A Phenological Analysis of Páramo Vegetation Along an Altitudinal Gradient: The Influence of Camelids on Andean Flora in the Páramo of Chimborazo, Ecuador

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A Phenological Analysis of Páramo Vegetation Along an Altitudinal Gradient

The Influence of Camelids on Andean Flora in the Páramo of Chimborazo, Ecuador

Volcán Chimborazo taken outside of La Reserva de Producción de Fauna Chimborazo. Author: Tessa Seifried

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Abstract
This study hopes to reveal the mechanisms behind camelid-plant interactions in the Chimborazo province of Ecuador, which is known for having a large population of domesticated alpacas (Vicugna pacos), along with wild vicuñas (Vicugna vicugna) that were reintroduced into the area 30 years ago. These camelid species, especially vicuñas, are understudied within Ecuador in regards to their effects on plant composition, diversity, and spatial phenology. To gain a better insight into this topic, three sites were chosen: a site inhabited by only vicuña, a site inhabited by only alpaca, and a site inhabited by both species. The vicuña site sat at the highest elevation, and the alpaca site at the lowest. Three circular quadrats with a ten-meter radius were set up in each site, and the main plant species were counted and recorded for total population and the presence of and number of senescing leaves, flowers, fruits, and dying leaves. Both the vicuña and alpaca site followed the patterns expected with increasing altitude. This includes a higher percentage of senescing, flowering, and fruiting plants at lower altitudes and higher proportions of plants with dying leaves at higher altitudes. The combined site, however, did not follow these patterns. It not only had the lowest species evenness, but the species here that were found in all three sites also had a number of phenological differences that did not fall under any kind of altitudinal or microclimatic explanation. This disruption in the expected phenological gradient is possibly due to high grazing pressures and trampling done by both the large populations of alpaca and vicuña that graze in the area. Consequences include disruption in pollination and the reproductive success of páramo flora.

Resumen
Este estudio espera revelar los mecanismos detrás de las interacciones de las plantas y los camélidos en la provincia Chimborazo de Ecuador, que se conoce por tener poblaciones grandes de las alpacas domesticadas (Vicugna pacos) y vicuñas silvestres (Vicugna vicugna) que se reintrodujeron al área hace 30 años. Estas especies de camélidos, especialmente las vicuñas, están pocas estudiadas en Ecuador con relación a sus efectos en la composición de las plantas, la diversidad y la fenología espacial. Para obtener una mejor comprensión de esto, se eligieron tres sitios: un sitio habitado por sólo las vicuñas, un sitio habitado por sólo las alpacas y un sitio habitado por las ambas especies. El sitio de las vicuñas estaba en la elevación más alta, y el sitio de las alpacas estaba en la elevación menos alta. Tres áreas de muestreo circulares con un radio de 10 metros se construyeron a cada sitio, y las especies de las plantas principales en cada uno se contaron y se registraron para establecer su presencia, estimar su población y determinar su condición fenológica (número de las hojas nuevas, flores, frutas y hojas muertas). Los sitios con pastoreo de vicuñas y alpacas siguieron los patrones esperados con la altitud aumentada. Esto incluye un alto porcentaje de las plantas con hojas nuevas, flores y frutas en las altitudes más bajas y altas proporciones de hojas muertas en las altitudes más altas. El sitio combinado, sin embargo, no siguió estos patrones. No solo tenía la menor paridad de especies aquí, sino que también las especies que se encontraron en todos los sitios tenían muchas diferencias fenológicas que no estaban comprendida en las explicaciones de la altitud o el microclima. Este trastorno en el gradiente fenológico esperado es posiblemente a causa de altas presiones de pastoreo y el pisotear hecho por las poblaciones grandes de las alpacas y las vicuñas que pastan en estas áreas. Consecuencias incluyen los trastornos en la polinización y el éxito reproductivo de la flora del páramo.
Acknowledgements

I would like to thank my project advisor, Ana María Ortega, for accompanying me to my study site and helping guide me through the logistics of my research. She answered all questions I had and made me gain a newfound confidence for my project that I would not have had otherwise. I would also like to thank the academic advisors of SIT Ecuador: Comparative Ecology and Conservation, Diana Serrano and Xavier Silva. Without them, this paper would not exist, and I would not have gotten the opportunity to study and spend time with the wonderful community of Casa Condor. Lastly, I would like to thank Miguel Angel Guamán Guamán for guiding me through Casa Condor and showing me the different sites that I used for data collection. He taught me the ins and outs of the land and gave me valuable information that I was able to use to strengthen my paper. I’m unbelievably grateful for every last person who has helped make this research a success, and I will never forget the kindness that was shown to me. Once again, thank you so much.

Introduction

Context and background

The páramo is a neotropical ecoregion between 3200-5000 meters above sea level that is characterized by its intense solar exposure, high water retention, and ecological impact as the fastest evolving and coldest biodiversity hotspot in the world (Peyre et al., 2019). The ecosystem has a cold and generally humid climate and an average annual precipitation of approximately 1000 mm (Hofstede, 2001). It is most commonly found in Peru, Ecuador, Colombia, and Venezuela with a spatial distribution of 20 degrees in latitude and 2000 meters in elevation (Peyre et al., 2019). In Ecuador alone, it covers 2.7 million hectares of land (Romero Lobato, 2021). There are three main types of páramo: grass páramo/pajonal, shrub and cushion páramo, and desert páramo, all of which are ordered from lowest to highest in altitude (Hofstede, 2001).

The páramo ecosystem as a whole has an extremely large phytodiversity with nearly 500 genera and 5,000 species of plants, 60-80% of which are endemic to the Andes (Peyre et al., 2019). Even so, this ecosystem tends to have a consistent growth form composition dominated by tussocks and inhabited by other vegetation forms such as rosettes, cushions and mats, shrubs, and herbs (Ramsay et al., 1997). On Chimborazo specifically, which will be the focus of this study, the western and southern slopes can have desert páramo much lower in altitude due to the rain shadow effect. These areas have been described as having clumps of Stipa grasses with some shrubs and herbs like Azorella pedunculata, Chuquiraga jussieui, and Hypochaeris sonchoides. The pajonal below 4000 meters is dominated by Calamagrostis, Festuca, and Stipa.
The presence of *Stipa* grasses represents the link between the Arenal vegetation above and puna vegetation below, which is characterized by *Stipa ichu* specifically (Ramsay, 1992).

Despite its high phytodiversity, little information is available regarding the phenology and plant-animal interactions of the páramo (Roxibell et al., 2019). It is known that the shifting of phenological events with climate change will likely have a noticeable impact on flora-fauna interactions, therefore making it pertinent to expand this field of research (Maglianesi et al., 2020). In the páramo specifically, there is little information about how phenological events might be affected by altitude, although studies done in the alps show that flowering (Ziello et al., 2009), leafing, and bud bursts are delayed with increasing elevation (Pellerine et al., 2012). It is known presently that most páramo plants flower during the rainy season (between March and April; and October and November in the montane regions of Ecuador) although some flower continuously. It is also known that the timing of flowering and fruiting of many flora is a large factor in structuring ecological communities since they sit at the base of the trophic pyramid (Roxibell et al., 2019). These phenological events influence specialized species more than generalists, (Maglianesi et al., 2020), especially organisms that rely heavily on the cyclic parts of the plant as a food source (Llambí et al., 2019).

