

Determining Long-Term Success of Revegetation Efforts in Disturbed Sites

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ABSTRACT

At the Rocky Mountain Biological Laboratory (RMBL), revegetation is an important area of research because there are many areas of disturbed land that are more vulnerable to the spread of invasive species. In my project, I revisited a former student's revegetation work in order to determine the long-term success of her transplanting efforts. I found that *Potentilla pulcherrima*, *Fragaria virginiana*, and *Erigeron speciosus* were still alive after three years, but none of the *Linum lewisii* and only half of the *Achillea millefolium* survived. My findings differed from her initial results, mainly that side of cabin affects the height and flowering of some transplant species. When determining percent cover of the plant community around Mammal Lab and in an undisturbed meadow, I found more nonnative plants, grasses, and transplants on the south side of Mammal Lab, where there is more sunlight. There was also more bare ground on the north side of Mammal Lab, compared to the south side. In my project I also tested the effects of various treatment methods (fertilizer, potting soil, peat moss, and native soil) on transplant survival, height, flowering, and number of new leaves produced. None of the treatment methods significantly affected these plant traits, but results may differ when looking at the long-term transplant community.

INTRODUCTION

Revegetation is an attempt to reverse environmental disturbance caused by human impact. If a natural system is altered, its ecological role is either eliminated or substantially changed (Cairns 1988). The goal of restoration is to restore biodiversity and create an environment hospitable to native plant and animal species. To achieve this goal, the spread of invasive species, which alter ecosystems and lower biodiversity, must be slowed and eventually stopped. Since disturbed areas are more vulnerable to the spread of invasive species, it is critical to revegetate these areas. Transplanting native species is a good revegetation technique since this vegetation represents a genetic product of an environment that is already adapted to the extreme conditions of an area (Sheley et al. 2008). Native plants are well suited to establish in disturbed sites, and their use is more likely to prevent later successional changes that are unrepresentative of an area (Hnada and Jefferies 2000).

There are many different methods of revegetation, including natural recruitment of vegetation, seeding of native and introduced species, transplanting vegetation, fertilizer application, and use of peat or mulch. The success of these methods has been debated, especially the effectiveness of fertilizers. Several

researchers have shown that fertilizer can provide desirable nutrients for growing plants and soil microbial populations. However, fertilizers can also negatively affect the plant community by favoring competitive invasive species (Peteresen et al. 2004). Also, many native plants are well adapted to soils with few nutrients, making the use of fertilizer unnecessary. Transplanting of native species is usually preferable to reseedling in harsh environments (Hnada and Jefferies 2000). In a high-altitude meadow ecosystem, the growing season is very short and the highly compacted soil of many disturbed sites is a poor seedbed (Cole and Spildie 2006). Transplanting also accelerates the restoration of disturbed sites, since unassisted recovery of plant cover can be a very slow process.

This issue of revegetation is important when considering the ecological and aesthetic quality of all plant and animal life in Gothic, Colorado. Revegetation is necessary in order to reverse the damage done by construction and renovation around cabins. If native plants can be salvaged and transplanted, local gene pools and ecotypes can be preserved around RMBL (Sheley et al. 2008). Effective revegetation techniques also improve the physical, biological, and chemical properties of the soil by restoring native vegetation (Cole and Spildie 2006).

In 2006 Helen Beeson researched revegetation after disturbance in high-altitude meadow ecosystems. She transplanted 100 native plants (20 of five different species: *Potentilla pulcherrima*, *Fragaria virginiana*, *Erigeron speciosus*, *Linum lewisii*, and *Achillea millefolium*) in the disturbed area around the newly renovated Mammal Lab. She tested the effects of varying amounts of sunlight, plant size prior to transplant, and species on survival, new growth, and reproductive success. Helen suggested that the best species for future revegetation projects are *Erigeron speciosus* and *Fragaria virginiana*, since they produced the most new growth after transplantation. She also concluded that side of cabin (which correlates with the amount of sunlight, temperature, and soil moisture) and size of plant prior to transplant had no effect on plant survival and new growth.

Helen's findings offer an interesting starting point for my own revegetation research. **The goal of my research was to study the long-term success of Helen Beeson's transplanting efforts around Mammal Lab and to improve upon her techniques by experimenting with different treatment methods on transplanted plants.** In the first part of my experiment, I compared Helen's initial results to the current state of vegetation around Mammal Lab. In the second part of my experiment, I attempted to improve upon Helen's revegetation techniques by experimenting with different treatments such as fertilizer, nutrient-rich soil, peat moss, and native soil on transplants of *Potentilla rubricaulis*. I tested to see if these different treatments had an effect on plant survival, growth, and reproductive success (based on flowering).

