

The impact of climate change on Rocky Mountain plant communities: Differences
in floral traits along an elevational gradient of transplanted communities

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Abstract

Alpine climates are seemingly adverse environments for plants. These habitats directly impact plants via pollinator scarcity and abiotic factors like extreme temperatures and precipitation that influence resource allocation. As a result, elevational gradients are natural laboratories that can be used to examine how climate shapes plant form, function, and diversity. The aim of this project is to assess the effects of temperature and snowmelt date on the floral traits and reproductive phenology of experimental transplanted communities along an elevational gradient. Traits measured in this study were flower length, diameter, petal length, and height of the highest flower; phenology stages recorded were bud, flower, withered petals, and fruiting. Data collection occurred along three subalpine meadow sites off of Washington Gulch Road in Crested Butte, CO, each of which contains transplanted turfs from higher/lower on the mountain as well as both transplanted and untouched control plots. Comparisons between controls on the elevational gradient show that diameter is least affected by changes in elevation, whereas height of the highest flower changes significantly. Additionally, floral traits measured in transplants are more similar to those of their original site than those in their destination site. This indicates a lesser degree of phenotypic plasticity and more genetic determinacy in the floral traits measured, which could pose serious concerns to the reproductive fitness of these communities in the future as climate change rapidly alters alpine environments.

Introduction

Alpine climates are known to be inhospitable for vegetation growth. As elevation increases, temperatures decrease, precipitation becomes more extreme, snow cover shortens growing seasons, wind velocity increases, and nutrient availability decreases (Peng et al., 2012).

Additionally, the abundance and diversity of pollinators tend to decrease as elevation increases. In some cases, this trend causes direct changes in plant functional traits, such as flower morphology, in order to decrease competition among the already limited pollinator populations (Cuartas-Hernández et al., 2019). Differences in microclimates found between small changes in vertical elevation make mountains prime ecosystems in which scientists can experimentally model predictions for greater global trends such as climate change. These elevation changes are associated with highly divergent selective pressures on plants and phenotypic variation (Frei et al., 2014). Floral traits are considered to be primarily selected by pollinators due to their central role in plant reproductive success (Campbell and Powers, 2015). However, other studies have also implicated the roles of environmental factors such as soil nutrients as well as biotic factors like herbivores, implying that floral traits are also subject to inherent resource costs of the flowers to the plant (Galen, 1999).

Many studies on both plants and pollinators in alpine environments have documented the effects of increased elevation on floral traits between similar montane environments. Generally, floral structures tend to increase in size at higher elevations, even as overall plant size decreases due to less resources and extreme conditions (Maad et al., 2013; Dai et al., 2017). This increase in both display size and overall structure “showiness” is considered an investment in compensation for the general scarcity of pollinators at higher altitudes. Similarly, many alpine flowers also exhibit open, actinomorphic displays rather than specialized structures in order to utilize a more limited, generalized pollinator assemblage at high elevation (Peng et al., 2012). Some species allocated as much as three times more above-ground biomass to floral structures than anything else (Fabbro and Korner, 2003).

Opposite trends in flower morphology and elevation have also been recorded. Such contrasting results are thought to stem from a number of other factors intrinsic to alpine environments. Lower alpine pollinator visitation rates can alternatively result in an increase in self-pollination among certain species, which can subsequently decrease flower size as the plant no longer needs to expend energy into larger floral structures to attract pollinators (Maad et al., 2013). Alternatively, in high elevation populations with smaller flowers but less evidence of selfing, the decrease in floral display size may be indicative of stronger resource limitation of seed sets (Totland 2001). In the Taisetsu Mountains of Japan, no flower size gradient was found, and floral traits in the study sites were more variable among populations within each site than among sites on their snowmelt gradient (Kasagi and Kudo 2001).

The fact that all floral trait studies do not result in similar data trends highlights the potential importance of phenotypic plasticity in adverse and variable conditions. For example, previous work on the Himalayan alpine plant *Pedicularis siphonantha* has found that floral traits like phenology, longevity, and display size can exhibit strong phenotypic plasticity. When transplanted into a new population downslope on the mountain, these plants diverged from their original traits to converge with the characteristics of their warmer host population (Dai et al., 2017). Analysis of the resource-cost hypothesis (which predicts that smaller, inconspicuous flowers are more advantageous under resource-poor conditions) similarly alluded to the importance of plasticity in these environments, stating that floral display sizes may be affected not only by pollinators but also by herbivores and abiotic environmental factors (Galen 1999). As such, plasticity in allocation to floral traits is considered a crucial aspect of many alpine species which may face a changing set of conditions to their survival.

Similar trends were found in studies focusing on phenology, which is also influenced by pollinator competition, especially in a high-altitude environment where pollinator species are limited by factors such as nutrients, resources, and strong winds. Plants at these greater elevations have advantages in better temperature and water availability, but restricted time periods in which they can grow, flower, and disperse (Lara-Romero et al., 2014). As a result, phenology is a major factor in a plant's ability to adapt to adverse habitats. In the Rocky Mountains, flowering phenology is primarily determined by the amount of snow cover and snowmelt date, which can vary drastically in short time periods as it did between the extremely dry summer of 2018 and the unusually late snowmelt of 2019, further emphasizing the role of phenotypic plasticity in a plant's adaptability (Howard and Ward, 1965). Flower longevity (the duration of time for which the plant is in the *flowering* phenology stage) is also a specific metric of interest at higher elevations. Studies that contrast with other literature by reporting that there is no significant difference in floral structure or size as elevation increases often find that instead flower longevity increases to allow a greater window for successful pollination (Peng et al., 2012; Trunschke and Stöcklin, 2017). Increased plasticity for flower longevity becomes an advantage in an alpine environment, as pollination opportunities and success rates are often unpredictable and thus plants capable of lengthening or restricting their flowering time based on climatic conditions and pollinator presences have higher rates of reproductive success. Though some studies have found no correlation between elevation and flower longevity, there is a demonstrated increase in phenotypic plasticity for longevity at higher elevations (Trunschke and Stöcklin, 2017).

This study examined how changes in temperature and snowmelt date influence floral traits and phenology along an elevational gradient of transplanted communities. The turfs of

intact vegetation that have been moved to higher or lower sites allowed for direct investigation of the effects of different climate scenarios on these measurements, and the drastic change they have undergone in a relatively short time span (transplanted in 2017) tests the limits of their plasticity in relation to origin and destination sites. I tested results against a null hypothesis that no statistically significant changes in floral traits and phenology would be found along the elevational gradient of the transplant, and the alternative hypothesis that differences would be significant. Data that supports the alternative would indicate a degree of phenotypic plasticity in floral traits in these plant communities, whereas a failure to reject the null hypothesis would support the idea of niche conservatism in these reproductive characteristics. The role of plasticity in the reproductive success of transplanted communities can be used as an indicator of predicted responses to climate change and the future conservation of these species and plant communities.

Methods

Sites

I collected data within the transplant experiment established by Lorah Seltzer, a doctoral student working with Brian Enquist at the University of Arizona. This experiment spanned three sites along Washington Gulch Road in Crested Butte, CO: Upper Montane (elevation of 2,900m), Pfeiler (3,200m), and Monument (3,300m) as seen in **Figures 1 and 2**. Each transplant site has six blocks of five* 0.5m² turfs, each of which has been removed from the ground intact and replanted at either a higher or lower site (or within the same site as a control). There are also several untouched controls that were not removed from the ground. Following Rocky Mountain Biological Laboratory requirements, all transplanted turfs and half of the untouched controls were covered in thin netting to prevent gene flow between transplanted and non-transplanted plants.

*Some blocks have only four plots due to gopher damage over the years; block 6 in Upper Montane has six plots. Additionally, the plots in block 6 of each site were transplanted in 2018, one year after the first set of transplants.