The problem focused on in this paper and discussed below is the overgrazing of páramo ecosystems in Ecuador by South American camellid populations: the domesticated alpacas and the reintroduced vicuñas. Alpacas have been known to, when grazing sustainably, increase the ecological diversity of herb resources (McGregor, 2002). Additionally, their gradual feeding selectivity can have a positive effect on threatened species and more palatable species, which encourages the re-establishment and robustness of these plants. Their efficient digestive conversion rate and preference for low-quality grasses means they don’t require burning or fertilization for proper grazing (Charry et al., 2003). Even so, higher density populations of alpacas can lead to overgrazing. Alpacas tend to feed in the areas that have already been grazed, cutting down vegetation in these areas even more and creating a series of selection pressures that are extremely unbalanced across larger areas of land (McGregor, 2002). Vicuñas are also known to have a positive influence on páramo vegetation when grazing is sustainable. Even so, their grazing is also thought to raise the mortality rate of grasses and change the composition structure and distribution of local vegetation (Fernandez-Oto et al., 2019). Additionally, as they’re populations began to decrease in the past, their grazing pressures were likely replaced by the increased presence of livestock. Co-existence between vicuña and grazing livestock, including alpacas, has led to a perceived notion of competition between the two. If this is true, then their combined grazing pressures could have negative influences over páramo flora (Laker, 2004). Camelids specifically, however, are much less damaging to surrounding vegetation than sheep and cattle due to their unhooved feet, ability to eat low quality plants, and feeding behaviors involving cutting grasses instead of pulling them out by the roots (Hofstede, 2001).

Vicuñas are one of the only South American camellids that are not domesticated. 300 individuals of this species were reintroduced to Ecuador through La Reserva de Producción de Fauna Chimborazo between 1988-1993, and now, according to local guides, there are between 8,000 to 10,000 vicuñas on the reserve (X. Silva, personal communication, 2021). According to McLaren et al., their population was sitting at 8,000 in 2015. This population growth has not yet proven to be a problem because of the range of the reserve. It is approximately 58,560 hectares with an altitude of 3800 to 6310 meters above sea level (Caranqui et al., 2015).
The reintroduction of vicuñas to La Reserva de Producción de Fauna Chimborazo has been seen as both a success story and a burden upon the local people. For one, it is still heavily debated whether or not vicuñas were native to Chimborazo in the first place. It is known that domesticated camelids began appearing in coastal, southern, and montane Ecuador between 300 BCE and 100AD. Hundreds of years later, they also followed the Incans north as they conquered land all the way into southern Colombia. Due to a lack of information and knowledge of the history before Spanish colonization, however, there is very little proof that vicuñas once occurred naturally on Chimborazo. It is fully possible that they were brought and left there by civilizations that occurred before Incan society. If this is the case, it could cause higher tensions between the ministry and the local people because these possibly-introduced vicuñas are a resource the communities hardly profit from that also happens to be grazing in the same areas as their cows, sheep, and alpacas (McLaren, 2019).

Additionally, the very limited distribution of vicuña in northern Peru brings up the question of how vicuñas could have naturally arrived in Ecuador in the first place (Baldo et al., 2018).

Their reintroduction has also brought up the question of their impact on páramo vegetation in the area. Their populations are known to be very high and grow very fast. In 2016, there were 2053 registered vicuñas in the Chimborazo province of the reserve alone. The species that the vicuña prefer to feed on are not the dominant species found in these ecosystems, although they will also feed on common grasses such as Calamagrostis, Festuca, and Stipa (Wheeler, 2006). Because of this and a lack of studies on the subject, it isn’t necessarily clear how exactly vicuña affect the vegetative layer of the páramo on Chimborazo. They are known, however, to graze within the same areas as domesticated grazing populations, and they have been found dead with evidence of wild dog attacks. They also create what are known as “dung gardens”: areas of extremely fertilized soil that create high diversity patches and influence plant composition at higher altitudes (Franklin, 2021).
Regarding how alpaca feeding behaviors might affect páramo flora, it has been studied that alpacas aren’t necessarily known to reduce the overall height of grasses within their grazing sites within the drier season. Even so, the more palatable grasses found in the wet seasons can get significantly reduced in their height and diameter. Compared to bovines and llamas, the amount of change that they bring to natural páramo vegetation is relatively low. It is not just grasses that are reduced, either. The herbaceous stratus has also been shown to be reduced by all grazing species (Bartolomé et al., 2021). Out of all domesticated grazers, studies show that alpacas are the best for sustainable grazing. They leave the grasses the tallest, and their sites have the largest vegetation and basal coverage (Romero Lobato, 2021).

Alpacas prefer tall grasses, forbs, and leaves during the wet season and shorter grasses during the dry season. Vicuña overall tend to avoid taller, coarser bunch grasses and prefer more nutritional grasses. In the dry season, they consume tall grasses with high biomass and low quality, while in the wet season they eat shorter grasses. Because of their opposite and seasonal diet preferences, there is less competition between the camelids and higher selection pressure on grasses that inhabit areas where both vicuñas and alpacas graze (Cassini et al., 2009). These selection pressures could be a problem as vicuñas have begun to descend into the lower lands around Chimborazo (M. Guamán, personal communication, 2021). Because vicuñas were introduced into areas where livestock was already present, they are already tolerant of these populations. Facilitation even occurs between vicuñas and alpacas when forage plants are accessible and of a higher quality (McLaren et al., 2018), but if they are not then the combined grazing of both of these species are likely to disturb páramo vegetation and create competition between the two species.
This study will take place in Casa Cóndor Turismo comunitario, a small community that sits south of La Reserva de Producción de Fauna Chimborazo and southwest of the actual mountain. They total roughly 50 people, all of which work together to care for around 100 alpacas. These alpacas are utilized for clothing and meat, along with tourism that comes from people who wish to know more about shearing and processing wool, along with those that come to hike around Chimborazo. The community owns roughly 3500 hectares, much of which is also under the control of the Ecuadorian government and labeled as a part of the reserve. This is a clear example of a common conflict between state and community, and it’s become worse as the vicuñas from the reserve begin to impede on the food sources of Casa Condor’s alpaca population (M. Guamán, personal communication, 2021).

For my research, I hope to answer the following questions: How do the phenological events of plants change spatially when inhabited by different camelid species? Also, what kinds of effects might altitude have on the cyclical stages of páramo flora?

Based on past studies, it is expected that increasing altitude (and therefore decreasing temperature) will cause a delay in the flowering and fruiting of páramo plants and an increase in the number of dead leaves due to slower levels of decay. It is also expected that the páramo flora will be under higher stress where both alpacas and vicuñas graze together in high numbers. Because the alpacas are limited to their grazing areas by human range, they likely have denser populations that could negatively affect the surrounding plants. Even so, they get cycled frequently, while the vicuñas are free to pick their own spots and graze them down until there is nothing left. These vicuñas, though, have much more room to graze than the alpacas, although their populations are up to 100 times higher. The areas where both graze are likely to be the most susceptible to vegetative changes due to higher levels of herbivory (remember that their diet preferences are opposed based on the season) and denser camelid populations. An additional variable that could have helpful consequences for the plant communities is the dung of the camelids fertilizing nearby plants and changing plant composition or providing enough nutrients to allow a better chance for the creation of flowers and fruits.

