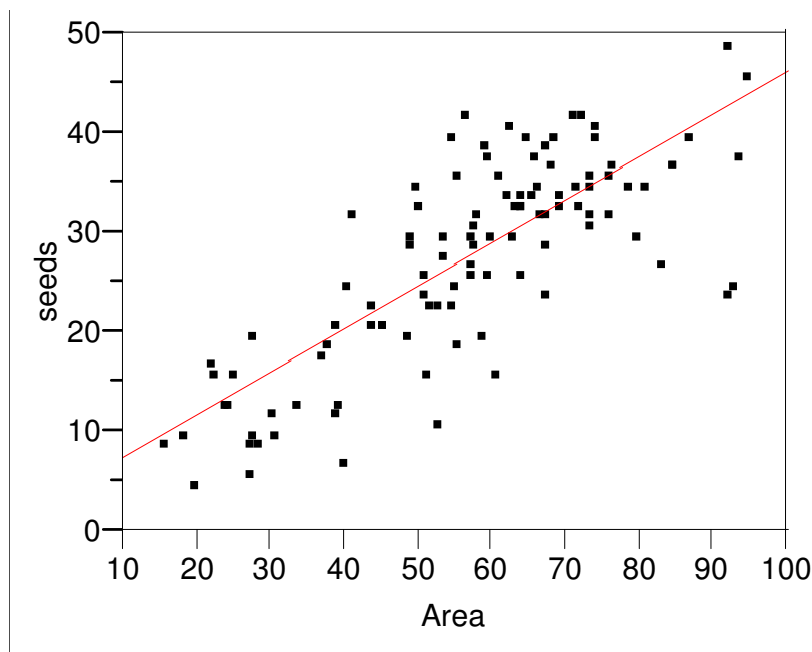


Table 5: Mean Carpel Areas for caged (c) and uncaged (u) focal plants.

Plant	Mean(Area)
1c	52.3868966
1u	58.0175
2c	42.5814286
3c	49.2563636
4c	76.523
5c	58.2335714
5u	63.1990909
6c	56.1833333
6u	59.25875

Seed Set

Anova showed that caging treatment had an effect on average seed set at significance level .07 (table 6a, b).

Table 6a: Analysis of Variance on Focal Seed Set

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	520.0833	520.083	10.5959
Error	10	490.8333	49.083	Prob > F
C. Total	11	1010.9167		0.0086

Table 6b: Effect Tests of Caging on Seed Set of Focal *Aquilegia coerulea*

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Treatment	1	1	7427680.0	4.0227	0.0727

Discussion

Deer abundances

Deer were observed more often inside the protection of the RMBL fence than outside. I speculate that the main reasons for this preference are the exclusion of competing ungulates, cattle specifically, and protection from hunters and predators. The fence may create a “safe haven” atmosphere that deer are aware of. Another reason my data could reflect this result is that there might have been a higher proportion of meadows observed inside the fence. Not only do deer prefer to browse in meadows, (discussed in the next section) but it is much easier to see deer in an open field than between the aspen trees. There could have been more deer on the trails outside the fence, beyond my visibility range in the forest. In less accessible areas of wilderness, I wonder if deer are as abundant compared to preserved valleys like Gothic. In unprotected wilderness they may be at higher risk for predation and hunting, but unbothered by human interaction. Perhaps deer have learned which areas are safer than others and become accustomed to tourists and scientists in exchange for security. Another interesting trend I found while observing is that the deer populations in the immediate area consist primarily of does and fawns, not once did I observe a buck on a deer survey. It has been observed that females, especially does with young, are significantly more aware of surrounding risks (Trixie Lee, 2005). It must also be noted that whenever a deer was observed, so was the observer. It was impossible to tell if the deer was sited moving to another area or running away from me. I could not observe deer browsing on deer surveys for this reason.

Relative Browsing of Plant Species and Resistance

Analysis of my transects revealed that deer browse significantly more in meadows than in forests, but did not significantly browse more inside the fence than out. It could be that meadows provide higher quality forage than forests where plants compete with aspen trees for resources. The species compositions in the two habitats could be different as well; it is possible that more palatable plants grow in open meadows. Meadows also offer better visibility of surroundings which reduce the risk of predators and maximize foraging efficiency. (Lee, 2005)