My expectations were that peat moss would help the initial survival of the transplants, since peat decreases water loss, moderates soil temperatures, stabilizes the soil surface, and provides protection from frost and herbivores (Cole and Spildie 2006). This organic layer can also provide a “continual release of nutrients to colonizers in the growing season” (Hnada and Jefferies 2000.) However, previous research has shown that while fertilizer and peat increased the growth of transplants, it had little effect on survivorship (Cole and Spildie 2006). My expectations were that added nutrients from fertilizer and potting soil might increase growth and reproductive success of the transplants. However, in previous studies inorganic fertilizers were found to be detrimental to the growth of plants, especially at high elevation (Cole and Spildie 2006).

In the first part my research project, I studied the long-term success of Helen’s transplants around Mammal Lab. My questions were: Are some transplant species more likely to survive than others three years after transplantation? Are the transplants doing as well as the same species in an undisturbed meadow (based on height of plant and flowering)? What does the transplant community look like three years later compared to an undisturbed meadow? In the second part of my study I looked at success of transplants with four different treatments. The question I asked was: Do different treatment methods have an effect on transplant survival, growth, and reproductive success?

METHODS

In order to determine the success of Helen’s revegetation work she performed in 2006, I surveyed the area around Mammal Lab. Helen put tags on the transplants, so my first step was finding the tags and determining the presence or absence of the five native species she planted (*Potentilla pulcherrima*, *Linum lewisii*, *Fragaria virginiana*, *Erigeron speciosus*, and *Achillea millefolium*). I used a Fisher’s Exact test to analyze statistically whether long-term survival differed among species. I also studied the relative success of each species by comparing Helen’s revegetated plants (on both the north and south side of the cabin) to a random sample of native plants of the same species in an undisturbed meadow. I compared these three populations based on height of plants and whether each plant was flowering. I did this in order to understand if Helen’s transplants were doing as well as plants in an undisturbed meadow. In the meadow I used a 20-meter transect to find the same five species Helen revegetated. I made 2 x 2 meter plots every 2 meters, alternating on each side of the transect. In each of these plots I hoped to find one of each of the five transplanted species and measure its height and whether it was flowering. In this part of my experiment I used one-way ANOVA to test the effect of site (north and south side of Mammal Lab and

undisturbed meadow) on differences in the height of plants among species. I used a Fisher's Exact test to see whether site influenced the likelihood of flowering. Next I used plant quadrats (10 quadrats .5 x .5 meters on each side of the cabin and in the meadow along my transect) to look at the current makeup of the plant community around Mammal Lab in comparison to that of the undisturbed meadow. I determined percent cover of surviving transplants, native plants that have established naturally, invasive plants, grasses, and bare ground, and analyzed these data using a chi-squared test. I did this to get a picture of what the plant community of a revegetated area looks like three years after transplantation. I also used plant quadrats in the undisturbed meadow to compare that community to the transplanted community.

When I used different treatments on my transplants, I had $\frac{1}{4}$ planted in native soil, $\frac{1}{4}$ treated with fertilizer, $\frac{1}{4}$ planted in nutrient-rich soil, and $\frac{1}{4}$ planted in peat moss. I used "Miracle-Gro" fertilizer, which was primarily made up of nitrogen (24%), soluble potash (16%), and available phosphate (8%). The potting soil was "Earth-Gro Organic Hummus and Manure," made up of 90% organic hummus (peat, compost, forest products, manure, and organic materials) and 10% manure. It contained .05% nitrogen, .05% available phosphate, and .05% soluble potash. The peat moss was "Fison's Sunshine" peat moss, made with sphagnum moss. My sample size was 40 plants, with ten in each treatment. I performed these different treatments on *Potentilla rubricaulis* and kept all other conditions (sunlight and watering) constant. I chose *Potentilla rubricaulis* as my transplant species mainly because it was the most available plant I could remove from Barclay Cabin, which is in the process of being renovated. There were a few of these species around the disturbed area, so I knew it was able to grow in that area. Also, Helen's revegetation research shows that *Potentilla pulcherrima* had a high survival rate after transplantation. I watered my transplants everyday in the morning, unless it had rained the previous day. A Fisher's Exact test was used to analyze the survival of plants in the different treatments. At the end of my experiment, I analyzed the success of the revegetation based on height of plant, number of original leaves vs. number of new leaves, and whether the plant was flowering. When measuring height of plant, I took weekly measurements throughout the summer to determine growth rate for the four different treatments. I used a MANOVA test to determine whether transplant treatments (native soil, potting soil, fertilizer, peat moss) affected plant height and whether that effect changed over time. An ANCOVA test was used to determine whether transplant treatments significantly affected plant growth measured as number of new leaves. The covariate was number of original leaves, which is a measure of plant size. I used a Fisher's Exact test to see if treatment method affected whether the plant flowered.

