ECOLOGICAL SIGNIFICANCE OF AND THREATS FACING THE PARAMO

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INTERNATIONAL SUSTAINABLE DEVELOPMENT (ENVL/SUST 3701)

SPRING 2020

STOCKTON UNIVERSITY
SUSTAINABILITY, ENVIRONMENTAL SCIENCE, AND GEOLOGY PROGRAMS
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Table of Contents

1. Abstract

The paramo is a very biodiverse high-altitude region that provides a variety of ecosystem services including fresh water supply, carbon sequestration, and cultural services. Anthropogenic threats plaque the ecosystem as agricultural, grazing, and burning are prominent in these regions due to their fertile and water-retaining soil. In the face of climate change, these practices accentuate the risks of altering the soil composition, reducing biodiversity, decreasing water retention and flow, and increasing carbon turnover. This poses risks to both the environment and humans as the role of a vital carbon sink and water source is threatened. A case study in Cajas National Park, measuring the soil moisture and water-holding capacity of soils with low-lying vegetation and trees as well as both burned and unburned vegetation treatments, helped determine suitable management practices in this region. Results demonstrated that woody trees increase soil drainage and evapotranspiration and therefore are not ideal land-use strategies for paramo ecosystems. Burned and unburned areas showed minimal differences in soil water-holding capacity indicating that burning poses less threat to groundwater retention though it can contribute to erosion. The most threatening risks to the paramo appear to be afforestation and lack of knowledge on the proper management practices for differing regions, especially in the face of climate change. Looking to the future, further funding for long-term research and education will help to obtain more understanding of the hydrology and ecology of the region. Ecological silviculture techniques could help manage afforestation in the paramo. Additionally, using case-specific strategies will help to mitigate the effects seen in the areas where land management is being conducted.

2. Introduction

The paramo is a biodiverse high-altitude grassland ecosystem unique to the Ecuadorian, Venezuelan, Peruvian, and Colombian Andes, of which their locations can be seen below in Figure 1, with the exception of small regions in Central America, Africa, and Asia. These ecosystems are found in the northern Andes in the Neotropics between 11N and 8S (Frantzen and Bouman, 1989 as cited in Keating, 1999). Its location can be found above the tree line, around 10,000 ft (3000 m), and below the snow line, around 16,000 ft (below 5000 m). The tree line is the elevation at which trees can grow. Beyond it, environmental conditions do not allow for their sustained growth and result in shrubs and other low-lying vegetation. The snow line is where you will find permanent snow in places year-round, but this is susceptible to fluctuation as the climate continues to change.

Prepared by T. Consiglio, MBG

Figure 1: The distribution of paramo ecosystems in South America.
Consiglio, T., (n.d.)

Differences in climate can be seen throughout altitudinal zones of the same paramo and across different paramos. The northern Ecuadorian and Colombian paramos experience more humidity because of the ICTZ while Venezuela and northern Colombia experience a dry season due to trade winds (Lauer, 1981). Solar radiation is relatively constant throughout the year due to the equatorial position of the ecosystems; temperatures can oscillate across the freezing point during the day, with differences of 20 degrees Celsius common (Buytaert et al., 2006). Precipitation is variable across paramo ecosystems, ranging from 700 to 3000 mm annually, due to topography and wind as further described by Buytaert et al. (2006). Therefore, a wide variety of vegetation and varying soil conditions allow for diversity across different regions of the paramo.

Several vegetation regions exist in the paramo due to altitudinal differences. The general layout of this ecosystem begins with the lower paramo grassland, which continues to rise due to exploitation, consisting of scattered shrubs, diverse flora, and transitional trees around 3200 m (Acosta-Solis, 1984, as cited in Hess, 1990). The middle paramo or grass paramo is the next region, which is a continuous grassland-shrub region at around 4000m, and the highest paramo region is the high paramo at around 4500m with sparse vegetation, sandier soil, and more woody species (Acosta-Solis, 1984, as cited in Hess, 1990). Respective terms for these regions include subparamo, paramo, and superparamo.