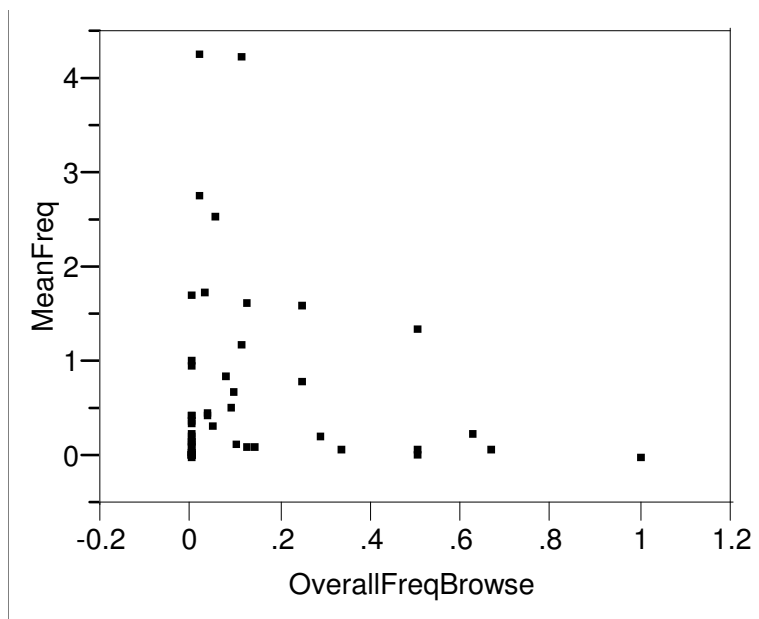
Transect data also provided a wealth of information concerning plant species community composition, abundance and relative browsing rates in areas where *Aquilegia* are found. From observation alone I can infer which plants are resistant to browsing simply because they are so abundant. *Heracleum lanosum* and *Ligusticum porteri* for example are extremely abundant and almost never browsed. There are other species that were very rare but were browsed when I encountered them in my transects (table 7). It is possible that these species have already been impacted by selective deer browsing. It is my impression from simply walking around Gothic all summer observing plants, that *Pedicularis bracteosa* is another species like *Aquilegia coerulea* that is being impacted greatly by deer browsing.

Table 7: Plant species with low frequencies and high browsing percentages in transects

Species	Frequency/5m transect	Average browsed %
<i>Populus tremuloides</i>	0.01666667	1
<i>Ipomopsis aggregata</i>	0.03333333	0.5
<i>Pedicularis bracteosa</i>	0.1	0.5
<i>Valeriana edulis</i>	0.1	2.5

A scatter plot (figure 5) of average frequency and overall browsing reveals no linear relationship. There are two extremes: plants that were very abundant and hardly ever browsed and plants that were highly browsed and not very abundant. There's a cluster of species that were neither abundant nor browsed.

Figure 5: Bivariate Fit of Average Frequency By Overall Freq. Browsing



Impacts upon *Aquilegia coerulea*

Significant differences were found between the fitness caged and uncaged plants. Plants open to browsing had far fewer flowering stalks, fruits, carpels and seeds. The uncaged plants did however produce slightly larger carpels and more seeds per carpel. I have speculated two reasons for this: one, that browsed plants have fewer reproductive parts to divide resources among, and two, browsed plants have fewer flowers and would receive less self pollen and consequently higher fitness.

The primary measure of fitness is seed set. According to my focal plant study, browsed *Aquilegia coerulea* produce almost 40% of the seeds that they would have. I think deer browsing has already had an impact on Columbine abundance in the Gothic area. I predict that the Colorado state flower will become less and less frequent in areas where deer populations are increasing.

Works Cited

Belsky, A. J. 1986. Does herbivory benefit plants? A review of the evidence. *American Naturalist* 127:870-892.

Cote, S.D., T.P. Rooney, J. Tremblay, C. Dussault, and D.M. Waller. 2004. Ecological Impacts of Deer Overabundance. *Annu. Rev. Ecol. Evol. Syst.* 35:113-47

Freddy, D.J., G.C.White, M.C.Kneeland, R.H. Kahn, J.W. Unsworth, W.J. deVergie, V.K. Graham, J.H. Ellenberger, and C.H. Wagner. 2004. How many mule deer are there? Challenges of credibility in Colorado. *Wildlife Society Bulletin* 32(3):916-927

Gill, R.B., 1999. Declining Mule Deer Populations in Colorado: Reasons and Responses. A Report to the Colorado Legislature. Colorado Division of Wildlife.

Lee, T., 2005. Antipredatory Response of Mule Deer.

Rooney, T.P., and D.M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management* 181:165-176

Sharaf, K. 1999. The effects of ungulate herbivory on phenology, pollination, and reproductive success in *Ipomopsis aggregate*. REU program.