RESULTS

Part One: Long-Term Success of Helen's Transplanting Efforts around Mammal Lab

When looking at long-term survival of Helen's transplants around Mammal Lab, there is a significant relationship between species and whether the plant survived or died three years after transplantation (Fischer's Exact Test, $P < .001$, $N = 61$, $DF = 4$; Fig. 1). Most *Potentilla pulcherrima*, *Fragaria virginiana*, and *Erigeron speciosus* survived since 2006, whereas none of the *Linum lewisii* survived. Similar amounts of *Achillea millefolium* were present and absent.

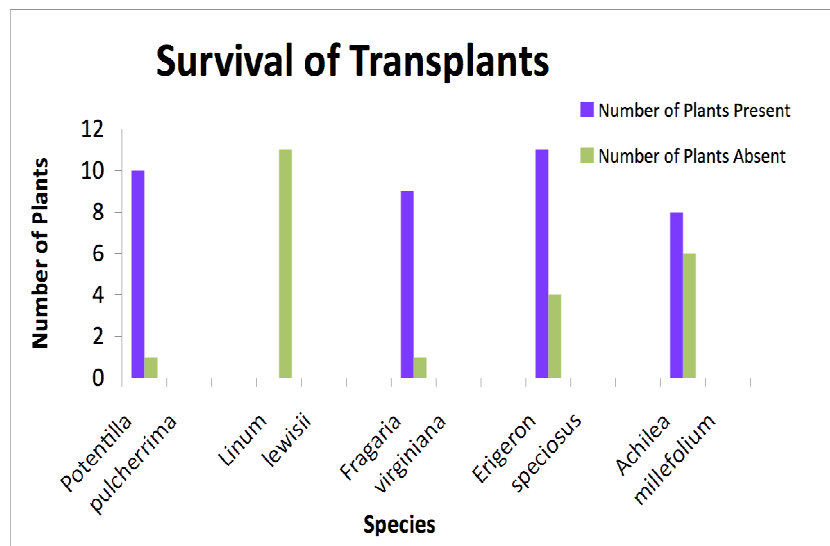


Figure 1: Survival of Helen's transplants around Mammal Lab

For *Potentilla pulcherrima* and *Erigeron speciosus*, whether or not the plants flowered depended on the site (Fischer's Exact Test, $P = .016$, $N = 20$, $DF = 2$ and $P = .0088$, $N = 21$, $DF = 2$, respectively; Fig. 2). *Potentilla pulcherrima* was more likely to flower in the undisturbed meadow, while *Erigeron speciosus* was more likely to flower on the south side of the cabin. For *Fragaria virginiana* and *Achillea millefolium*, there was not a significant relationship between flowering and site (Fischer's Exact Test, $P = .2$, $N = 11$, $DF = 2$ and $P = .2$, $N = 11$, $DF = 2$, respectively; Fig. 2). *Linum lewisii* was not statistically analyzed because no transplants survived.

