Land Use Changes and its Impact on the Ecuadorian Pàramo

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Abstract

The Ecuadorian pàramo is an ecosystem growing in importance as it is being recognized for its key ecosystem services including biodiversity, carbon sequestration, and the regulation and storage of water. The land is inhabited by indigenous and rural communities, people who have always used the land for agriculture, grazing, and plant collection. Starting in the 1990's, the government began to fund pine plantations as a way to sequester more carbon and combat climate change, as a result of the Clean Development Mechanism. Studies now show that this method actually diminishes ecosystem services, and transfers carbon from belowground where it is stable, to above ground where it is less stable. More sustainable methods of preserving the pàramo and enhancing its ecosystem services came about in the form of Payment for Ecosystem Services. One such program, SocioPàramo, has the goals of conserving 800,000 ha of unprotected pàramo while alleviating poverty in the area.

Introduction

In Ecuador and other South American countries, the mountain ecosystems consisting of plains, glacial valleys, and a wide variety of lakes, marshes, and wet meadows, is known as the pàramo. The pàramo covers the upper parts of the northern Andes, creating a belt between the Dordillera de Merida in Venezuela and the Huancabamba depression in northern Peru. These high Andean grasslands (locally called the Sierra), make up about 34% of Ecuador's total area and feature a typical tropical high mountain climate (Cèlleri and Feyen, 2009). Precipitation is variable, but due to the closeness of the equator the daily solar radiation is almost constant throughout the year. It is a unique, fragile ecosystem that provides many ecosystem services and is of importance regarding regional water supply, soil organic carbon content, and biodiversity.

The fragmented occurrence of the pàramo over the Andean highlands promotes high speciation and high levels of endemism. The vast array of valleys, peaks, and slopes creates microhabitats that can host a wide range of plant and animal species. About 60% of the 5,000 different plant species in the pàramo are endemic and consist of tussock grasses, ground rosettes, dwarf shrubs, and cushion plants. These endemic plant species are adapted to specific climatic conditions such as low atmospheric pressure, intense daily solar radiation, and high winds (Buytaert, Cèlleri, Bièvre, Cisneros, Wyseure, Deckers, Hofstede, 2006). The pàramo grasslands are home to approximately 45 restricted-range bird species and 30 globally threatened avian species including the Andean Snipe and the Ecuadorian Hillstar (Astudillo, Samaniego, Machado, Aguilar, Tinoco, Graham, Larra, and Farwig, 2014).

Soil types in this region include Entisols, Inceptisols, and Histisols, with the most prominent being Andosols, or soils with a volcanic origin. The soils are relatively homogenous throughout the landscape, ranging from a few centimeters to several meters in thickness depending on the topography. The grasses that cover the landscape are always supplying the soil with a source of organic matter belowground in the form of broken or dead roots. The wet and cold climate impedes decomposition and allows organic matter to accumulate in the soils. In addition to the climate, Al and Fe supplied by the breakdown of volcanic ashes forms organometallic complexes which resists microbial breakdown even further. According to Buytaert et al (2006), organic carbon content in the humid pàramos can commonly surpass 40%, while in the younger and dryer pàramos organic carbon content will be around 4- 10% As a result of climate and parent material, the soils are dark and humic with an open pore structure.

The high organic matter content, open pore structure, and large volume of mesopores and micropores within the aggregates contribute the extremely high water retention capacity of the soil. The saturated hydraulic conductivity, or the ease of which pores of a saturated soil transmit water, ranges from 10-60 mm/h (Poulenard, Podwojewski, Janeau, and Collinet, 2001). The large water surplus and sustained base flow of the pàramo feeds the rivers that flow to the coastal regions and the Amazon basin.

The pàramo is a region growing in importance, as the ecosystem services it provides are gaining attention. In addition to the beauty and habitat for flora and fauna, the pàramo stabilizes large amounts of soil carbon, playing an important role in global climate change. Furthermore, it serves as the primary catchment and regulates the hydrological system of the northern Andes and provides clean water to the populated inter-Andean towns and cities.

Land Uses

Human presence in the pàramo goes back to pre-Columbian times. A large variety of natural products can be extracted from this ecosystem including gums and exudates, essential oils and flavorings, resins, dyes, tannins, vegetable fats and waxes, and natural insecticides. In addition, cattle grazing and burning were common practices for the indigenous who lived and travelled through the land. The social importance of this ecosystem is reflected in the people who depend on the high soil productivity to produce meat, milk, wool, traditional crops, and fiber to earn money(Espinosa and Rivera, 2016). Irrigation is a long standing practice, which started with the Cañari culture who constructed large irrigation schemes. Water is supplied almost exclusively from surface water, supplying more than 98% of the water used for irrigation. The Incan culture improved these infrastructures with the knowledge of other conquered cultures. (Cèlleri and Feyen, 2009).