Trait Collection

The floral traits I measured (see **Figure 3.** in appendix) were flower diameter (mm), petal length (mm), flower length (mm), and height of the highest flower (cm). For radially symmetrical flowers, I measured diameter once, whereas for those with bilateral symmetry I recorded two diameters – D1 and D2 – to properly represent the flower size. For inflorescences, I measured the diameter and flower length measurements of the entire inflorescence (acting as one visual display in the context of pollination) in addition to the petal length measurement of one floret. Due to the fact that the first flowers produced by an individual may in some cases be larger in size than later flowers, if possible, I recorded the dimensions of the first flower of an individual (if not, the most recent was used instead).

These traits are indicative of the general size of the flowers, which provides context as to the general allocation of resources and prioritization of flowers within each species. Further measurements (such as stigma and anther arrangement or corolla length) were not feasible for this project as proper measurement requires dissection of the flower, and the transplant plots are still currently being studied and as such cannot be damaged or tampered with. The traits chosen for this experiment were measured noninvasively with a pair of digital scientific calipers.

I collected floral trait data once per site primarily at the peak season (a community level indicator of biomass) period for each plot. For each peak measuring day, one flower from each flowering individual in each plot was measured for all traits, and the total number of flowers for

that individual was also recorded. In the case of inflorescences, the number of flowers was sometimes approximated based on the specific morphology of the flower.

Statistical Analyses

I used three main comparisons of the data to analyze patterns along the transplant elevational gradient. First, I compared controls (including within site transplants, untouched controls, and netted untouched controls) across the three sites to demonstrate effects of the elevational gradient without manipulation. Second, I compared transplants (both cooled and warmed either one or two steps) to the controls of their origin sites to see how their composition and traits had changed as a result of the treatments. Third, I compared warmed and cooled transplants to the controls of their destination sites in order to evaluate how much plasticity the traits had demonstrated to adapt to their new environment.

Due to the relatively small sample size of each treatment (approximately five plots per site), statistical analyses may not be the only relevant indicator of results. Accordingly, I also displayed the data via distribution plots. Each trait (diameter 1, diameter 2, petal length, flower length, and height of the highest flower) for each site (low, middle, and high elevation) was tested for normality via a Shapiro-Wilk test. Results indicated that most of these variables were not normally distributed ($p < 0.05$). As such, differences in each trait between sites were tested with a two-sample Wilcoxon Rank Sum Test for significance.

Results

Sampling Distribution

I sampled a total of 323 individuals from 22 different species at peak measurement days over the course of this survey. The low site had the highest number of individuals (145), while

the middle (94) and high (84) sites were more equal. The most commonly measured species overall was *Delphinium nuttallianum*, with a total of 73 individuals, though the majority of these are from the low site, with only 5 found at the high site. *Sedum integrifolium* was the second most frequently sampled at 40 individuals and was more evenly distributed between the three sites. Presence or absence of each species can be seen in **Figure 4**. The total number of species at each site was approximately even (15 at low site, 16 at middle site, and 14 at the high site), though the distribution of species in the sampled individuals varied (**Figure 5**).

Comparison of controls along elevational gradient

Analysis of the data for flowers in the controls plots along the elevational gradient indicated that diameter 1 did not change significantly ($p = 0.084, 0.123, 0.472$) for the two-sample Wilcoxon Rank Sum Test between any of the three sites. In contrast, maximum flower height data showed significant differences ($p < 0.001$) between all of the sites. Diameter 2 (for zygomorphic flowers only) and petal length differed significantly only between low and middle controls ($p = 0.019$ and $p = 0.045$, respectively), and flower length differed significantly between the low and middle sites ($p = 0.019$) as well as between the middle and high sites ($p = 0.013$). (See **Table 2** for all p-values). Distribution plots showing comparisons between the controls for all five measured traits can be seen in **Figure 6**. In general, the findings for the controls demonstrate that of the floral traits measured, maximum flower height is most significantly changed as elevation increases whereas diameter is the least affected. Maximum flower height decreased between the low and middle sites, but increased slightly between the middle and high sites.

Comparison of transplants to their origin sites

The two-sample Wilcoxon Sum Rank Test indicated that overall transplanted plots in all sites were more similar to their origin sites than significantly different (**Table 3, Figure 7**). The plots transplanted from the high site and warmed two steps to be replanted at the low site had no significant differences in any of the traits ($p = 0.794, 0.889, 0.363, 0.204$, and 0.145), whereas the plots transplanted from the low site and cooled two steps to be replanted at the high site had the most significant differences in traits (diameter 1, $p = 0.012$, diameter 2, $p = 0.039$, and maximum flower height, $p < 0.001$).

In terms of each floral trait, differences were not uniform across site comparisons. Maximum flower height had the most significant differences (four) out of the six total possible transplant to origin comparisons. In contrast, petal length and flower length differed the least with each having one significant difference between sites. Diameters 1 and 2 each had two out of six significant differences. Distribution plots for each trait in each comparison site can be seen in **Figure 5**.

Comparison of transplants to their destination sites

As tested by a two-sample Wilcoxon Sum Rank Test, the transplanted plots are generally more significantly different from the destination sites in which they now reside than similar. None of the floral traits differed significantly over every comparison, nor did any consistently measure only insignificant differences (**Table 4**). Diameter 2 and petal length were the only traits to differ more significantly than not. Diameter 2 changed significantly in comparisons between respective destination sites both warmed (one step and two step) transplants at the low site ($p = 0.011, p = 0.042$), the cooled one step transplant at the middle site ($p = 0.003$), and the cooled one step transplant at the high site ($p = 0.020$). Petal length changed significantly when compared to destination sites in the one step warmed transplant at the low site ($p = 0.003$), the

one step cooled transplant at the middle site ($p = 0.017$), the one step warmed transplant at the middle site ($p = 0.018$), and the one step cooled transplant at the high site ($p = 0.020$). All other traits had three insignificant and three significant differences each, though not for the same comparisons. Full trait distributions for each destination site and its transplants are given in **Figure 8**.

Discussion

Species Distribution

Unusually late snowmelt dates in the summer of 2019 delayed the growing season for many plant communities, especially at higher elevations, and pushed back peak biomass dates for all sites along the elevational gradient. Other early flowering species of *Delphinium* have been recorded in the past to vary in abundance according to winter snowpack, and as such is often used as an example of the effects of climate change (Inouye and McGuire, 1991). The significant proportion of this species in the low site sampling and lesser abundance at both higher sites may be a marker of the effects of climatic alteration on community composition along elevational gradients. Snowmelt dates are drivers of phenology, and as previous studies have shown not all plants and insects respond evenly to changes in the growing season (Totland and Alatalo, 2002). This can lead to mismatch between plants and their pollinators, lowering reproductive success and placing more importance on properly adapted floral traits.

Controls, Transplants, Origins, and Destinations

Along the unmanipulated elevational gradient, the low and middle sites showed the most differences in floral traits, while the lowest and highest sites showed the least differences. This is somewhat unexpected since species richness at the lowest and highest sites differs more than richness at the lowest and middle sites. This incongruence may be a result of abiotic factors

separate from elevation, such as soil type, or biotic factors, such as species abundance. Further work that differentiates traits between each species may be needed to better understand these patterns.

Statistical comparisons between origin and destination controls and transplants indicate that though no floral traits show uniform differences across all treatments, in general there are more differences between transplants and their destination sites than between transplants and their origin sites. As a result, the floral traits in the plant communities resemble those of their origin sites and have changed minimally if at all to accommodate their new surroundings.