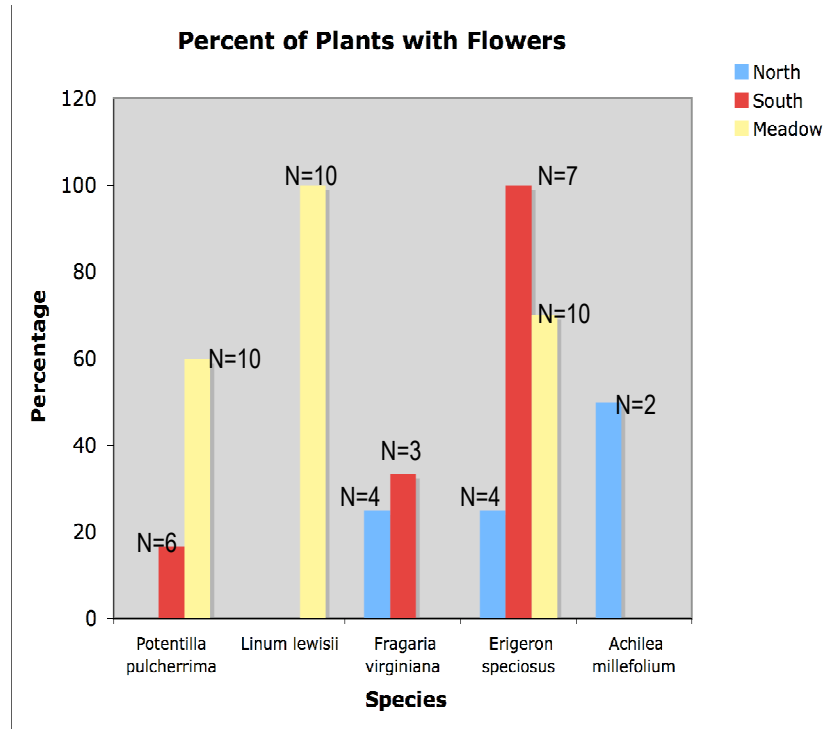


Figure 2: Percent of plants with flowers on the north and south side of Mammal Lab and an undisturbed meadow

A significant relationship was found between height of plant and species, as well as between height of plant and site (ANOVA, $P=.0043$, $N_{\text{parm}}=3$, $DF=3$ and $P<.0001$, $N_{\text{parm}}=2$, $DF=2$, respectively; Fig. 3, Table 1). *Linum lewisii* appears to be the tallest plant, followed by *Potentilla pulcherrima* and *Erigeron speciosus*. In general, the tallest plants were found on the south side of the cabin, followed by the meadow and then the north side of the cabin. I also found that there is a significant interaction between species and site in the effect on plant height (ANOVA, $P=.0462$, $N_{\text{parm}}=6$, $DF=6$; Table 1).

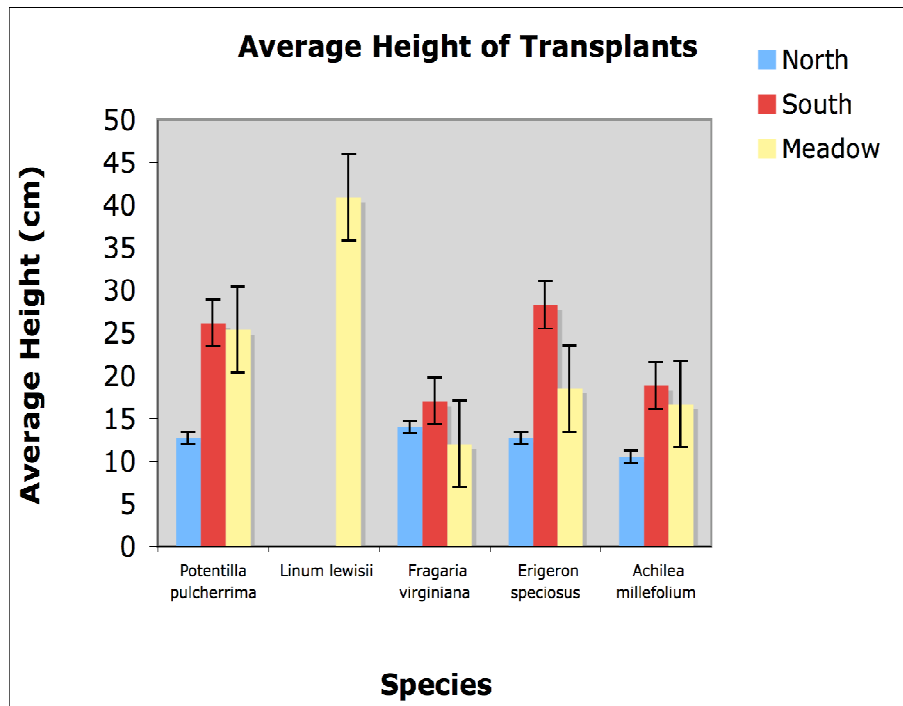


Figure 3: Average height of plants on the north and south side of Mammal Lab and in an undisturbed meadow

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Species	3	3	484.41971	4.9567	.0043
Site	2	2	793.46032	12.1783	<.0001
Species*Site	6	6	454.83146	2.3270	.0462

Table 1: ANOVA table for average height of transplants around Mammal Lab and in an undisturbed meadow

There was also a difference in the plant community make-up between the north and south side of Mammal Lab, as seen in Figure 4. The percent cover differed significantly between the north and south side of the cabin (Chi-squared, $\chi^2=36.889$, $P<.001$, $N=269$, $DF=4$; Fig. 4). The amount of native plants on both sides was strikingly similar. However, more nonnative plants, transplants, and grasses were observed on the south side, while more bare ground was found on the north side.