If the camelids have extremely dense populations, they will likely compact the vegetative layer and lower its ability to retain water, which could change phenological events. In addition, the staggering number of vicuñas on Chimborazo could impact plant growth and, therefore, phenological stages due to high levels of grazing and soil compaction. If these camelids prohibit a plant from receiving enough energy, water, or time to create flowers or fruits, then their natural cyclic events could be disrupted. In addition, it has been observed that camelids will eat the flowers and seeds of different grasses and herbs (M. Guamán, personal communication, 2021). This, in turn, could lead to lower reproductive success, which could then result in lower populations and an increase in stress factors for the camelid populations. Even so, Robert 2018 found that, regarding trampling, specifically alpacas have little to no impact on the ecosystem when it comes to effects on soil bulk density, porosity, water content, and degree of saturation. The 100 alpacas on Casa Condor have as much as 3500 hectares of grazing area (M. Guamán, personal communication, 2021), which is more than enough to constitute a healthier páramo. In addition, the 10,000 vicuñas have the nearly 60,000 hectares of La Reserva de Producción de Fauna Chimborazo (Chimborazo Fauna Production Reserve, 2021), which likely results in sustainable grazing despite the fact that some of this land is inhabitable to them. The area in between, however, where both the numerous vicuñas and the dozens of alpacas both graze could easily be hitting it’s sustainable grazing limit.
The main objective of this research project is to record the phenological stages of dominant plant species in the páramo at different camelid-inhabited areas to properly understand how these different populations can change or “skew” the phenological cycles of different páramo flora. These camelid populations include a site inhabited by wild vicuñas near La Reserva de Producción de Fauna Chimborazo and two pasture/grazing sites, one grazed upon by both vicuñas and alpacas and the other by alpacas alone. The goal is to see if there is a difference between the present-time phenological stages of the plant species at the vicuña site and the same species at both pasture sites. Because the impact of camelids on the páramo plant phenology has not been well studied, completing this objective could be extremely helpful in expanding the understanding of the ecological interactions that take place in parts of the Andean Highlands, especially those that might have come about by both community and government action. In addition, discovering phenological differences between sites could help to draw more accurate conclusions about the effects that these impacts have on other important organisms that rely upon the fruits, seeds, and flowers of páramo plants, such as insect pollinators and birds.

In addition to the main objective, is it important to record and consider information regarding abiotic factors that might be affected by camelid populations or influence plant phenology. The factor that will be mainly focused on in this study is altitude. Other included factors will be air temperature and the presence of water. The consequences of certain circumstances that occur in an ecosystem are never influenced by a single factor, and because of this it’s important to take into consideration other aspects of the environment and properly see how they relate to the results found through the main objective. This way, it will be easier to characterize how exactly the phenological differences between the three sites occur and what abiotic characteristics have a higher or lower influence over the end results.

**Methods and Materials**
Figure 1.4: Satellite images of Casa Condor and the surrounding sampling sites. The bottom right image shows the entire area with all three sites included, while the rest show more detailed shots of each separate area where each quadrat is easily distinguishable. VQ signifies Vicuña Quadrat, AVQ signifies Alpaca and Vicuña Quadrat, and AQ signifies Alpaca Quadrat.

Site Descriptions

This study occurred in November, during the end of the rainy season. All data was taken on Casa Condor property just outside of La Reserva de Producción de Fauna Chimborazo. The alpaca site sat the closest to Casa Condor at 3900 meters, and a trail could be taken up north to the vicuña and alpaca combined site at 4000 meters. The vicuña site required a longer hike of about 6 kilometers, and it had the highest altitude of 4100 meters.

The vicuña site was located in a high mountain valley that was constantly cloudy or foggy. It was inhabited at all times by around 60 vicuñas, which used the area to graze and as a source of water. The small lake at the center was seasonal, and at the time of data collection, it was present, but very shallow. The edges of the valley rose into large hills that were characterized by bunch and tuft grasses, while the flat land within had cut-down, shorter grasses, low-growing herbaceous plants, and cushion and mat vegetation.

The combined site was located in a mountain valley on the side of a highway. When alpacas weren’t present, it was inhabited by anywhere from 30-60 vicuñas. The alpacas grazed in this area roughly two to three times a week, and they numbered around 90. The valley was characterized, once again, by shorter, cut-down grasses and bunches of Calamagrostis grasses that were too tough for the camelids to eat (M. Guamán, personal communication, 2021). The surrounding hills had these same grasses as well. This area was hillier and characterized by a number of streams, and the vegetation was a mixture of grasses, cushion plants, herbs, and woodier bushes near the water shores.

The alpaca site was located on the side of a hill about half a kilometer away from the Casa Condor. Alpacas grazed here a little less often, and this land was used more by individual families and less by the entire community. Diversity here was much easier to see, and grasses stood taller with cushion plants in between and a number of herbs and flowering plants. Woodier bushes lined the roads and the stream in a nearby valley, but the rest was characterized mostly by herbs and tussocks.

Methods and Materials

The materials for this research project included a 10-meter-long rope, temperature sensor, measuring tape, quadrat markers, and various páramo plant guides. The area where data collection occurred was properly captured in a satellite image, as seen in Graphic 1.4, to map out the placement of the camelid occupation sites, along with the locations of the quadrats used to observe and record the populations and phenomenological stages of páramo flora.

For half of the first week, the sites were properly studied so that 15-25 main plant species could be identified at each site using several páramo plant guides. These main plant species were then counted and recorded for their phenological stages within the quadrats. These species were very different between all three sites (vicuña, combined, and alpaca) due to different altitudes and microclimates, but it was expected that there would be at least 10 overlapping species between the different areas.
Data collection began at the vicuña site, which was the furthest away from Casa Condor. It then proceeded to the combined site and ended with the alpaca site. Quadrats were, as illustrated in Graphic 1.5, created by taking a 10-meter-long rope, attaching it to a stick, and drawing a circle using the other end. Markers were set up along the perimeter of these circles to better visualize the quadrat and mark the coordinates using a GPS system. All plants that belonged to one of the 15-25 species within the circle were identified, and their phenological stages were counted as having senescing leaves, flowers, fruits, and dying leaves. The number of leaves, flowers, fruits, or inflorescences on each were then counted or estimated. If the number of plants within a certain phenological stage was too great to count by hand, six random 1x1 meter squares within the quadrat were counted, averaged, and multiplied by the overall area of the circle to gain a good idea of the population size and the average number of leaves, fruits, and flowers per plant. In addition, on a drawn map, the locations of these species within the quadrat were recorded and labeled with a color and the number of individuals. Each area was also tested for presence of water (written as distance from the closest lake or stream), temperature, and altitude.

![Figure 1.5: A visual of the size of the quadrat used for data collection. The photo was taken ten meters away from the center, and each red line represents the same distance.](image)

Each quadrat took roughly a day, with three quadrats in each of the three camelid sites. All nine quadrats were taken along the trails and/or roads that led up to La Reserva de Producción de Fauna Chimborazo. Each quadrat was recorded on a satellite map, and all mapped species were transferred into a computer program to better organization and visualize species distribution. Much like the drawn species maps, all data was taken by hand and then properly transferred to a computer program for later use.