The high-altitude location of the paramo has resulted in plant adaptations that allow them to survive in low atmospheric pressure, high UV radiation, and intense wind. A variety of low-lying plants are found here due to these conditions. High endemism is a characteristic of the paramo due to the challenging conditions that species are exposed to. In conjunction with its high levels of biodiversity, the paramo also provides essential ecosystem services to surrounding communities and local populations, including being a prominent supply of freshwater. In addition to providing freshwater, the soils of paramo are also a large carbon sink and thus are essential in climate change mitigation.

As with many ecological systems, the paramo has and continues to be exploited by those that live in the region, resulting in many anthropogenic threats. Intensive land use has resulted in the practices of afforestation, agriculture, burning, and overgrazing plaguing the paramo and threatening its health as well as those that rely on this ecosystem as a water source. Pressure continues to be placed on the paramo ecosystems with alterations in hydrology and climate in the regions as a result of land-use requiring further time and efforts placed into researching this area (Hribljan et al., 2016).

It is difficult to quantify and ascertain the ecological changes that will occur in these biodiverse ecosystems as the climate continues to change and human exploitation continues.

Further research must be conducted to understand future effects on the biodiversity and resiliency of these ecosystems under these conditions. The purpose of this paper is to analyze the importance of the paramo ecosystem to local communities and the anthropogenic threats that it faces as well as threats posed by climate change. Specifically, this paper will look at the major threats facing the paramo and actions that can be done to help mitigate negative effects in the long-term.

3. Ecosystem Services of The Paramo

3.1. Freshwater

The groundwater retention in the paramo that makes this area so essential to life is due to the weather conditions and soil composition. The cooler climate and higher humidity in these regions combined with rich volcanic soil due to geologic activity (Hess, 1990) contribute to the carbon-rich, porous soil and water retention found here. This also contributes to the natural filtration of the water, often making it suitable for drinking in the lower altitudinal communities that depend on it. According to Buytaert et al. (2006), the cities of Quito and Bogota are almost entirely reliant upon this ecosystem for their water supply. The presence of low-lying grasses and other vegetation acts as a sponge and holds moisture in the soil and contributes to pore space which in turn determines the amount of water the soil system can hold. Essentially, the paramo is both a natural storage system and supplier of water for communities in the lowlands.

Water from the paramo supplies many of the rivers that enter the Amazon Basin and coastal regions. This water is utilized for personal use, irrigation, and to generate electricity, therefore supplying the power to operate and maintain agriculture and industries at lower elevations. This ecosystem is essential in providing drinking water and allowing for the functioning of many jobs and industries, thus carrying financial significance. Additionally, due to the high water retention of the soils and extensive grasslands, the land of the paramo is often utilized for agriculture, tree plantations, grazing, and mining.

3.2. Climate Regulation

The significance of the paramo further increases as this ecosystem is also a large carbon sink, therefore providing a unique role against climate change through carbon sequestration. Due to the presence of low-lying plants and rich soil that is often saturated, which slows decomposition rates, almost all of the carbon pool is belowground, especially in peatlands (Hribljan et al., 2016). The paramo can store more carbon per hectare than tropical forests can (Hofstede et al., 2014 as cited by Gutierrez & Medrano-Vizcaíno, 2019). The slow accumulation of carbon and organic matter makes it a stable, long-term source of organic materials and a strong advocate for the future of climate fluctuations. This underground storage, in both mineral soils and peat bogs, acts as a sink for atmospheric carbon and provides a mechanism for battling increasing levels of carbon dioxide in the atmosphere.

Figure 2: Cajas National Park Paramo Ecosystem (Viator, n.d.)

3.3. Cultural Services

High biodiversity is a key characteristic of the Andean paramos. The paramo is home to a wide array of endemic plant species. As many as 60% of the 3500 vascular plant species in the Andean paramo are endemic (Luteyn, 1992 & 1999 as cited in Sklenář & Balslev, 2005). A major portion of plant species derived from indigenous flora that resulted in the evolution of plants that tolerate high-altitude environments over the millions of years that mountain formation occurred (Sklenář et al., 2011). Furthermore, more temperate plant species also migrated through dispersal, further contributing to the plant diversity as environmental conditions diversified (Cleef, 1979 as cited by Sklenář et al., 2011). Changes in climate and geology over millions of years has led to the wide variety of species that can be found in the paramo. Emadriñán et al.