These strong similarities in the floral traits of the transplanted community and its origin site indicate a prevalence of genetic determination, or niche conservatism, rather than phenotypic plasticity. It may also be possible that the plant communities may not have had enough time to adapt to their new environments since the plant communities were transplanted only two years prior to this study. Though adaptive plasticity may occur given more time, many climatic changes are predicted to occur rapidly in the future and plant communities may have to adapt more quickly to survive. Niche conservatism of floral traits in particular may pose a serious problem to the reproductive fitness of these communities, as these traits control both the quality and quantity of pollination (Waser, 2012). Reproductive allocation is a highly plastic trait in many flowering species as an adaptive response to immediate ecological conditions; environmental stress can limit nutrients and resources and may directly cause hormonal fluctuations reducing floral development. In some cases the loss of this plasticity occurs with evolutionary assimilation when there is some cost not outweighed by uncertainty in the environmental conditions (Carr, 2013).

As climate change and environmental degradation become more prevalent global issues, especially in alpine ecosystems such as the Rocky Mountains, the abilities of plants to adapt and evolve to new environments is crucial in interpreting and predicting the future of these communities. When conditions shift more rapidly than communities or species can evolve, their survival may depend on the phenotypic plasticity of their growth and reproductive traits. The genetic determinacy alluded to in this study's floral traits may be indicative of more serious potential threats to whole alpine communities in the near future.

Further work could be done to differentiate between the factors that may drive the differences or lack thereof in floral traits between these sites. Floral traits are primarily driven by pollinators (Waser, 2012) and as such an equivalent survey of the ranges of pollinators in each area may be useful in understanding the principle causes of the differences and similarities recorded in this study. Additionally, these measurements could be continued in the future to provide a more informative long-term analysis for predicting the impacts of climate change on and potential conservation requirements of these plant communities.

Acknowledgements

I want to thank Lorah Seltzer and Dr. Brian Enquist for their mentoring, suggestions, and aid with this project. Additionally, this project was conducted on the plots transplanted, set up, and maintained by Lorah as her dissertation work and her permission to use these sites for my project is greatly appreciated. I am also grateful to Brian Maitner, Sandra Duran, Lindsay Backhaus, and Lisa Simonsen for assistance with fieldwork and data analysis. I want to thank the Rocky Mountain Biological Laboratory for the assistance, advice, feedback, and further help offered through their education program.

Literature Cited

- Campbell DR, Powers JM. 2015. Natural selection on floral morphology can be influenced by climate. *Proceedings: Biological Sciences*. 282(1808): 1-7.
- Carr DE, 2013. A multidimensional approach to understanding floral function and form. *American Journal of Botany*. 100(6): 1102-1104.
- Cuartas-Hernández SE, Moreno-Betancur DJ, Gibernau M, Herrera-Palma M, Hoyos-Serna L. 2019. Contrasting patterns of floral size variation in two sympatric species of *Anthurium* along an elevation gradient in a tropical mountain forest. *International Journal of Plant Sciences*. 180(3): 209-219.
- Dai WK, Amboka GM, Kadiori EL, Wang Q, Yang C. 2017. Phenotypic plasticity of floral traits and pollination adaption in an alpine plant *Pedicularis siphonantha* when transplanted from higher to lower elevation in Eastern Himalaya. *Journal of Mountain Science*. 14(10): 1995-2002.
- Fabbro T, Korner C. 2004. Altitudinal differences in flower traits and reproductive allocation. *Flora*. 199:70-81.
- Frei ER, Hahn T, Ghazoul J, Pluess AR. 2014. Divergent selection in low and high elevation populations of a perennial herb in the Swiss Alps. *Alpine Botany*. 124(2): 131-142.
- Galen C. 1999. Why do flowers vary?: The functional ecology of variation in flower size and form within natural plant populations. *Bioscience*. 49(8): 631-640.
- Holway JG, Ward RT. 1965. Phenology of alpine plants in northern Colorado. *Ecology*. 46: 73-83.
- Inouye DW, McGuire AD. 1991. Effects of snowpack on timing and abundance of flowering in *Delphinium nelsonii* (Ranunculaceae): implications for climatic change. *American Journal of Botany*. 78: 997-1001.
- Kasagi T, Kudo G. 2001. Variations in floral traits of sympatric alpine shrubs, *Phyllodoce caerulea* and *Phyllodoce aleutica*, along snowmelt gradients. *Polar Bioscience*. 14: 99-109.
- Lara-Romero C, García-Camacho R, Escudero A, Iriondo JM. 2014. Genetic variation in flowering phenology and reproductive performance in a Mediterranean high-mountain specialist, *Armeria caespitosa* (Plumbaginaceae). *Botanical Journal of the Linnean Society*. 176: 384-395.
- Maad J, Armbruster WS, Fenster CB. 2013. Floral size variation in *Campanula rotundifolia* (Campanulaceae) along altitudinal gradients: patterns and possible selective mechanisms. *Nordic Journal of Botany*. 31: 361-371.

- Pelabon C, Diekmann M, Graae BJ. 2013. Decoupled phenotypic variation between floral and vegetative traits: Distinguishing between developmental and environmental correlations. *Annals of Botany*. 111(5).
- Peng D, Zhang Z, Xu B, Li Z, Sun H. 2012. Patterns of flower morphology and sexual systems in the subnival belt of the Hengduan Mountains, SW China. *Alpine Botany*. 122:65-73.
- Totland O. 2001. Environment-dependent pollen limitation and selection on floral traits in an alpine species. *Ecology*. 82(8): 2233-2244.
- Totland O, Alatalo JM. 2002. Effects of temperature and date of snowmelt on growth, reproduction, and flowering phenology in the arctic/alpine herb, *Ranunculus glacialis*. *Oecologia*. 133: 168-175.
- Trunschke J, Stöcklin J. 2017. Plasticity of flower longevity in alpine plants is increased in populations from high elevation compared to low elevation populations. *Alpine Botany*. 127: 41-51.
- Waser NM. 2012. The adaptive nature of floral traits: Ideas and evidence. In Real L, ed. *Pollination Biology*. Elsevier: 241-285.

Tables and Figures



Figure 1. The experimental transplant sites, Upper Montane (2900m), Pfeiler (3200m), and Monument (3300m) in relation to the nearby towns of Gothic and Crested Butte, Colorado.

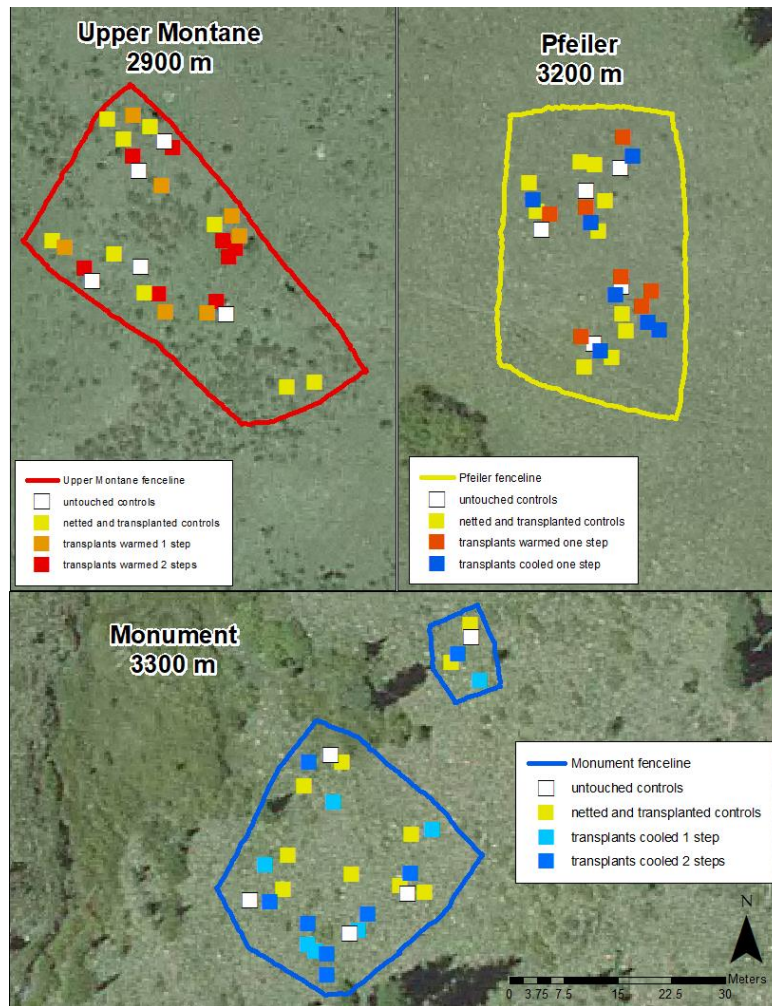


Figure 2. A layout of the plots, including transplants and controls, in each of the three sites