The last week was used to write up a report and complete data analysis. Data analysis involved visualizing the distribution, number, and abundance of each species within the quadrats and comparing these among the different sites and altitudes using diversity and similarity.
indices. The exponential of Shannon entropy was calculated for diversity using the following equation:

\[ e^H \text{ where } H' = - \sum_{i=1}^{R} p_i \ln p_i \]

From the exponential of Shannon entropy, the Shannon diversity index was also used to find species evenness with the equation below:

\[ J' = \frac{H'}{\ln S} \text{ where } S = \text{species richness} \]

The Sørenson, Jaccard, and Morisita-Horn similarity indices were calculated using the following equations respectively:

\[ \text{Sørenson index} = \frac{2(\text{# similar species})}{\text{species richness}_1 + \text{species richness}_2} \]

\[ \text{Jaccard index} = \frac{\text{# similar species}}{\text{# all species from both samples}} \]

\[ \text{Morisita – Horn index} = \frac{2 \sum_i p_i^l \cdot p_i^c}{\sum_i (p_i^l)^2 + \sum_i (p_i^c)^2} \]

Afterwards, the phenological stages of each species found in all three sites was compared to see if there were any differences between the camelid sites and the increasing altitudes. The percentage of flowering, fruiting, senescing, and dying plants was calculated and graphed to easily compare the differences between all three areas using the formula below:

\[ \% \text{ flowering plants} = \frac{\# \text{ flowering individuals}}{\text{total plant population}} \]

The remaining factors of temperature and presence to water were also taken into consideration and compared to the main variables (altitude, phenological phases, and camelid occupation) to better understand how abiotic factors might influence or skew the results of this study. To calculate the drop in temperature with increasing altitude, the following equation was used:

\[ \text{Change in altitude per } 1 \text{ °C} = \frac{\text{altitude}_1 - \text{altitude}_2}{\text{temperature}_2 - \text{temperature}_1} \]

Visuals were created using a spreadsheet program. All tasks were overseen by an experienced advisor, and local guides assisted with locating the different sites and avoiding accidental data collection on La Reserva de Producción de Fauna Chimborazo. Time was properly allocated as the following: half a week to identify the main plant species, a week and a
half to collect data from nine separate quadrats, and a week to analyze all collected data and write up a 25-page report on the findings.

**Ethics**

During this research project, no harm was done to any animals, plants, or environments. All guides were fairly compensated, and the community and surrounding areas were properly respected and cared for.

**Results**

As shown in Table 1.1, the vicuña site sat the highest at approximately 4140 meters, while the combined site sat 76 meters below at 4064 meters. The alpaca site had the lowest altitude of 3875 meters, which is 189 meters below the combined site. The difference in altitude between the combined site and the alpaca site was over twice as much as the difference between the combined site and the vicuña site.

The combined site sat the closest to a body of water (in this case, it was a stream), while the vicuña site was larger and held a small, seasonal lake. The alpaca site had a nearby stream like the combined site, but this stream was further down into a valley and further away from the grazing area. The morning temperature increased with lower altitudes. The difference between the vicuña and the combined site was only 1°C, while the combined and alpaca sites were 4 °C apart. It was calculated that the temperature fell approximately 1 °C for every increase in altitude of approximately 53 meters.

<table>
<thead>
<tr>
<th></th>
<th>Vicuña</th>
<th>Combined</th>
<th>Alpaca</th>
</tr>
</thead>
<tbody>
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<td>Altitude (m)</td>
<td>4140</td>
<td>4064</td>
<td>3875</td>
</tr>
<tr>
<td>Proximity to water (m)</td>
<td>108</td>
<td>42</td>
<td>172</td>
</tr>
<tr>
<td>Morning temperature (°C)</td>
<td>12</td>
<td>13</td>
<td>17</td>
</tr>
</tbody>
</table>

The number of species found at each site increased with decreasing altitude, meaning that the vicuña site had the lowest richness, while the alpaca site had the highest. In addition, the species abundance graphs in Figures 1.6, 1.7, and 1.8 show that the number of individuals per dominant species was the highest in the vicuña site, with *Lachemilla orbiculata* having over 10,000 individuals and both *Geranium maniculatum* and *Gentianella cerastioides* following close behind with roughly 10,000 and 9,000 individuals respectively. The combined site, on the other hand, had nearly 120,000 individuals of *Azorella pedunculata* and nearly 9,000 individuals of *Lachemilla orbiculata* while the rest of the species fell at least 3,000 individuals behind these numbers. The alpaca site was also dominated by *Azorella pedunculata*, but the number of individuals sat far lower at roughly 6,500 individuals. The rest of the species fell at least 3,000 individuals behind this number. Overall, the vicuña site had the fewest species, but more species had higher abundances, while the combined and alpaca site both had more species, but the one or two species with the highest abundances were significant outliers. All species distribution and numbers can be better visualized in Appendix A.
**Figure 1.6:** Average species abundance graph for the vicuña site. All flora are listed using both genus and species if possible. If not, then just the genus is displayed. *Baccharis caespitosa* and *Geranium maniculatum* were both counted in bunches of 2-4 leaves to better represent the area of land that they cover and because of unclear separation between individuals.

**Figure 1.7:** Average species abundance graph for the combined site. All flora are listed using both genus and species if possible. If not, then just the genus is displayed. *Geranium maniculatum* was counted in bunches of 2-4 leaves to better represent the area of land it covers and because of unclear separation between individuals.
Species richness was the lowest in the vicuña site at 17, the combined site sat in the middle at 22, and the alpaca site was had the highest richness of 25 (Table 1.2). In addition, the alpaca site had the highest evenness of species of 0.7782, while the combined site had the lowest species evenness of 0.7070. The vicuña site’s evenness was 0.7350. All numbers fell within a higher range of evenness, meaning that the abundances of each species were relatively close together.

The exponential of Shannon entropy was highest for the alpaca site at 12.24, meaning that it was the most diverse. For the vicuña and combined site, the entropy was 8.02 and 8.89 respectively, which is a difference of 0.8. The difference between the alpaca and combined site, for comparison, was 3.35. Overall, the highest site (vicuña) had the lowest overall diversity, while the lowest site (alpaca) had the highest.

Both the Sørenson and Jaccard indices in Table 1.3 showed the highest similarities between the combined site and the alpaca site of 0.6383 and 0.4688 respectively. The vicuña and alpaca site, also known as the highest and lowest altitudes, showed the least amount of similarity. The similarity between the vicuña and combined site only sat about 0.02 below the alpaca and combined site. The Morisita-Horn index, which takes species abundance into higher consideration, showed the highest similarity between the combined and alpaca site of 0.5750, and the lowest between the vicuña and alpaca site of 0.1365. The similarity between the vicuña and combined site sat towards the middle of the highest and the lowest at 0.2194.

Table 1.2: Species richness, exponential of Shannon entropy, and species evenness for all three sites.

<table>
<thead>
<tr>
<th></th>
<th>Vicuña</th>
<th>Combined</th>
<th>Alpaca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species richness</td>
<td>17</td>
<td>22</td>
<td>25</td>
</tr>
</tbody>
</table>
Table 1.3: Sørensen, Jaccard, and Morisita-Horn index comparing the similarities between all three sites.