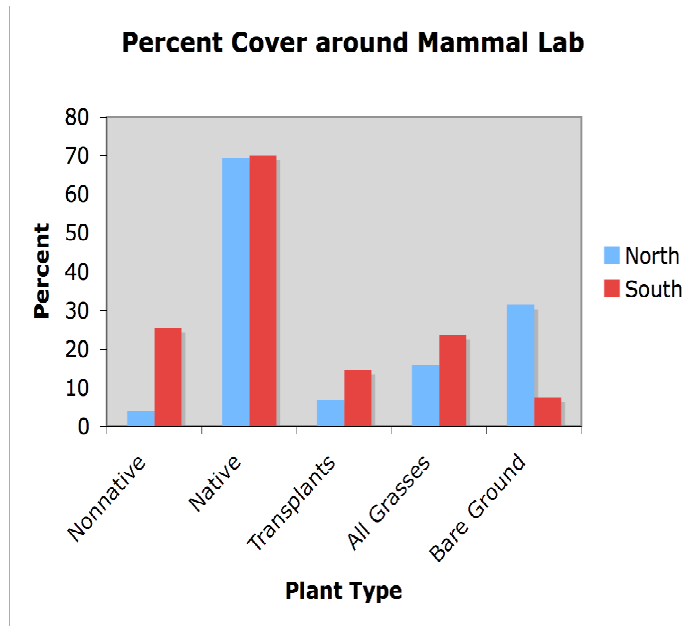


Figure 4: Percent cover of transplanted forbs, native forbs naturally colonizing, grasses, nonnative plants, and bare ground on the north vs. south side of Mammal Lab

When comparing the percent cover around Mammal Lab to that of the undisturbed meadow, a significant difference was also found in plant community make-up (Chi-squared, $P < .001$, $\chi^2 = 61.881$, $N = 407$, $DF = 6$; Fig. 5). There were very few nonnative plants observed in the meadow, while there were more native plants, grasses, and bare ground.

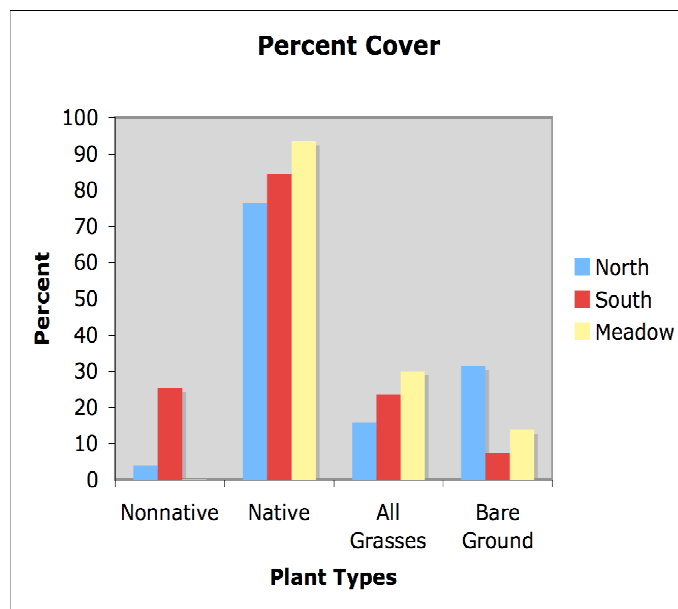


Figure 5: Percent cover of nonnative forbs, native forbs naturally colonizing, grasses, and bare ground on the north vs. south side of Mammal Lab and in an undisturbed meadow.

The numbers of species that make up the transplants, native plants, and nonnative plants on each side of the cabin and in the meadow can be seen in Table 2.

Species	North	South	Meadow	Native, Nonnative , Transplant ?
Achilea millefolium	0	1	0	Transplant
Achilea millefolium	2	5	0	Native
Androsace septentionalis	1	5	0	Native
Collomia linearis	2	0	4	Native
Descurainia incisa	144	0	0	Native
Dugaldia hoopesii	1	0	0	Native
Erigeron speciosus	1	8	0	Transplant
Erigeron speciosus	0	3	47	Native
Fragaria virginiana	2	0	0	Transplant
Fragaria virginiana	7	24	0	Native
Gayophytum parviflorum	18	0	0	Native
Hackelia floribunda	34	7	0	Native
Helianthella quinquenervis	0	0	5	Native
Ipomopsis aggregata	0	0	18	Native
Lathyrus	0	0	7	Native
Linaria vulgaris (invasive)	7	86	0	Nonnative
Linum lewisii	0	0	164	Native
Mentha arvensis	0	4	0	Native
Oligosporus dracunculus	0	11	63	Native
Polemonium foliosissimum	25	46	4	Native
Polygonum minimum	46	5	1	Native
Potentilla pulcherrima	0	2	0	Transplant
Potentilla pulcherrima	11	27	44	Native
Rumex triangulivalvis	28	53	0	Native
Senecio bigelovii	0	0	4	Native
Taraxacum officinale	2	24	0	Nonnative
Thalictrum fendleri	3	0	1	Native
Tragopogon dubius	0	0	1	Nonnative
Trifolium spp.	1	0	0	Nonnative
Unknown aster	2	0	0	Native
Unknown arrow leaf	50	0	0	Native
Viguera multiflora	13	26	102	Native
Viola spp.	1	0	0	Native