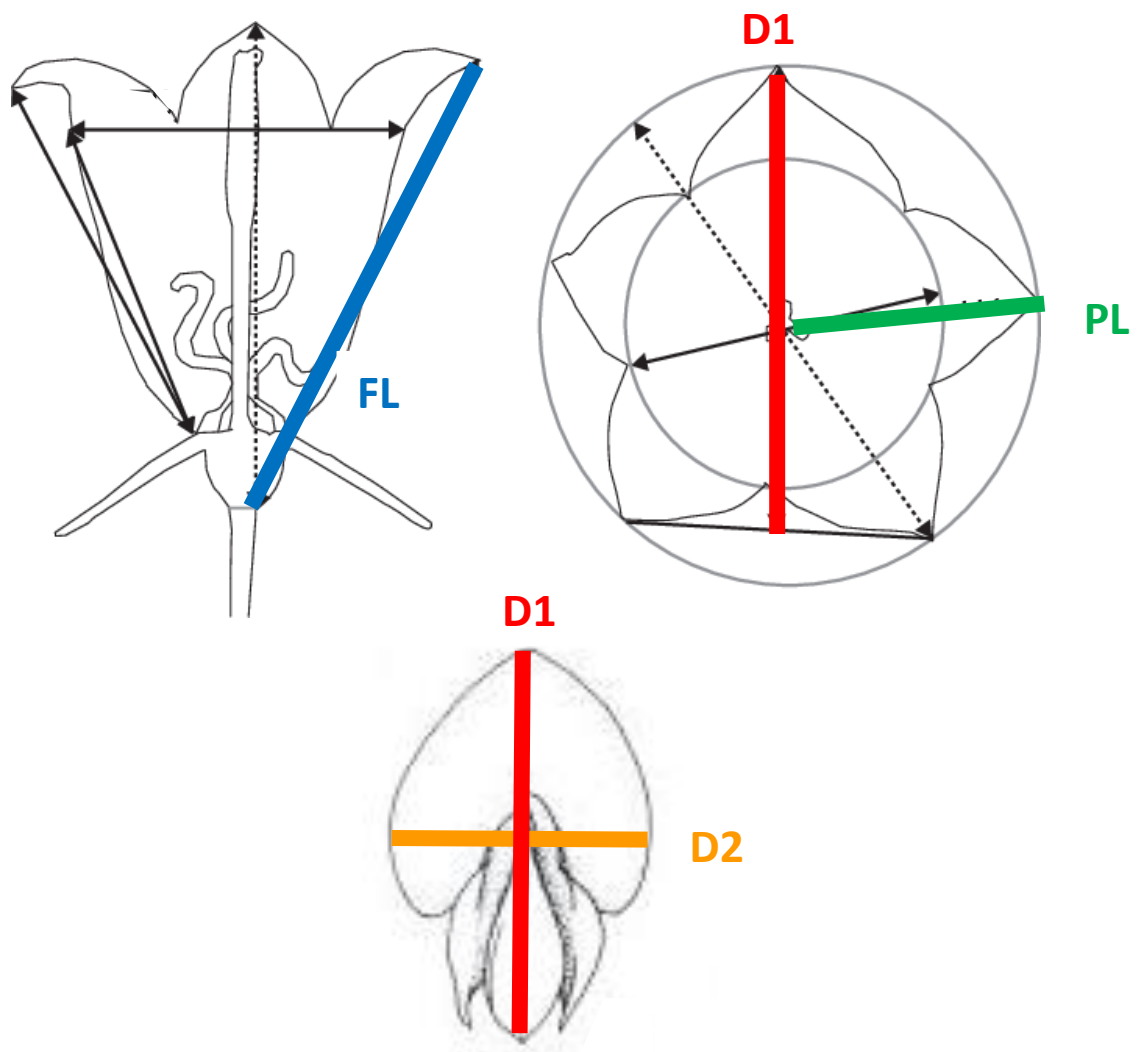


Figure 3. Traits measured are seen in this image as FL (flower length), PL (petal length), and D1 (diameter) (Figure adapted from Pelabon et al., 2013).

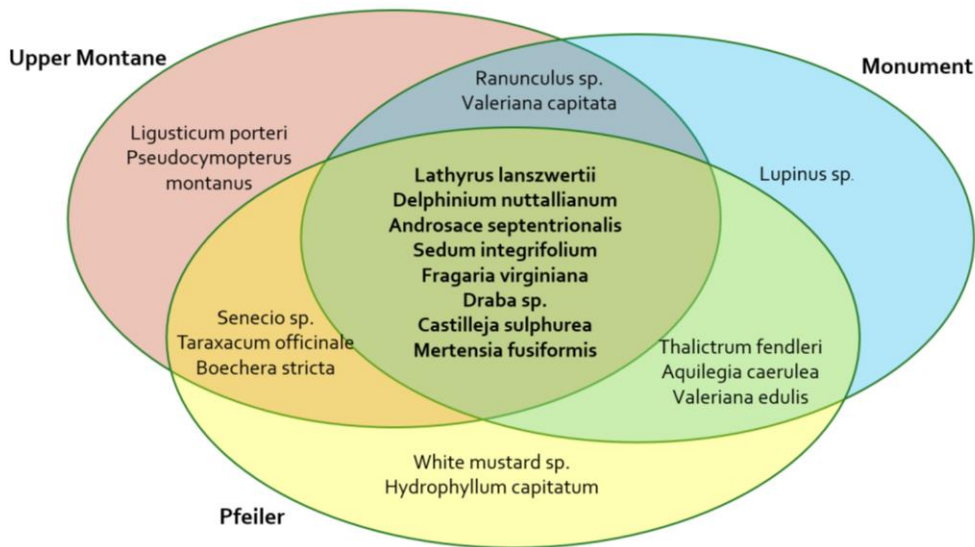


Figure 4. A Venn-Diagram showing the site locations where each species in the survey were sampled. Of the 22 species listed, 8 were found across all three sites. Both transplants and control plots are included.