<table>
<thead>
<tr>
<th></th>
<th>Vicuña vs Combined</th>
<th>Vicuña vs Alpaca</th>
<th>Combined vs Alpaca</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sørensen index</td>
<td>0.6164</td>
<td>0.4762</td>
<td>0.6383</td>
</tr>
<tr>
<td>Jaccard index</td>
<td>0.4444</td>
<td>0.3125</td>
<td>0.4688</td>
</tr>
<tr>
<td>Morisita-Horn index</td>
<td>0.2194</td>
<td>0.1365</td>
<td>0.5750</td>
</tr>
</tbody>
</table>

Out of all three sites, there were a total of nine similar species shared between them. Four were grasses, two were unidentifiable and had no noticeable phenological characteristics, and the last three were low-growing, herbaceous and mat plants. The grasses are *Stipa*, *Festuca*, *Agrostis*, and *Calamagrostis*. The herbaceous plants are *Lachemilla orbiculata*, *Hypochaeris s.* (which includes both *Hypochaeris sessiliflora* and *Hypochaeris sonchoides*), and *Geranium maniculatum*.

Out of the population of the plant community that had shared species between all three sites, the percentage of plants in each phenological stage was calculated and presented in Figure 1.9. The percentage of plants with senescing leaves was lowest in the vicuña site at about 4% and highest in the alpaca site at about 23%. The same was seen for the percentage of fruiting plants, with the vicuña site having roughly 4% and the alpaca site having 26%. The number of plants with dying leaves was highest in the vicuña site at 31%, although the combined site followed close behind at about 30%. The alpaca site, on the other hand, sat lower at 24%. The percentage of flowering plants did not change significantly between the three sites, although the alpaca site had the lowest of a little under 10%, while the other two sites had nearly 12%.

![Percent of Plants in Each Phenological Stage](image)

**Figure 1.9:** Percent of plants in each phenological stage for the entire plant community. Some plants were counted multiple times as they had two or more phenological characteristics, such as having dying leaves and flowers at the same time. In addition, some plants were observed to be in no phenological stages at all.
In Figure 2.1, all Festuca grasses showed little change in phenological stage between the three sites. The other grasses, on the other hand, did. Stipa grasses had the largest percentage of fruiting individuals in the alpaca site and the lowest in the vicuña site. Agrostis grasses had the largest percentage of both dying and fruiting individuals in the combined site, while it was lowest in the vicuña site. Calamagrostis grasses had the highest percentage of fruiting individuals in the alpaca site and the lowest in the combined site.

Regarding the other overlapping plant species that showed signs of senescing, flowering, fruiting, and/or dying, Lachemilla orbiculata had the highest percentage of flowering and dying individuals in the alpaca site and the least in the combined site. Geranium maniculatum also had the highest proportion of flowering plants in the alpaca site, but it had the least in the vicuña site instead of the combined. Regarding individuals with dying leaves, there was a higher percentage in the vicuña site, and the lowest in the combined. Hypochaeris s. had the most individuals with senescing leaves in the vicuña site and the least in the combined site. The highest percentage of flowering individuals and individuals with dying leaves was found in the combined site, while the least amount of flowering was found in the vicuña site and the least amount of dying in the alpaca site. Both Unknown B and Unknown F were not found to be in any particular phenological stage in any of the three study sites.
Figure 2.1: The percentage of individuals of each species in each phenological stage. Some individuals were counted multiple times because of indications that they were experiencing multiple phenological phenomena at the same time, such as having both fruits and dying leaves. This graph can be read as, for example, the percentage of a certain species that have flowers, and so on.

Regarding the number of leaves/flowers/fruits per leaving/flowering/fruiting plant of the overlapping plant species in Figure 2.2, Festuca grasses had the most dead leaves per plant in the combined site and the least in the vicuña site. It had the most fruits per plant in the alpaca site and the least in the vicuña site. Stipa grasses had the most dead leaves per plant in the alpaca site and the least...
in the vicuña, and the fruits per plant was the same. The dead leaves and fruits per plant of the *Agrostis* grasses did not change significantly between the three sites. *Calamagrostis* grasses had the highest number of dead leaves per plant in the combined site and the least in the vicuña site. The highest number fruits per plant was in the alpaca site and the lowest in the vicuña site.

*Lachemilla orbiculata, Hypochaeris s., and Geranium maniculatum* did not change significantly between the three study sites. *Unknown B and Unknown F* were not found in any phenological stage throughout all three sites.
**Figure 2.2:** Parts per plant in each phenological stage for overlapping plant species in all three sites. The top picture shows the full graph, while the bottom eliminates anything above 25 leaves/flowers/fruits per plant to better visualize more of the phenological dynamics of all similar species. These graphs show, for example, the number of flowers per flowering plant of each species, the number of fruits per fruiting plant of each species, and so on.
Data Analysis

As stated before, the vicuña, combined, and alpaca sites were at 4140, 4064, and 3875 meters above sea level respectively. The difference between the combined and the vicuña site is only 76 meters, while the difference between the combined and alpaca site is 189 meters. The fact that the vicuña and combined sites sat closer in altitude may possibly skew the results found in this paper if not taken into consideration when comparing the flora composition and phenological stages between these three study areas. This is important because it’s been proven in multiple studies, including this one, that plant community dynamics and phenology are heavily influenced by altitude (Pinto-Junior et al., 2020). In addition, while the changes in altitude will likely reveal some of the abiotic influences over páramo plant communities, they may also blur the assumptions made about how camelid occupation affects these same communities. Having two independent variables, while they are connected, means it will be more difficult to pinpoint which factors are causing which outcomes. Even so, many times there is not a single cause for an effect, and it’s possible that altitude could work with camelid occupation to create the resulting phenological and vegetative composition.

In addition, this study found that temperature dropped about 1 °C for an increase of 53 meters in altitude. This number is much higher than what has been found in past studies. In Bolivia, it has been calculated that temperature drops about 0.2 °C every 50 meters (Montgomery, 2006). This number was found on a sufficient amount of solid data regarding average annual temperatures, while the number calculated from this study specifically was based upon morning readings taken for three days at each site and then averaged to get an overall temperature for each area. If these readings were taken multiple times a day at each site for a year on a calibrated sensor, the results likely would have been closer to the number calculated in the various studies comparing altitude to temperature.

Regarding presence to water, the combined site sat closest to a glacier stream, while the alpaca site sat furthest away from another stream that was further down in a nearby valley. The vicuña site was in a mountain valley that held a seasonal lake. From personal observations, both sites with streams had very different plant compositions along the shores consisting of bigger, woodier bushes like Chuquiraga jissieu and Valeriana microphylla. The lake, on the other hand, did not have such changes. All quadrats were far enough away from the bodies of water that it is unclear whether or not they affected plant composition. In terms of phenology, however, it has been suggested in a study done in a tropical dry forest of Costa Rica that the phenological stages of trees are highly influenced by water stored in the ground during the dry season because plants are able to then use the stored water to assist in making new leaves, flowers, and fruits (Borchert, 1994). While there are no studies of this phenomena closer to Ecuador, multiple projects done in parts of Africa have found that water can be a limiting factor of plant growth, but that it alone does not significantly influence plant phenology (Seghieri et al., 2009). The presence of a body of water at each site might therefore affect the soil moisture of the surrounding area and, in turn, affect the phenology of páramo flora.