These historical activities have always remained local with minimal effects on the soil and hydrology. With time, the intensity and the nature of human activities in the pàramo has increased drastically. Infrastructure is built at a faster pace, livestock grazing is intensified, and grasslands are drained and converted to agricultural fields. Deforestation and gold mining are causing severe environmental degradation. As a result, the hydrologic cycle is altered, ultimately changing the soil properties as well. Drainage results in dryer soils, reduces evaporation, and increases runoff and erosion (Farley, Kelly, and Hofstede, 2004). Overgrazing and burning can also lead to an increase in runoff and erosion, threatening the clean water surface bodies which many Andean cities rely on. Quito, Ecuador uses surface was for 85% of its supply, with all of that exclusively from the pàramo (Buytaert et al, 2006).

Exotic tree species have been planted in the Andes since the mid 1800's, starting in parts of Ecuador, Bolivia, and Peru. The earliest plantations were established for meeting fuel and timber needs, with the added intention to improve soils that have been overgrazed and were susceptible to erosion. In places where burning and grazing was repetitive, plant cover was greatly reduced, leading to fewer nutrients in the system, resulting in lower productivity and a slower regrowth (Poulenard et al, 2001). Incentives to promote forestry projects in Ecuador have been included in the national forestry laws. Pine plantations were promoted through government programs such as the Ministry of Agriculture and other public or private landholders. The programs initiated in the 1970's marked the beginning of the growth and spread of pine plantations in Ecuador. The factors that promoted pàramo to pine transitions began to change in the 1990's, when new sources of financing appeared to fund pine plantations for other reasons (Farley, 2007).

The creation of the Clean Development Mechanism (CDM), has lead to an increase in the establishment of exotic pine plantations in Ecuador for their potential as carbon sinks and sources of carbon credits. The CDM was created under the Kyoto Protocol to the United Nations Framework Convention on Climate Change to enable countries to meet part of their emission reduction requirements by carrying out reforestation and afforestation projects. Pilot projects began in Latin America in the 1990's, carried out by PROFAFOR (Programa FACE de Forestacion), which had the objective of planting 75,000 ha of tree plantations in Ecuador. By 2006 there were 22,000 ha of plantations in the highlands of Ecuador, with 94% of those plantations being pine (Farley, 2007).

Impact of Pine Plantations

Although funded by the government as a way to combat climate change, the transition from grassland to pine changes the ecological system and has impacts on soil carbon sequestration and water retention. In the pàramo of Ecuador, goals of these pine plantations included enhancing ecosystem services, even though little research has been done to show that pine plantations do improve soil quality, water quality, and carbon sequestration. In fact, a study in the pàramo grasslands of the Cotopaxi province, Ecuador, shows that although pine plantations may provide economic benefit, it severely diminishes key ecosystem services- soil carbon storage and soil water retention. In the long run, a transition to pine plantations in the pàramo may not be a sustainable method in reducing atmospheric carbon (Bremer, Farley, Chadwick, and Harden, 2016).

Soil Carbon

The conversion of grasslands to tree plantations allows for the aboveground sequestration of carbon in the biomass of the trees. In many cases of other ecosystems that have been incorporated into tree plantations, the planting of the trees increases the soil carbon stock. However, because pàramo soils tend to already have very high accumulation of soil carbon, planting trees cause a loss of soil carbon, which offsets the carbon sequestered in the biomass of the trees. The overall carbon storage capacity of the system has changed to one where carbon is stabilized below ground, to aboveground (Farley, 2007).Carbon losses from the soil can be a result of losses through decomposition, changes in substrate quality, and changes in soil moisture and temperature which affect microbial activity. Grasses of the pàramo form extensive fine root systems, which are the main input of soil organic matter (SOM), in this ecosystem. When a grassland is transformed into a tree plantation, SOM inputs decrease greatly because root production and turnover for pines tends to be much lower than that of grasses (Hofstede, Groenendijk, Coppus, Fehse, and Sevink, 2002).

In pàramo soils, the high moisture is considered to be one of the most important factors in slowing decomposition and the loss of soil carbon. Under pine plantations the soil dries, causing an increase in decomposition and driving the loss of soil carbon. Pine plantations create a positive feedback loop where soil organic matter declines, soils are less able to retain water, further accelerating decomposition, causing further declines in soil organic matter. Soil temperature also plays an important role in decomposition. A cool soil temperature under the grasslands slowed decomposition, but pine plantations elevate soil temperature and can increase decomposition rates (Espinosa and Rivera, 2016).