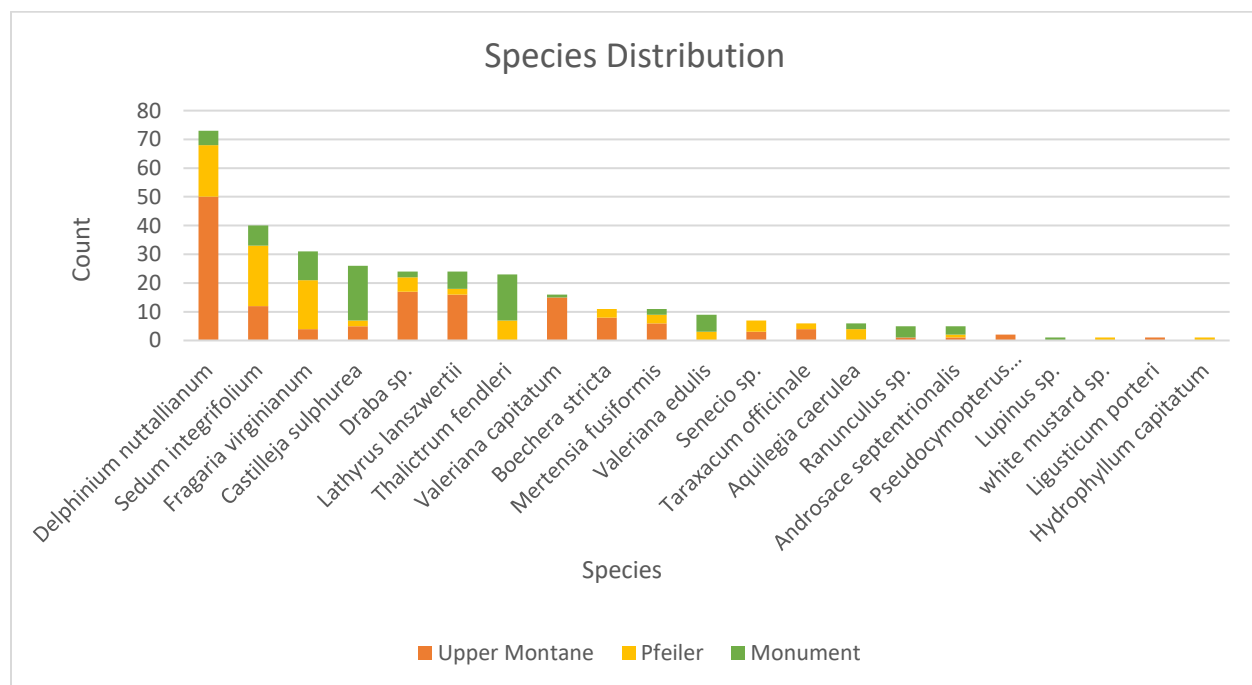


Figure 5. The number of individuals of each species sampled across the three sites (by increasing elevation) in order from most frequently sampled to least frequently sampled.

Table 1. Comparisons of all variables within and between sites.

Site	Treatment	Diameter 1 (mm)	Diameter 2 (mm)	Petal Length (mm)	Flower Length (mm)	Max Flower Height (cm)
Upper Montane	Controls	20.9 ± 8.87	25.6 ± 6.49	10.8 ± 5.93	19.9 ± 9.94	39.9 ± 19.98
	Transplants Warmed One Step	12.0 ± 7.33	17.5 ± 7.30	5.9 ± 3.39	11.4 ± 5.77	33.7 ± 21.61
	Transplants Warmed Two Steps	22.1 ± 10.73	23.8 ± 10.82	11.2 ± 8.19	16.9 ± 8.97	34.1 ± 17.96
Pfeiler	Controls	18.6 ± 8.05	19.4 ± 6.43	8.4 ± 5.02	14.7 ± 11.11	13.5 ± 12.78
	Transplants Warmed One Step	26.2 ± 15.8	20.6 ± 7.29	6.8 ± 4.43	19.6 ± 13.95	26.5 ± 9.19
	Transplants Cooled One Step	22.1 ± 11.03	29.6 ± 6.50	12.3 ± 6.17	23.1 ± 10.13	25.1 ± 11.14
Monument	Controls	22.9 ± 10.65	24.0 ± 10.20	13.6 ± 9.39	24.9 ± 17.94	28.4 ± 17.92
	Transplants Cooled One Step	18.1 ± 7.39	16.8 ± 3.79	6.7 ± 2.52	17.1 ± 5.89	25.1 ± 9.69
	Transplants Cooled Two Steps	14.6 ± 8.32	20.4 ± 8.78	9.2 ± 5.71	16.9 ± 10.48	17.1 ± 7.42

The mean and standard deviation of each floral trait for each variable group.

Table 2. Comparisons of floral traits along a 400m elevation gradient

Control Comparison	Diameter1	Diameter2	Petal Length	Flower Length	Max Flower Height
UM - PF	0.084	0.019	0.046	0.020	<0.001
PF - MO	0.123	0.308	0.079	0.013	<0.001
UM - MO	0.472	0.220	0.182	0.566	<0.001

Red shading indicates a p-value > 0.05, an insignificant difference. Green shading indicates a p-value < 0.05, a significant difference. Sites sampled are Upper Montane (UM, 2900m), Pfeiler (PF, 3200m), and Monument (MO, 3300m). Floral trait values compared were sampled in control plots only.

Control Comparisons

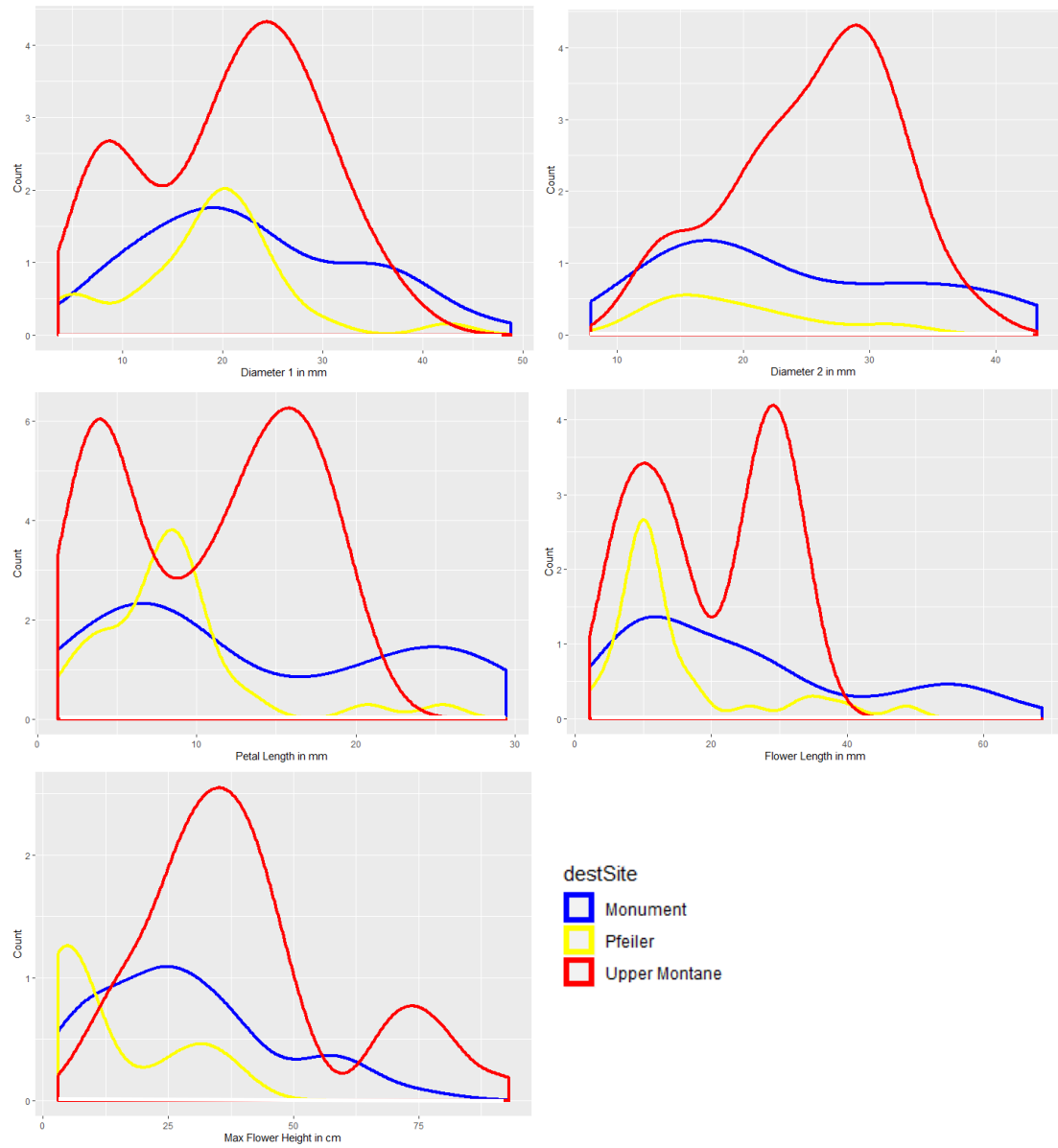


Figure 6. The distributions of each floral trait measured for all individuals sampled in the control plots at each site (Upper Montane (2900m), Pfeiler (3200m), and Monument (3300m)) across the elevation gradient.