The species richness at the vicuña, combined, and alpaca site were 17, 22, and 25 respectively. Therefore, richness decreased with increasing altitude and decreasing temperature. This same result has been found in a number of studies. For example, on inselbergs in Brazil altitude significantly influences species richness and community composition, and it is one of the best predictors for these given factors (Pinto-Junior et al., 2020). In the Wof-Washa highlands of Ethiopia, the highest species richness was found in the lowlands, and the lowest in the highlands. It was also discovered that altitude had a high influence over the plant composition of the area.
A Disruption in the Altitudinal Gradient of Andean Montane Vegetation

(Yirga et al., 2019). In the Moghand-Sabalan rangelands of Iran, the highest concentration of plant species was found at a mid-elevation bulge, and beyond that richness decreased with altitude. This study takes place at altitudes far higher than the mid-elevational bulge, meaning it is expected that richness will fall with rising elevation. It was also explained that lower altitude areas were expected to hold more diverse communities due to wider geographical ranges and a lower degree of isolation for immigrant species (Ghafari et al, 2018). Areas of lower altitudes are also known to have warmer temperatures, which allows for more forms of life that can’t endure the cold (Grytnes, 2003). It is expected that the results regarding species richness relies mainly on altitude because of the inverse correlation found between the two variables. Additionally, while both vicuñas and alpacas are thought to possibly change plant composition and disturb certain areas, there is no proof that either camelid has any kind of effect on species richness in areas where they graze (Muñoz et al., 2015). An interesting result of this study is that, despite the smaller altitudinal difference between the vicuña site and the combined site, the difference in species richness was 5. The combined and alpaca site was much further away altitudinally, yet the difference in species richness between these two areas was only 3. Even so, only the principal species were taken into consideration, so it is very possible that there were more species in these areas that were too few and far between to be counted and recorded.

The species evenness of all three sites did not follow what has been found in past studies. Normally, evenness has been observed to be higher at lower elevations and lower at higher elevations (Sahu et al., 2008). It has also been discovered that species evenness and richness are positively correlated (Yirga et al., 2019), meaning that the vicuña site should have the lowest evenness, and the alpaca site should have the highest. This, however, was not the case. The alpaca site did in fact have the highest evenness of 0.7782, but the lowest was instead found in the combined site with a value of 0.7070. This suggests that camelid occupation likely has some influence over the species evenness of this area, especially considering that the combined site is grazed upon and inhabited by populations of both alpacas and vicuñas. While there are no sources regarding how camelid grazing effects species evenness, this study shows that areas with high grazing pressures are likely to have species with higher, outlying abundances and others that are diminished by high density camelid occupation and unsustainable herbivory.

The exponential of Shannon entropy followed the same pattern as species richness: lowest in the vicuña site and highest in the alpaca site. This was expected, as it is normally the case where a higher richness leads to a higher diversity value (Sánchez-González et al., 2005). As stated before, species richness increases with decreasing altitude, so diversity should also do the same (Yirga et al., 2019). Even so, the diversity values of the vicuña and combined site were much closer together: 8.02 and 8.89 respectively. The alpaca site, on the other hand, had an entropy value of 12.24, which is significantly higher. This correlates with the smaller change in altitude between the vicuña and combined site and the much larger change between the combined and alpaca site. The alpaca site is the only area that sits below 4000 meters, and it was significantly warmer. Because of this, it is likely that it had higher species richness and abundances that made for a higher diversity (Sánchez-González et al., 2005). Additionally, the alpaca site was less grazed upon than the other sites, so the influence that the camelids may have over species evenness isn’t as strong as it is in the combined site and the vicuña site, which are both constantly inhabited by at least 60 vicuñas and/or 100 alpacas.

All three similarity indices used in this study indicated the same results: the combined and alpaca sites were the most similar, while the vicuña and alpaca sites were the least. It’s important to remember the very large altitudinal difference between the combined and alpaca
site, and the much smaller one between the combined and vicuña. Based on elevation, it would be assumed that the combined and vicuña would be the most similar because they’re only 76 meters apart in height, but this is not the case. Instead, the most similar sites had the greatest elevational differences. Yirga et al. found a similar case in the Wof-Washa highlands of Ethiopia, where the species composition revealed an overlap of species in the low- and midlands, while the highlands did not overlap at all. To explain this, they turned to geographic, and the same can possibly be said here. The vicuña site sat in a flat plain mountain valley surrounded on all sides by higher elevation land. The combined and alpaca sites, while located at very different altitudes, were both on hillsides and in valleys with mountain streams. The geographical characteristics of these two sites were far more similar, and it likely caused a higher similarity between the two as plants tend to grow in the same geographical locations.

Despite receiving the same results, all three indices provided different levels of similarity. The Søreson index gives greater weight to species that are common in both compared areas than to those that are only found in one of the two sites. Because of a decent amount of overlap between species found in all three sites, the Sørenson index numbers were quite high, ranging from 0.4762 to 0.6383. The Jaccard index uses the presence and absence of species while avoiding abundance completely. Because of this, similarities were slightly lower, ranging from 0.3125 to 0.4688 (The University of Arizona, n.d.). In addition, both the Sørenson and Jaccard indices found that the similarity between the combined and alpaca site was only slightly higher than the similarity between the vicuña and combined site, which shows the connection the combined site has to both of the other areas and makes the high similarity between the two farthest sites hold less weight. Lastly, the Morisita-Horn index takes abundance into consideration, making it one of the more accurate similarity indices (A. Ortega, personal communication, 2021). The index numbers for the comparisons of the three sites for Morisita-Horn are significantly different from the Sørenson and Jaccard indices. The vicuña/alpaca comparison value is 0.1365, which is extremely low, while the vicuña/combined value is 0.2194 and the combined/alpaca value is 0.5750. So, while the combined and alpaca sites are relatively similar, the other site comparisons show that there are very different species present between the different study locations, along with different species abundances.

In all three sites, there were nine overlapping plant species. Four of the species were grasses, two were unidentifiable with no noticeable phenological developments, and three were low-growing, herbaceous or mat plants. All species had different phenological stages and were affected differently by the elevational changes, along with the changes in camelid occupation. Even so, a few patterns can be easily seen and discussed.

Out of all individuals in the plant community, the alpaca site had the highest percentage of senescing plants, and the vicuña site had the lowest. This is likely due to slower growth rates in plants at higher altitudes (Hunter et al., 1971). The colder temperature at high elevations means that plants grow slower, and therefore are likely to be seen with less senescing leaves (Coomes et al., 2007). This same pattern was seen with fruiting plants, and it can be additionally supported by the fact that, when transplanted to lower altitudes, plants develop faster, which includes growing flowers and fruits (Swartz et al., 2014). The proportion of plants with dying leaves showed the opposite results, where the largest percentage of individuals was found in the vicuña site and the least in the alpaca site, likely because decay rates decrease with increasing elevation and decreasing temperature (Kirwan et al., 2014). Something to note is that the percentage of flowering plants did not change significantly between the three studies. It is known that with increasing altitude comes increasing flower longevity to strengthen the chances of
pollination. It is possible, therefore, that the lower altitudes have more flowering plants over a longer period of time while the species at higher altitudes don’t flower as often, but keep their flowers for longer (Schwartz, 2014). This, of course, cannot be fully captured within a shorter amount of time, and so spatially is might simply look like each location has the same proportion of flowering plants. Additionally, while there are no sources regarding flowering plants and camelid influence, it has been personally observed that camelids will in fact eat the flowers from plants, and this could have been part of the reason for a lack of change in the percentage of flowering plants.