All grasses				
Bromus spp.				Native
Carex spp.				Native
Festuca thurberi				Native
Phleum spp.				Nonnative
Poa spp.				Native
Unknown grass 1				
Unknown grass 2				

Table 2: Species totals for the north and south side of Mammal Lab and the undisturbed meadow

Part Two: Success of Transplants with Four Different Treatment Methods

The four different treatments used on *Potentilla rubricaulis* did not have an effect on plant survival, as almost all plants survived (Fischer's Exact Test, $P=.3$, $N=40$, $DF=3$; Fig. 6).

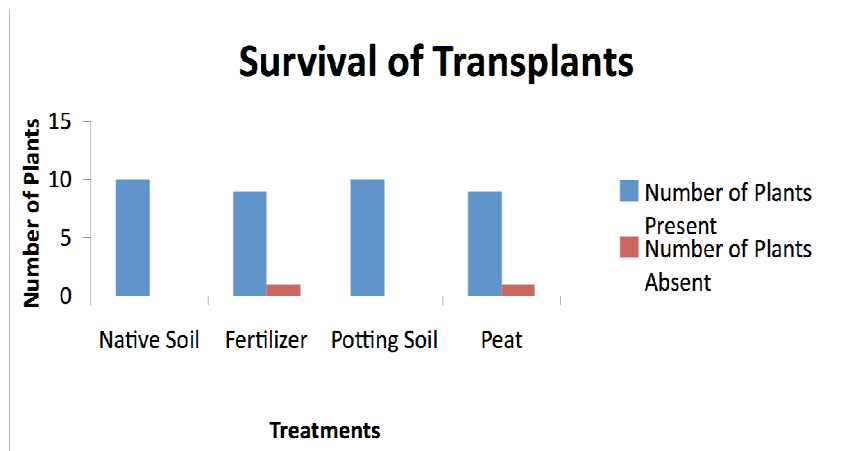


Figure 6: Survival of transplants in four different treatments

Success of flowering among transplants was also not significantly affected by treatment method (Fischer's Exact Test, $P=1.00$, $N=40$, $DF=3$; Fig. 7).

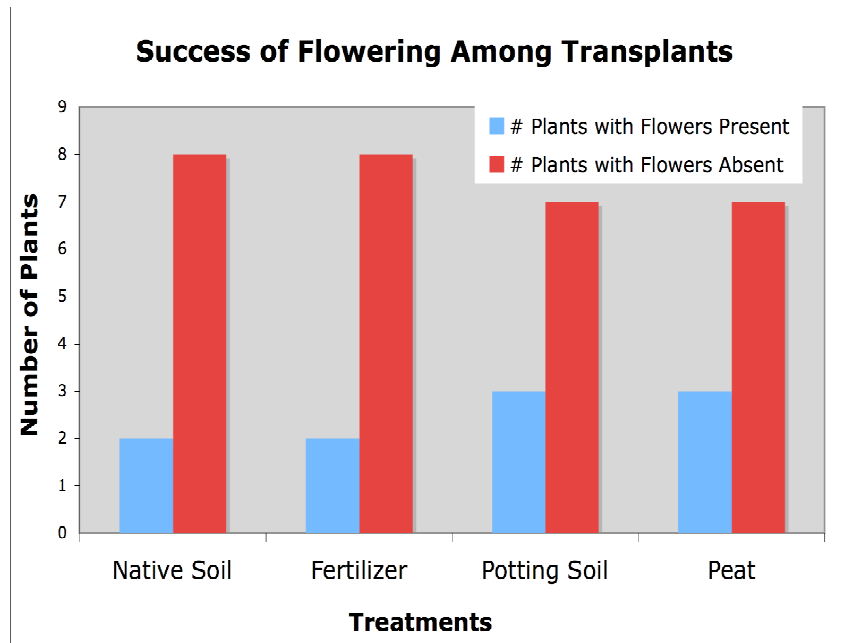


Figure 7: Success of flowering among transplants with four different treatments

Height of transplants was not significantly affected by treatment (MANOVA, $P=.6567$, NumDF=3, DenDF=34; Fig. 8, Table 3), but it was significantly affected by time (MANOVA, $P<.0001$, NumDF=4, DenDF=31; Fig. 8, Table 3). A Wilks' Lambda test was used to analyze the interaction between time and treatment on height of plant, where no significant relationship was found (MANOVA, $P=.9095$, NumDF=12, DenDF=82.31; Table 3).