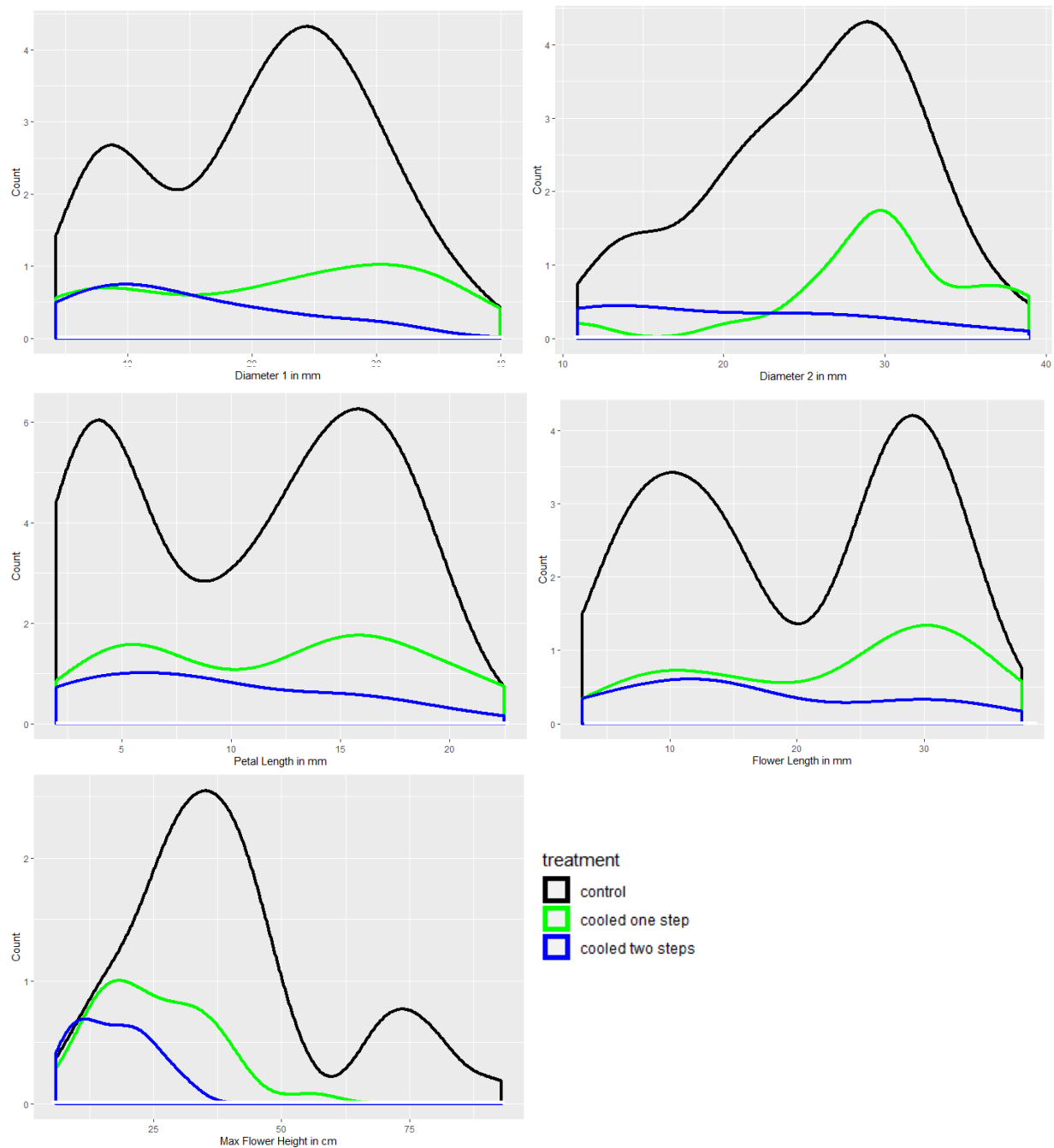
Table 3. Comparisons of transplants to the controls of their origin sites

Transplant to Origin Site Comparison	Diameter1	Diameter2	Petal Length	Flower Length	Max Flower Height
UMW1 - PFC	0.006	0.297	0.058	0.494	<0.001
UMW2 - MOC	0.794	0.889	0.364	0.204	0.145
PFC1 - UMC	0.428	0.016	0.164	0.092	<0.001
PFW1 - MOC	0.607	0.312	<0.001	0.324	0.963
MOC1 - PFC	0.917	0.440	0.264	0.013	0.006
MOC2 - UMC	0.012	0.039	0.284	0.378	<0.001

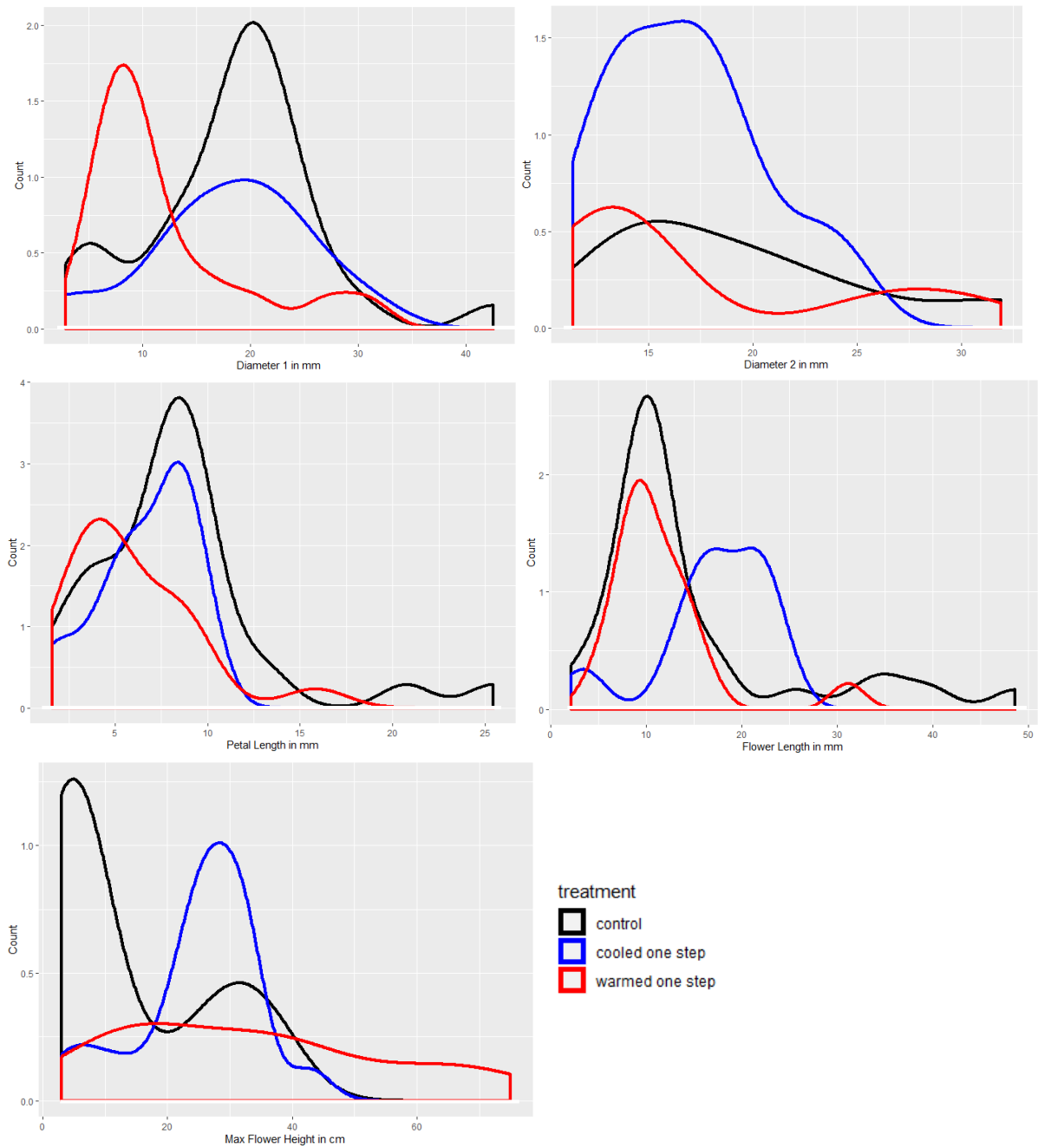
Red shading indicates a p-value > 0.05, an insignificant difference. Green shading indicates a p-value < 0.05, a significant difference. Sites sampled are Upper Montane (UM, 2900m), Pfeiler (PF, 3200m), and Monument (MO, 3300m). Treatments sampled for comparisons are Controls (C), Transplants warmed one step (W1), Transplants warmed two steps (W2), Transplants cooled one step (C1), and Transplants cooled two steps (C2).