(2013) found that in comparison to other hotspots, the paramo has higher diversification of plant species and the fastest mean diversification rate.

In addition, the use of the diverse vegetation of the paramo for medicinal purposes is common among many indigenous families and reinforces an essential need filled by the biodiversity of the region. Further services provided by the paramo include both recreational and educational benefits. Ecotourism, a popular and continually growing industry, can bring awareness and publicity to threatened areas and promote conservation efforts and research for the future.

4. Threats to The Paramo

4.1. Agriculture, Grazing, and Burning

The paramo is home to extensive grasslands and fertile soil, therefore making it appealing for agricultural practices. Potato crop and livestock agriculture are common activities seen in the paramo. These activities were found to decrease some of the enzymatic activity of the soil as well as carbon and cation exchange as compared to relatively undisturbed land in the paramo (Avellaneda-Torres et al., 2018). As land is continually utilized, the soil loses nutrient content and can affect both plant growth and ecological processes. In fact, “The conversion of paramo to cropland may be less dramatic than that of forest to cropland, but the potential erosion rates from exposed soils in the two environments are equally high” (White & Maldonado, 1991, p. 43)

Cattle have difficulty accessing low vegetation and find some unpalatable, resulting in farmers burning the land to allow for growth of younger more digestible vegetation around every two to three years. At higher elevations, disturbances such as burning can severely degrade the soil, especially if improperly regulated. Burning reduces grass cover and increases the amount of bare ground. The runoff coefficient is a way to relate the amount of runoff to how much precipitation occurs. Poulenard et al. (2001) found that paramos not subject to human activities have higher water infiltration and lower erosion and that “both tillage and burning increase the runoff coefficient threefold” and contribute to lower hydraulic conductivity. Hydraulic conductivity is essential in allowing for water to flow through the pores in the soil and thus allow for proper water movement. According to Harden (2006), the narrow and steep characteristics of Andean river valleys result in any changes in slope or soil properties that lead to erosion or runoff being transmitted to river systems thus affecting freshwater and livelihoods. Topographical gradients and the amount of ground cover largely affect erosion rates and the ability of the soil to retain water by increasing runoff. Therefore, grazing and burning can erode the land and influence water retention of the soil due to loss of vegetation. further influenced by topography. In addition, Hofstede (1995) found that sites with grazing and burning resulted in higher decomposition rates as opposed to those with minimal disturbances. This can result in increased carbon entering the atmosphere. These findings indicate that human activities have significant impacts on the ecosystem processes of the paramo.

4.2. Afforestation

Afforestation, typically the establishment of pine plantations, is a common practice in the paramo. The ultimate goal of these plantations is wood production, reducing erosion, and increasing carbon storage through tree growth. More recently, these plantations have been shown to possibly cause a reduction in carbon accumulation in the soils, though it can vary by region and soil type. In Cotopaxi, which has younger soil, a study found that while pine plantations increased aboveground carbon it simultaneously prevented further, more stable belowground carbon accumulation in the soil (Farley et al., 2004), which occurs for years before it stabilizes. Belowground carbon storage is vital as aboveground storage is more susceptible to being released back into the atmosphere through burning or leaf litter.

Afforestation also alters the hydrology of the paramo. Trees can change the porosity and drainage of soil. At a pine plantation in the Ecuadorian paramo, reductions in the soil moisture and less uniform water flow were found as opposed to land without pines (Harden et al., 2013). This indicates that the prevalent pine plantation industry, as well as any other afforestation practices, can dramatically affect the potential water capacity and flow thus affecting water distribution and altering the soil composition and species distribution. Continued use of plantations or expanded use in the future could be detrimental to low-lying communities.