The phenology of the overlapping species

Three of the four grass species discussed here had 100% of all individuals with dying leaves. Because of this, only the dying leaves of the Agrostis grasses will be discussed.

Festuca grasses are extremely common in the páramo, and there are 13 species on Chimborazo alone (Stančík et al., 2007). This genus had nearly the same percentage of plants with dying leaves and plants with fruits in each of the three sites. This species did, however, show differences in the average amount of dead leaves or fruits per plant. It had the most dead leaves per plant in the combined site and the least in the vicuña, which, in this case, signifies that the grasses in the combined site had an overall larger diameter and more leaves per plant in total because plants grow smaller at higher altitudes (Coomes et al., 2007). To support this fact, the alpaca site had the highest number of fruits per plant, while the vicuña site at the lowest, showing a positive correlation between the number of dead leaves and the number of fruits due to the overall size of the grass. Additionally, the specific chosen area for the combined site was in a valley that held numerous larger bunches of grasses.

Stipa grasses dominate the western and southern slopes of Chimborazo (Ramsay, 1992), and they are known for their ability to persist and adapt in a number of conditions (Fiallos et al., 2015). This genus had the largest percentage of fruiting individuals in the alpaca site and the lowest in the vicuña site, which could be a factor of both altitude and camelid populations. The alpaca site was much warmer, and it also was not being constantly grazed on. The vicuña site, on the other hand, was 5 °C colder, much cloudier, and continuously inhabited and grazed upon by the vicuña populations. These fruiting plants were likely less common in the vicuña site because of harsher environments, and also because of camelids grazing upon the seeds of these grasses. These grasses had the most dead leaves per plant in the alpaca site and the least in the vicuña, and the fruits per plant followed this same pattern. This once again signifies larger grasses in the lower altitudes.

Agrostis grasses are very common, and tend to have shorter, flatter leaves (Fiallos et al., 2015). This genus had the largest percentage of dying individuals and fruiting individuals in the combined site, while the lowest for both was in the vicuña site. In addition, the number of dead leaves and fruits per plant did not change significantly between the three sites. This signifies that Agrostis grasses likely aren’t as affected by altitude. In addition, some species of this genus are known to grow closer to riverbanks and areas with high soil moisture (Díaz, 2018), and the combined site, which had the highest number of fruiting individuals, was the closest to a body of water. It is also known that camelids feed more on Festuca and Calamagrostis (Wheeler, 2006), along with some herbaceous plants, so Agrostis likely isn’t highly affected by grazing, and it doesn’t follow the expected pattern of altitude. Because of this, it’s possible that proximity to water, or even microclimates, have caused the results seen here (Borchert, 1994). It is unclear
why the combined site has the largest percentage of *Agrostis* with dying leaves, although trampling by large populations of camelids is a high possibility.

*Calamagrostis* grasses are extremely common, and the species *Calamagrostis intermedia* is simply known as “paja” because of this (Romoleroux et al., 2016). This genus has around 54 accepted species (Sylvester et al., 2019). In this study, it had the highest percentage of fruiting individuals in the alpaca site and the lowest in the combined. While it is known that plants at lower altitudes develop faster (Schwartz, 2014), the reason why the combined site has the least number of fruits could possibly be due to the increased grazing by both camelid species, who have been observed to eat the seeds of grasses. The highest number of dead leaves per plant was found in the combined site and the least in the vicuña. The lowest number of dead leaves found in the vicuña site it due to the smaller size of the plants, while the large number of dead leaves per plant in the combined site is likely due to the fact that this area had clumps of much larger, tufted *Calamagrostis* species, and the same can be said for the reason why there’s more dead leaves per plant for the *Festuca* grasses in the same area. The highest number of fruits per plant was in the alpaca site, and the lowest in the vicuña due to faster development at lower altitudes (Schwartz, 2014).

*Lachemilla orbiculata* is a matted herb that is known as a pioneer species (Romoleroux, 2016). It is resistant to trampling, so it tends to grow in areas commonly used by people and livestock (Podwojewski et al., 2002). This species had the highest percentage of both flowering and dying individuals in the alpaca site and the least in the combined. The combined site was dominated by this species, making up 20% of the entire plant community, which signifies high levels of trampling by camelid species. This trampling is likely also the reason for the lowest proportion flowering plants. Why the percent of dying leaves was highest in the alpaca site is unclear, but it could possibly be due to the long distance from a nearby water source and being located on a hill where water drains down and leaches the soil (Romeo et al., 2015). The amount of flowering and dying leaves per plant did not change significantly between the three sites.

*Geranium maniculatum* also had the highest percentage of flowering individuals in the alpaca site, but the lowest was in the vicuña site, following the pattern seen in the study by Ziello et al. The highest percentage of plants with dying leaves was found in the vicuña site, and the least in the combined. The most being in the vicuña site follows altitudinal changes, and it is likely that the alpaca site does not have the least because, as stated before, it is on the side of a hill further from water, so it is likely drier with leached soils. The amount of flowering and dying leaves per plant did not change significantly between the three sites.

*Hypochaeris s.* is known to bloom throughout the year, and it’s an extremely common plant associated with drier, sunny areas. Anatomically speaking, the two species represented here have plants that only support one flower at a time (Urtubey et al., 2009). It had the largest proportion of senescing individuals in the vicuña site and the least in the combined site, while it had the highest percentage of flowering individuals and dying individuals in the combined site, and the least for flowering in the vicuña site and dying in the alpaca site. For this species, flowering meant the individual had no senescing leaves, which is why the vicuña site had the least flowering individuals, but the most senescing individuals and the combined site had the most flowering individuals and the least amount senescing individuals. The highest number of dying leaves found in the combined area could possibly be due to excessive trampling. This area was also the closest to a body of water and, as stated before, these plants like drier areas and might not do as well in stream valleys such as the combined site. The amount of flowering, senescing, and dying leaves per plant did not change significantly between the three sites.
For the herbaceous, low growing plants, the percentage of the population in each phenological stage changed between the three sites, but the number of senescing leaves, flowers, fruits, and dying leaves per plant did not. While there are no studies that investigate the number of parts per plant, here the results show that the percentage of individuals for these types of plants can fluctuate depending on whether or not they’re senescing, flowering, fruiting, or dying. But, the total number of flowers, fruits, etc. per plant are not necessarily affected by either altitude, proximity to water, or camelid occupation.

In addition, it is known that signs of overgrazing and trampling include decreased vegetation cover and the dominance of one or two species that are very resistant to trampling (Duchicela et al., 2019). The top two species of the combined site were *Azorella pedunculata* and *Lachemilla orbiculata*, which had abundances of 12,000 and 9,000 respectively. The next species falls 4,000 individuals behind *Lachemilla orbiculata*. Therefore, the combined site was inhabited by two extremely dominant species, both of which were mat or shrub vegetation and extremely resistant to trampling. This is a sign that the combined sites were severely overgrazed and overused. The vicuña site had no such dominant species. The alpaca site, on the other hand, was dominated by just *Azorella pedunculata*, and the next most abundant species fell 3,000 individuals behind. This shows that the alpaca site is also likely overgrazed and trampled, but not to the same degree as the combined site.