Figure 7(a-c). A comparison of floral traits between the transplanted plots and respective origin sites.

7a. The distributions of each floral trait measured for all individuals sampled in the control plots at Upper Montane (2900m) and transplanted plots originating from Upper Montane that were cooled one step and cooled two steps.



7b. The distributions of each floral trait measured for all individuals sampled in the control plots at Pfeiler (3200m) and transplanted plots originating from Pfeiler that were cooled one step and warmed one step.



7c. The distributions of each floral trait measured for all individuals sampled in the control plots at Monument (3300m) and transplanted plots originating from Monument that were warmed one step and warmed two steps.

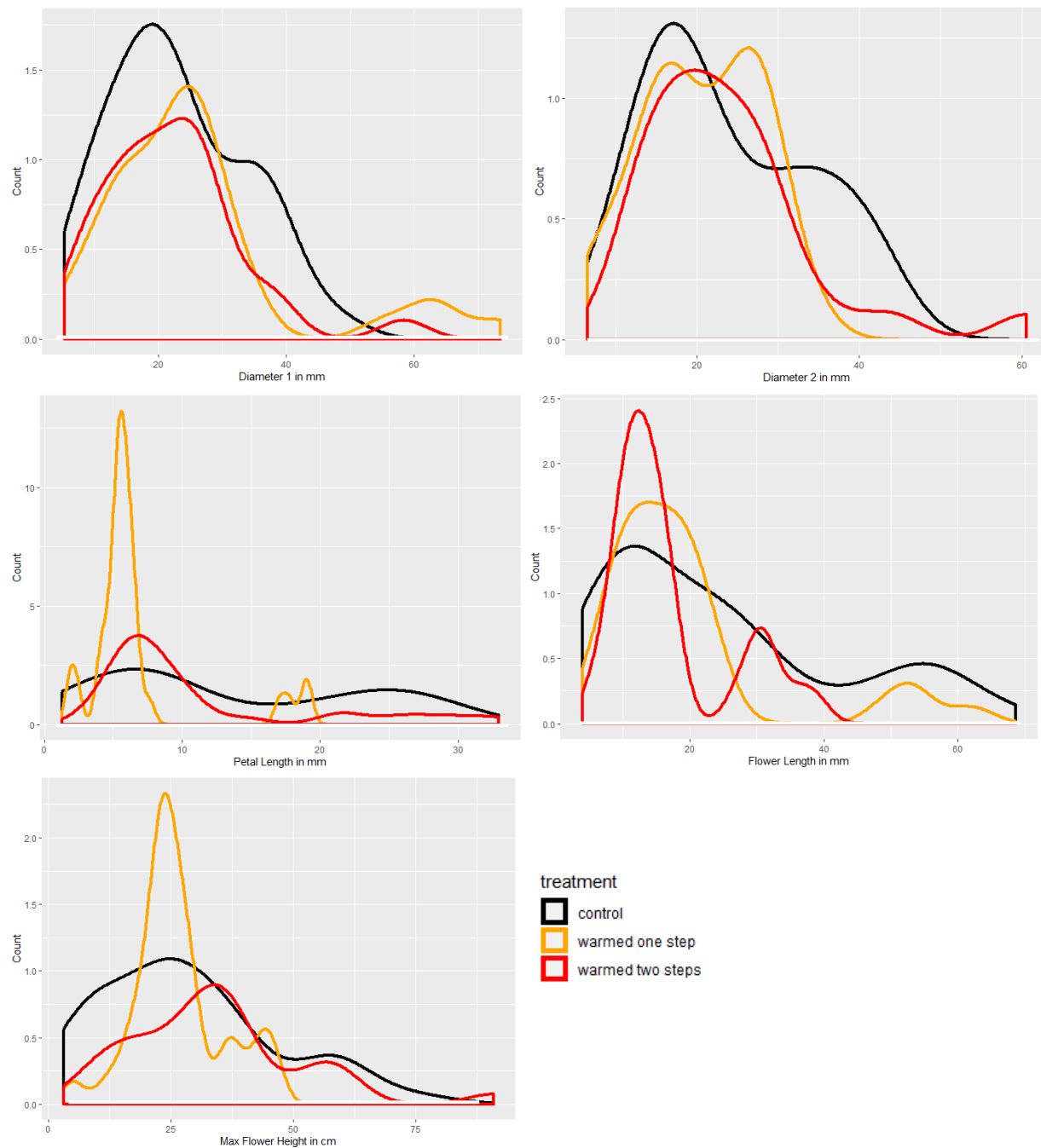


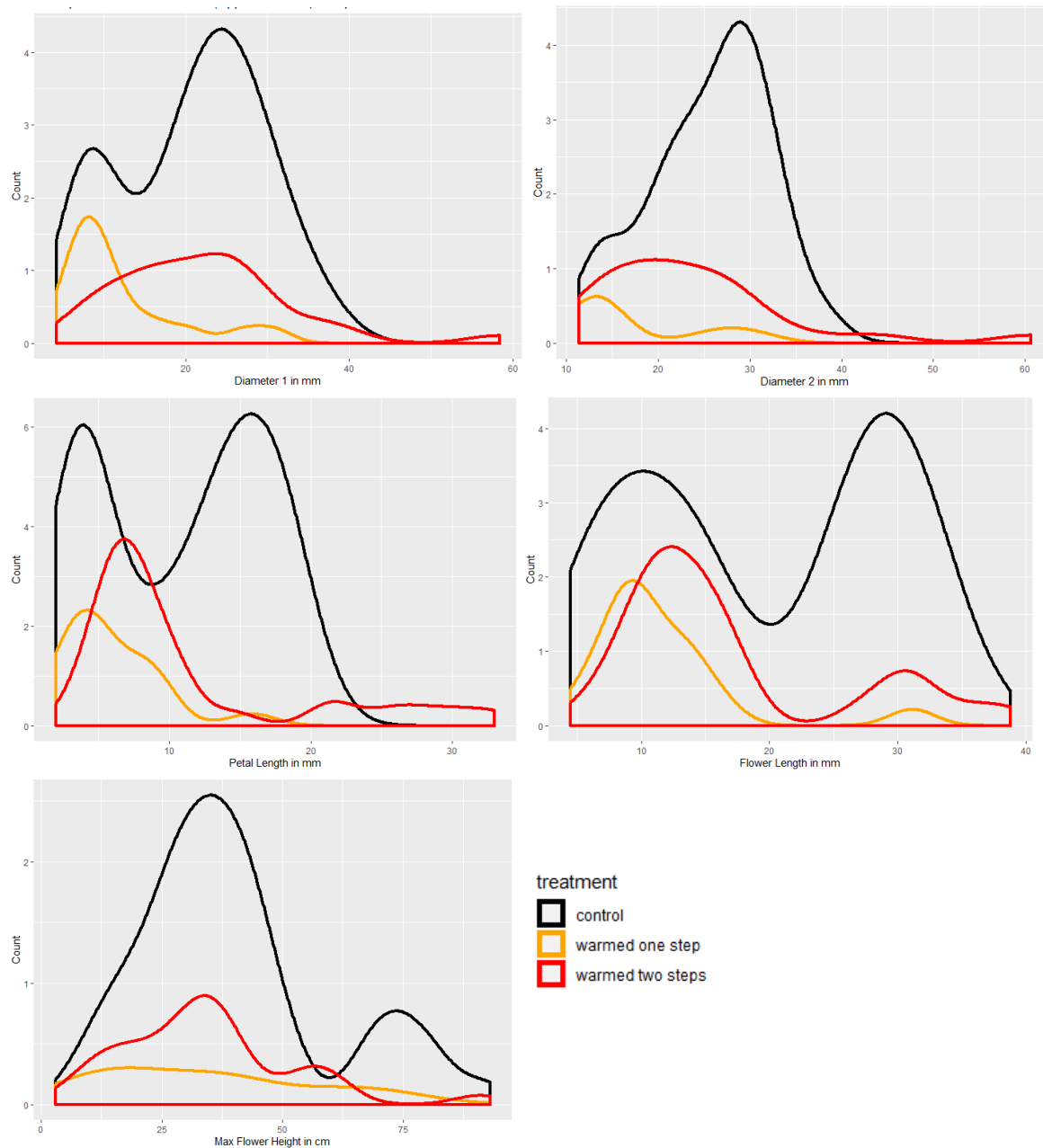
Table 3. Comparisons between transplants and the controls of their destination sites

Transplant to Destination Site	Diameter1	Diameter2	Petal Length	Flower Length	Max Flower Height
UMW1 - UMC	<0.001	0.011	0.003	0.003	0.201
UMW2 - UMC	0.903	0.042	0.878	0.319	0.150
PFC1 - PFC	0.095	0.003	0.017	0.006	<0.001
PFW1 - PFC	0.026	0.596	0.018	0.017	<0.001
MOC1 - MOC	0.155	0.0196	0.020	0.332	0.891
MOC2 - MOC	0.006	0.295	0.180	0.257	0.024