In addition, afforestation can alter natural habitat and threaten native species. Hofstede et al. (2002) noted that the response of native vegetation to pine plantations was variable with a multitude of plantations showing paramo grassland understory or woody understory, but several sites demonstrating no understory growth. Afforestation is highly variable in terms of its effects on species diversity and locational impact and the effects on the ecology of the area cannot be fully understood without further research.

4.3. Climate Change

The variability that comes with changing climate and weather patterns can impact ecosystems in a variety of ways. Emadriñán et al. (2013) explain that the plant species of the paramo possess the inability to quickly adapt to changing temperatures which emphasize the dire issue of how species will respond in shorter time frames over the coming years to increased temperatures brought by climate change. A review Buytaert et al. (2011) concluded that climate change will result in reduced area and alteration of boundaries of paramo ecosystems as well as increased patches that could result in extinction or loss of species. Additionally, it was found that in alpine ecosystems such as the paramo, precipitation and temperature are influential factors in determining life zones, vegetation, and species richness (Cuesta et. al, 2017). This, therefore, increases the susceptibility of the paramo ecosystem to the negative effects of rising temperatures and altering weather patterns associated with climate change and threatens the health and stability of the biodiversity of the region, of which the vegetation is essential in helping to store carbon and water.

Increasing atmospheric carbon resulting in warmer temperatures can change precipitation patterns and the carbon cycle. It was found that altered soil composition as a result of increasing temperatures will increase the rate of carbon turnover and decrease water retention and hydrologic flow resulting in a loss of below-ground carbon storage, increase in carbon released into the atmosphere, and a negative impact on human water supply (Buytaert et al., 2011). The delicate balance of ecological processes that allow for the paramo to function as it does is very easily disturbed and altered.

5. Cajas Case Study

5.1. Methods

A case study by Harden (2006) examined surface soil moisture in and around the Llaviucu watershed, most of which lies in Cajas National Park in the western cordillera of the Andes, which provides 20-30% of Cuenca's water supply. In this area, around 3000-4300 m, grass paramo is the prominent region with some Polylepis trees, tropical montane forests, and pasture grasses. Cattle grazing has been reduced but the use and amount of burning need to be determined as well as its effect on water resources. The study also looked at differences in soil between forested and unforested areas. During June and July of 2004 (a moist year), a study was conducted using pairs of soil moisture plots between 3163 m and 3527 m to determine how grass and tree cover impacted the soil in areas of relatively homogeneous topographical and soil characteristics. Volumetric moisture content was determined at 4 m^2 plots in the 23 sites using a HydroSense Time Domain Reflectometer to get 5-15 replications at each location. At each plot, two soils samples, around 12cm deep, were taken. Bulk density (using the sand replacement method) was measured in the lab after the soil was air-dried, oven-dried, and weighed. Gravimetric moisture content was found using the weight before drying to find the mass of water. Loss-on-Ignition was found using sample mass after burning the oven-dried sample to measure the percentage of organic material. These measurements were then used to determine the water-holding capacities, moisture content, and densities of the soil in burned and unburned conditions (Harden, 2006, p. 258-259).

Figure 3: Location of Cajas National Park

(Google Maps, 2020)

5.2. Results

In surface horizons, the mass of water was found to be 1.5 times the dry mass of solid soil, indicating that these soils have high water-holding capacities. The soil in the plots under grass had higher volumetric moisture content than soil under trees and soils under trees had more macropores. Additionally, the soil under trees was drier and less dense in each pair plot. Between three plots that had been recently burned and one that hadn't been, there were minimal differences in densities or volumetric moisture content. These results indicate that tree-covered areas store less water in the soil than grass sites while burn sites have no significant differences in soil moisture and density as compared to undisturbed sites. Therefore, the presence of woody trees can increase drainage and evapotranspiration and result in the reduced water-holding capacity of paramo soils. These results highlight the threats of afforestation and emphasize the need for management to prevent erosion, increased sediment in waterways, and reduced water supply. It also supports the idea that there are minimal short-term effects of burning on soil water retention (Harden, 2006, p. 259-261).