**Importance of Findings**

The plant composition and phenological differences between these three sites is extremely pertinent when put in a broader ecological context. For camelids, and certainly vicuñas, palatable grasses include *Stipa* and *Festuca* (Muñoz et al., 2015), both of which were very abundant in this study. These two grasses were found to be much smaller and have fewer fruits at the higher altitude vicuña site, which will influence vicuña feeding behaviors and foraging time, along with the reproductive success of the grasses.

In addition, pollination phenology is strongly affected by altitude. Species that are located at differing elevations are less likely to have overlapping pollination periods, which restricts gene flow in mountainous areas. Vegetative growth is also thought to last longer at lower altitudes, while upland species increase in flowering longevity by roughly three days for every 100 meters. Even so, all of this information has come from studies in North America or Europe. Very little is known about high altitude phenology in the southern hemisphere and tropical areas. Regarding South America specifically, flowering longevity still increases with altitude. Many flowers were also seen blooming at different times to avoid competition in regards to pollination (Schwartz, 2014). Climate change is also thought to be changing the timing of phenology in high altitude Andean flora, which has been shown to cause discrepancies between blooming and hummingbird migration. Regarding camelids, it is thought that heavier snowfall leads to phenological delays, which then creates high quality forage for grazing animals, which will then change the foraging time and feeding behaviors of these animals (Schwartz, 2014).

The altitudinal gradient of plant composition and phenology was seen very clearly here between the alpaca site and the vicuña site, and these differences can result in the consequences of genetic isolation and higher feeding pressures upon grazing species at higher altitudes where plants are smaller and less likely to be reproductively successful. However, this expected altitudinal gradient is disrupted at the mid-altitude combined site, which showed the lowest species evenness and had species that did not follow the expected phenological changes. It is
possible that this could be due to microclimates, but this area was in a stream valley much like the lower alpaca site. Therefore, this could be the influence of intensive grazing in the area by both dozens of alpacas and vicuñas.

The constant grazing and trampling by the camelid species seem to disrupt the natural phenological pattern that comes with altitudinal gradients. This could cause a disruption in pollination, especially for insects and avian species that rely on the flowering and timing of flowering of many plants within the area. A desynchrony between phenological events will either force the reliant species to adapt or go extinct if they can’t keep up with these changes. Additionally, this could influence reproductive success and possibly impact the food sources of the camelid species, along with the plant composition and dynamics of the páramo that a larger number of species rely on for survival.

It’s important to remember that the changes seen here are both locally and governmentally caused. The alpacas are controlled by local communities that chose where their livestock graze, while the vicuñas were reintroduced by the Ecuadorian ministry.

Conclusion

Main findings

All three sites showed very different results regarding plant composition and phenological make up. The vicuña site had the highest altitude, and therefore the lowest diversity and species richness. It showed the least similarity with the lower altitude alpaca site. Out of the entire plant community, it also had the lowest percentage of plants with senescing leaves and fruits and the highest percentage of plants with dying leaves. There was also a pattern within the nine overlapping species of lower percentages of flowering individuals, and all grasses had, on average, less fruits and dying leaves due to smaller sizes. All of these results point to high altitude and harsher temperatures, which impede growth and development and lower the rate of organic decay. From this data, the vicuñas do not seem to be affecting the plant community dynamics of the area.

The combined site had the lowest evenness, and it was least similar to the vicuña site despite their closeness in elevation. There were no solid patterns found within the phenological stages of the nine overlapping plants, although the overall percentage of plants in each phenological stage, ignoring flowering plants, was in between the values of the highest and lowest sites. This site had, however, an extremely high population of *Lachemilla orbiculata* and *Azorella pedunculata*, which are known to grow and become dominant in areas that are overgrazed and significantly trampled. The intense grazing by both vicuña and alpaca populations in the same area seems to disrupt the evenness of the plant species and lead to the dominance of one or two species that are resistant to trampling. The differing phenological reactions of each species to this grazing creates hesitant results as they do not follow any kind of solid pattern, but it still shows that the phenological and diversity patterns that would normally occur with increasing altitudes have been disrupted in this area likely due to increased grazing and trampling by multiple camelid species.

The alpaca site followed the expected patterns. It had the highest evenness, diversity, and species richness, and it was the least similar to the vicuña site. Out of the entire plant community, it had the highest percentage of senescing and fruiting plants and the smallest percentage of dying ones. The nine overlapping species followed a pattern of having the most fruits per plant
and the highest percent of fruiting and flowering plants. The percent of plants with dying leaves and dying leaves per plants, however, did not follow a pattern, which puts into question the role that decay rate has over the phenology of páramo flora.

Some factors, however, didn’t change at all. For example, the proportion of flowering plants overall did not significantly change between the three sites, and it was even slightly lower in the alpaca site. This could possibly be due to longer flower longevity at higher altitudes, and this reading could change if taken temporally instead of spatially. The herbaceous plants found in all three sites (Lachemilla orbiculata, Geranium maniculatum, and Hypochaeris s.) had changing percentages of plants in each phenological stage between the three sites, but the number of new leaves/flowers/fruit per plant did not in any significant way. This suggests that, while phenological stages may change, they won’t always change by magnitude (in parts per plant).

Sources of error

This study was, of course, not without its errors. Each site had anywhere from 15 to 25 species, of which only nine were the same between all three. Because of this, constant identification and familiarization with the plant species was required. Even so, many of the páramo plant species are understudied. Because of this, not every plant could be identified, and many that were had phenological stages that looked very different. Because of this, sometimes it was difficult to tell apart, for example, a flower from a senescing leaf. In addition, mat and shrub plants proved difficult to separate and count and were recorded and counted in bunches to better represent their overall surface area of the quadrat. Each quadrat was also a little over 314 square meters, meaning that many times they were too large to count every individual plant properly and accurately. Because of this, six 1x1 meter plots within the quadrat were taken, counted, averaged, and multiplied by the area of the circle. This, of course, gave a relative idea of the overall population, but not the exact population, which led to some inaccuracies.

While it’s not necessarily a source of error, phenology is principally a field that is studied temporally and in more temperate areas with four distinct seasons. This study, on the other hand, was done along the equator, meaning that photoperiod could not be considered, in an area with two seasons that aren’t quite as easy to pull apart. Additionally, data collection was done over a little under two weeks, meaning the results were more spatial than temporal. Because of this, results might not be quite as easy to follow or as easily understandable.

Future studies

This study is simply a start to páramo phenology and camelid-plant interactions. It is important that future studies work with phenology not just spatially, but also temporally. Long-term studies with a good amount of robust data are needed to better solidify the results found here. Additionally, having a number of people calibrate their counting methods and work on one plot together could help to get a faster and more accurate count of the flora population in place of the approximations and averages done here. Lastly, eliminating altitude from the study and simply focusing on camelids could end in clearer results. Setting up an experiment where all camelids graze at the same altitude using closed off areas is a suggested method to go about this.
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Appendix A: Species Maps

Figure A.1.0: Species distribution maps for all three quadrats at the vicuña site. All species are labeled with a color and a size to signify abundance. VQ1 signifies Vicuña Quadrat 1, and so on.
Figure A.1.1: Species distribution maps for all three quadrats at the vicuña and alpaca site. All species are labeled with a color and a size to signify abundance. AVQ1 signifies Alpaca and Vicuña Quadrat 1, and so on.
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Figure A.1.2: Species distribution maps for all three quadrats at the alpaca site. All species are labeled with a color and a size to signify abundance. AQ1 signifies Alpaca Quadrat 1, and so on.