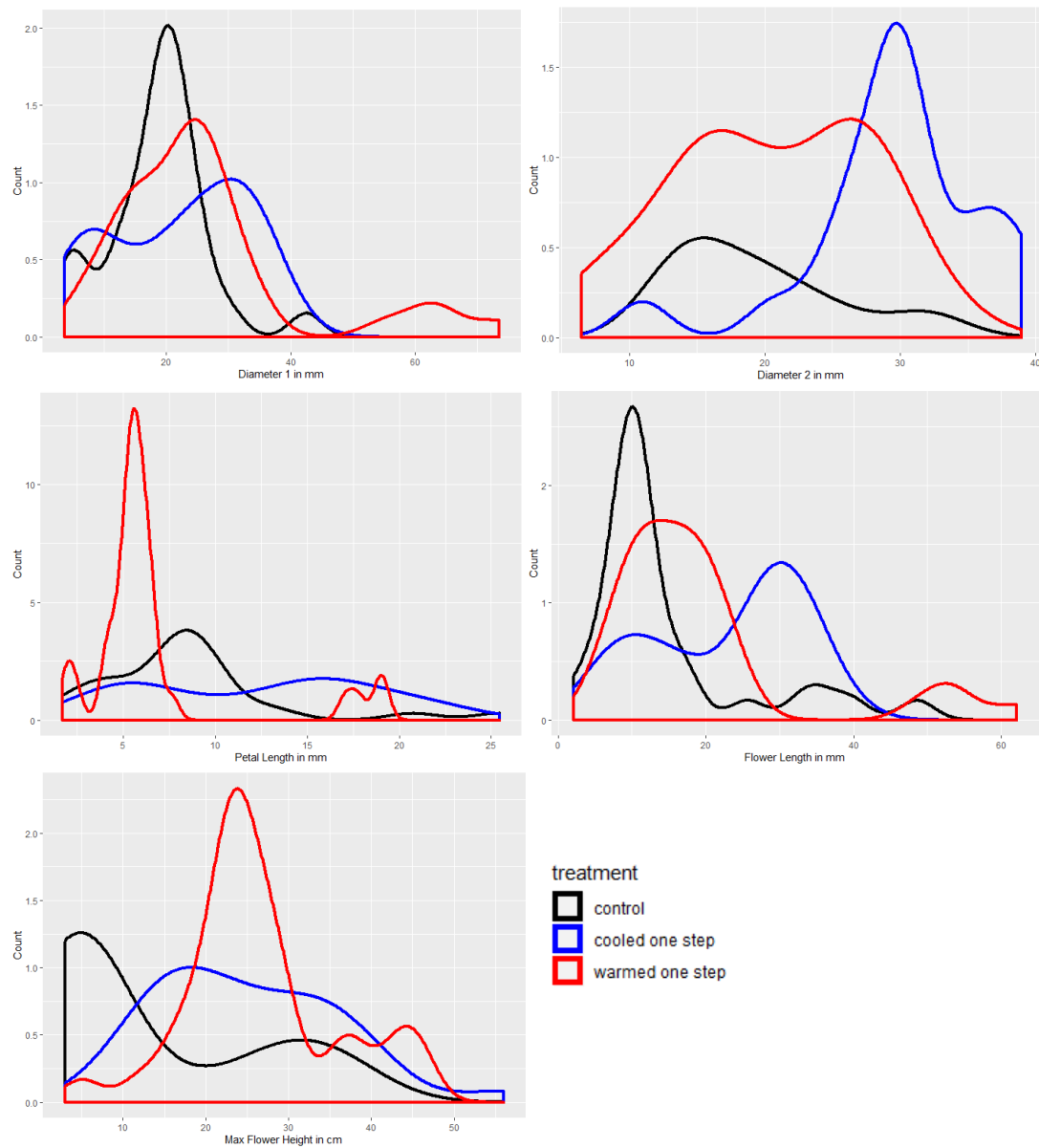
Red shading indicates a p-value > 0.05, an insignificant difference. Green shading indicates a p-value < 0.05, a significant difference. Sites sampled are Upper Montane (UM, 2900m), Pfeiler (PF, 3200m), and Monument (MO, 3300m). Treatments sampled for comparisons are Controls (C), Transplants warmed one step (W1), Transplants warmed two steps (W2), Transplants cooled one step (C1), and Transplants cooled two steps (C2).

Figure 8(a-c). A comparison of floral traits between transplanted plots and their respective destination sites.

8a. The distributions of each floral trait measured for all individuals sampled in the control plots at Upper Montane (2900m) and transplanted plots at Upper Montane that originated from Pfeiler (cooled one step) or from Monument (cooled two steps).



8b. The distributions of each floral trait measured for all individuals sampled in the control plots at Pfeiler (3200m) and transplanted plots at Pfeiler that originated from Upper Montane (cooled one step) or Monument (warmed one step).



8c. The distributions of each floral trait measured for all individuals sampled in the control plots at Monument (3300m) and transplanted plots at Monument originating from Pfeiler (cooled one step) or Upper Montane (cooled two steps).