6. Discussion

6.1. Imminent Threats

Land-usages that most highly affect the paramo include afforestation and the use of unregulated or uneducated burning. Afforestation drastically alters the carbon composition and water retention of the soil. Fire has likely been a recurring event in the paramo, given that humans have occupied the area for over 7,000 years, which may have contributed to the composition of the soil and vegetation (Keating, 2007). While fire may not affect the water content of soil, as seen in Harden's case study (2006), it can result in bare ground that may cause erosion and sediment runoff. As the climate continues to change, the loss of belowground carbon and groundwater retention will likely alter the soil composition and have effects that extend beyond increased atmospheric carbon. Erosion and poor water quality for lower altitude communities could affect thousands of people that rely on the paramo.

6.2. Mitigation of Threats

Proper management of these ecosystems can help to balance human needs with environmental quality and mitigate the threats that the paramo faces. However, it is often hard to formulate policies and management actions that benefit the environment and the people and apply to the varying conditions and qualities of the different regions of the paramo. Moreover, Quiroz Dahik et al. (2018) found that various land-use stakeholders had different perceptions on how to maintain healthy ecosystem aspects while regulating the effects of land-use changes.

According to Farley et al. (2013), limitations on burning is one of the land-use strategies that enhance carbon storage while grassland conservation can be essential moving forward to help with climate mitigation. In contrast, Bremer et al. (2019) highlight the need for desired objectives or outcomes in terms of the use of burning as the practice resulted in more native plant diversity in one study area with both woody and herbaceous plant species and more homogeneity of tussock grasses in another. Harden's case study (2006) explains the responses and needs of a particular region in the paramo to fire and implies the possible benefits of regulated and researched fire usage for those in the agricultural industry. In this area, burning had minimal impact on soil moisture. However, the susceptibility of erosion and runoff was not studied in this case. Therefore, understanding the location and response to burning and its frequency will help to benefit different areas of the paramo through either no use, minimal use or scheduled use of burning.

Wood production is a highly favorable industry in the paramo though it can have negative impacts as discussed earlier. As seen in the case study above, afforestation resulted in decreased water retention and increased hydraulic conductivity due to the presence of macropores. Some possible mitigation strategies include establishing designated areas for plantations and applying the use of finances and ecological silvicultural tactics to better manage afforestation practices (Quiroz Dahik et al., 2018). In terms of vegetation diversity, there is a need for more education and a more widespread understanding of the subject to help provide uniform responses and management actions on afforestation practices. In addition, the ecology of the area in which afforestation is being debated or conducted must be considered to fully understand how the particular ecosystem will respond to exotic species changes in soil composition.

Continued degradation will affect the holding capacity of water and could alter it entirely. Protection of the soil is of primary concern as this is the provider and source of water for millions of people. More needs to be understood about the hydrology of the paramo which entails finding funding for extensive research. According to Célleri and Feyen (2009), funding from national and international sources as well as local organizations can be highly beneficial to increasing knowledge, as well as developing research on paramo ecology through incentivization, and developing long-term research goals. Payment for ecosystem service programs, commonly used in the paramo grasslands of the Andes, can continue to provide incentives for land-use management. However, this requires further education and research on the topics and management strategies being employed.

7. Conclusion

As explained by Célleri & Feyen (2009), the complexity and diversity of the Andean paramos combined with its extensive size and lack of funding for research leave our understanding of the paramo far from complete and emphasizes the large knowledge gap of our quantification of its monetary value and services. Long-term research is an essential data source that is lacking in terms of paramo studies. These studies are essential to understand how paramo ecosystems respond over time and how they make be affected in the long term by both human activities and climate change.

An overarching theme for promoting the health and protection of the paramo is understanding that each site and location can have variable responses to different practices. This requires the use of testing or prior knowledge on an area before implementing practices that could have lasting negative effects. The practice of afforestation appears to have a larger impact than that of burning on the reduced function of water retention and organic composition of paramo soils. Agricultural practices can lead to erosion and the drying of soil which calls for regulations and alternative incentivization. Therefore, through the regulation or limitation of plantations and strategic implementation of fire, paramo flora has the opportunity to fare better and help retain the water holding capacity of these ecosystems.

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