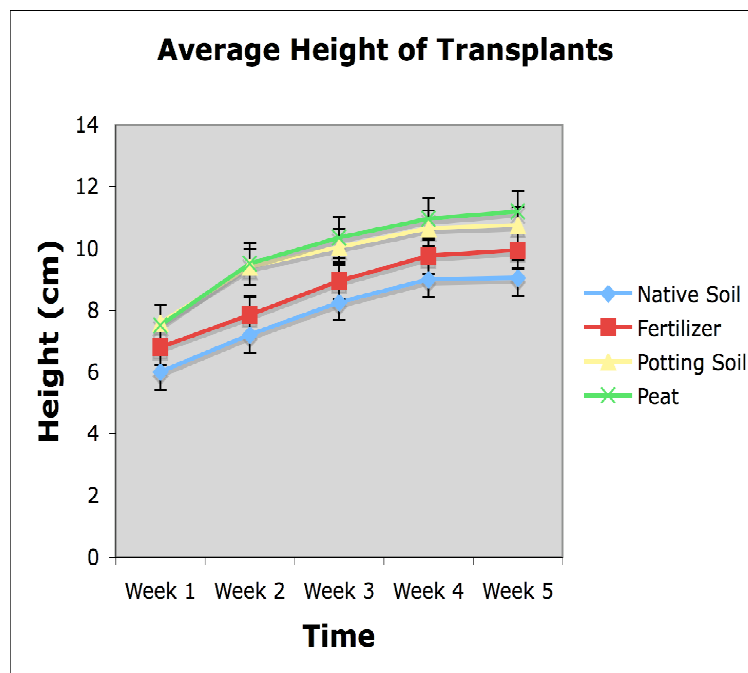


Figure 8: Average height of transplants in four different treatments

	Test	Value	Exact/Approx F	NumDF	DenDF	Prob>F
Treatment	F Test	.0478384	.5422	3	34	.6567
Time	F Test	1.8991365	14.7183	4	31	<.0001
Time*Treatment	Wilks' Lambda	.8303478	.4993	12	82.31	.9095

Table 3: MANOVA table for height of transplants in four different treatments

There was no significant effect of treatment on number of new leaves produced (ANCOVA, $P=.1454$, $N_{\text{parm}}=3$, $DF=3$; Fig. 9, Table 4). There was a significant effect of the covariate, number of original leaves (a measure of plant size), on number of new leaves produced (ANCOVA, $P=.0118$, $N_{\text{parm}}=1$, $DF=1$; Fig. 9, Table 4).

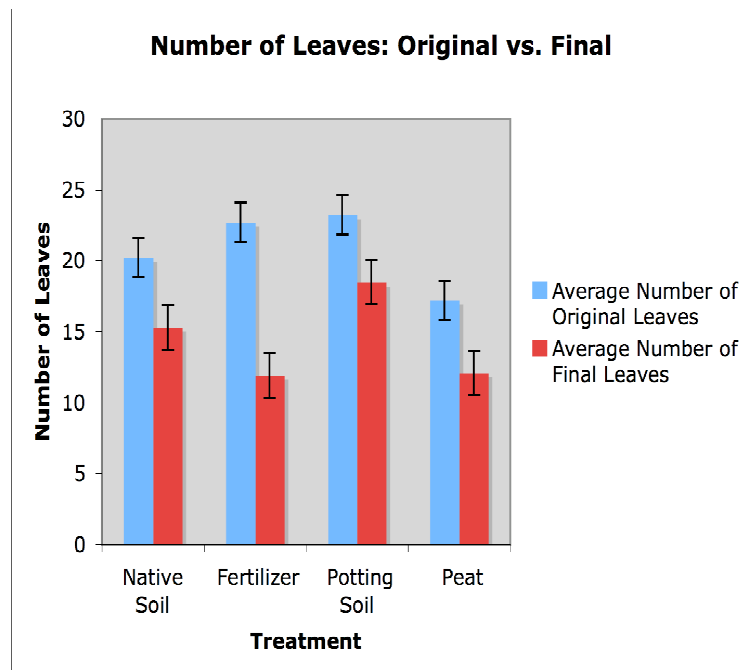


Figure 9: Original number of leaves vs. final number of leaves

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Treatment	3	3	144.50160	1.9132	.1454
Number of Original Leaves	1	1	177.74580	7.0602	.0118

Table 4: ANCOVA table for original number of leaves vs. number of new leaves for four different treatments

DISCUSSION

I found some differences between Helen's initial transplanting results in 2006 and the current plant community around Mammal Lab. After the summer of 2006, all of Helen's 100 transplants survived, but not

all of them are present three years later. None of the *Linum lewisii* transplants survived over the course of three years; however, there are many in the undisturbed meadow. These results suggest that *Linum lewisii* might have a hard time recovering over winter after it is transplanted. There were also many *Achillea millefolium* plants that did not survive over the course of three years, but there aren't too many of this species in the meadow either. If time and effort is going to be spent transplanting, *Potentilla pulcherrima*, *Fragaria virginiana*, and *Erigeron speciosus* are good candidates. Several years after transplanting, these three plants do comparatively well as plants in a nearby undisturbed meadow. Helen also found that side of cabin did not have a significant effect on reproductive success determined by flowering. However, I found that for *Potentilla pulcherrima* and *Erigeron speciosus*, side of cabin did have a significant effect on flowering. More plants flowered on the south side of the cabin, where there is the most sunlight. Side of cabin also influences height of plants, with the taller plants found on the south side. It is important to pick the right species when transplanting because some have higher survival rates than others. I would recommend *Potentilla pulcherrima*, *Fragaria virginiana*, and *Erigeron speciosus* as good species to transplant in the future.

When comparing percent cover of the different sides of Mammal Lab, it was found that nonnative plants do establish at disturbed sites after transplanting efforts. *Linaria vulgaris* and *Taraxacum officinale* are common around Mammal Lab, while there were very few nonnative plants found in the undisturbed meadow. While establishing native plant communities may decrease the spread of nonnative plants in disturbed areas, it does not completely stop nonnative species from establishing. While the same amounts of native plants were found on the both sides, more nonnative plants and transplants were found on the south side. This may be due to the increased amount of sunlight or drier soil of the south side. There was more bare ground on the north side, as well as some different species that were not found in the meadow (*Descurainia incisa*, *Gayophytum parviflorum*). These species that do well establishing in disturbed areas are prime candidates for revegetation efforts. From observation, you can tell that the plant community is thriving more on the south side three years after Helen's transplanting efforts. However, Helen's transplants are a small portion of the current plant community. Transplanting is still a worthwhile revegetation technique, since many of the seeds from the transplants spread and were able to colonize the area.

When looking at the four different treatment methods performed on *Potentilla rubricaulis*, no effect was seen on plant survival or production of flowers. Almost all plants survived, and only a handful of plants in each treatment flowered. Future research could determine whether or not treatment method is a significant factor in long-term plant survival or reproductive success. Also, height of plant was not

significantly affected by treatment method. The number of new leaves produced by the plant was not affected by treatment method, but it was significantly affected by number of original leaves on the plant. Number of original leaves is a measure of plant size; therefore, plant size prior to transplant has an influence on number of new leaves produced. This conclusion contradicts Helen's 2006 results, that plant size prior to transplant does not affect new growth. Previous transplanting research found that plant survival increased with size of plant. Most plants were still alive seven years after being transplanted (regardless of treatment), with survivorship mostly depending on soil moisture during the summer (Cole and Spildie 2006). Most revegetation work needs long-term study in order to determine long-term success of different species and different treatments. I expect that plants grown with fertilizer or potting soil might have greater seed production in the future due to the added nutrients. I also expect that in a few years, a significant difference should be seen between height of plants that were treated with fertilizer, potting soil, or peat and plants that were not treated (those planted in native soil). Previous revegetation work has shown that transplants treated with fertilizer and peat had "significantly higher growth than those in bare soil after two growing seasons" (Hnada and Jefferies 2000). Fertilizer and potting soil give added nutrients to the plants, while peat ensures adequate soil moisture for plant growth. However, the benefits of native soil must not be overlooked. Native soil helps maintain the native thermal cycle and promotes nutrient cycling by restoring microbial and mycorrhizal communities (Hnada and Jefferies 2000). Soil microorganisms play an important role in soil formation and revegetation by accumulating organic matter, increasing available plant nutrients, and improving soil texture and water-holding capacity (Cundell 1977). Native soil may also contain seed, rhizomes, and other vegetation plant parts that could help reestablish a native plant community when transplanted (Howard and Samuel 1979). Hopefully my 38 surviving transplants will make it through the winter and sow the seeds of a new plant community in a previously disturbed area.

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