In Cotopaxi a study was done to determine the effects of pine plantation on soil organic carbon and water retention. It was found that a loss of soil carbon occurred with plantation age, declining from 5.0 kg m^{-2} under grasslands to 3.5 kg m^{-2} under the 20-25-year-old pine stands in the chronosequence (Farley et al, 2004.) In the absence of a pine plantation, the soils would have continued to accumulate carbon for several thousand years. Soil carbon is being transferred from belowground, stable pools, to above ground pools which are much more susceptible to loss through fire and uses that release carbon after harvesting.

Water Retention

The large water retention capacities of pàramo soils allows this ecosystem to serve as the primary water catchment for most of the northern Andes. Disturbance from tree plantations can lead to irreversible drying of the soils, causing the loss of water retention, and leading to lower water storage.The decrease in SOM that occurs under pine plantations is also associated with the decrease in soil water retention capacity. Soil organic matter promotes the formation of stable soil aggregates, creating mesopores and micropores, which are able to hold capillary and hygroscopic water. In addition to the loss of SOM and its effects on holding water in pores, it has been hypothesized that pine roots may break soil structure and reduce the volume of mesopores and micropores (Guo and Gifford, 2002). Similar to the loss soil carbon, a positive feedback loops forms when a loss of water retention capacity contributes to the loss of SOM, which further reduces the ability of the soil to retain water. A comparative study found that soil moisture content at saturation was reduced by 14% at 10kPa negative soil water pressure and by 62% at 1500kPa (Farley et al, 2004).

Payment for Ecosystem Services

Payment for ecosystem services (PES) programs have been advocated as a way to finance conservation of threatened ecosystems while also improving human well-being. The most common ecosystem services considered in PES schemes are regulation of fresh water flows, carbon storage, provision of habitat for biodiversity, and scenic beauty (Koning, Aguiñaga, Bravo, Chiu, Lascano, Lozada, and Suarez, 2011). Although it has been questioned if the two goals of conservations and improving well being can be met simultaneously, many support the idea that conservation programs are less likely to be successful if local communities do not benefit from them in an equitable way (Farley, Anderson, Bremer, and Harden, 2011).

Since the implementation of PES programs, nine programs that focus on the pàramo of Ecuador are already in progress or are in the process of implementation. Of these nine programs, six of them included a socioeconomic goal including alleviating poverty or improving living standards. As mentioned previously, PROFAFOR was the first PES program that targeted pàramo grasslands with the main purpose of carbon sequestration. Most ecosystem service projects targeted pàramo grasslands and compensated landowners for afforestation with pine. As studies have shows that pine plantations do not increase soil carbon sequestration and interfere with water retention, the PES programs have shifted away from pine plantations and to conserving the natural vegetation of the pàramo and preventing overgrazing or burning of the land (Farley et al, 2011).

SocioBosque

The SocioBosque program is a national conservation agreement scheme that involves the transfer of a direct monetary incentive per hectare of native forest and other native ecosystems to individual landowners or indigenous communities who voluntarily protect these ecosystems. The goals of this program, as defined by the Ecuadorian Ministry of the environment are: (1) protect over 3,600,000 ha of forest and other native ecosystems, thereby conserving globally important biodiversity, reducing greenhouse gas emissions from deforestation, protecting soils and water, and controlling natural disasters, and (2) increase income and protect human capital in the poorest rural communities of the country, with a target group of people between 500,000 and 1,500,000 people (Koning et al, 2011). A preliminary analysis indicated that areas where SocioBosque has been implemented so far already store over 5% of the biomass of the entire country, and 62% of the national biomass of carbon (Bertzky, Ravilious, Araujo, Kapos, Carrión, Chíu, Dickerson, 2010).

SocioPàramo

SocioPàramo is a component of the SocioBosque program, which was expanded in July of 2009 to include the pàramo ecosystem and has a goal of protecting 800,000 ha of unprotected pàramos while contributing to poverty alleviation. The pàramo is an example of an area where high poverty rates and ecosystem production services are related, as the lands are often managed by some of the most marginalized communities and individuals in the country. The program provides $30 USD per hectare per year for pàramo conservation for small landowners, and progressively lower payments per hectare of larger areas. Sociopàramo excludes areas with monocultures, such as pine plantations, and intensive grazing. The program prohibits burning, intensive grazing, cutting vegetation other than for subsistence, and carrying out any other activities deemed to threaten ecosystem services. The site is visited once every three years for compliance, and annual remote-sensing analysis of land cover change is recorded (Bremer, Farley, and Lopez-Carr, 2013).

As of May 2011, 18 communities enrolled 34,416 ha of land and 63 individual contracts enrolled 15, 823 acres of land (Bremer et al, 2013). While the monetary incentive was almost always cited as the most important factor in participation of the program, non-monetary incentives were also cited as important factors in motivation to participate. Data collected of SocioPàramo participants found that all participants stressed that the pàramo needed to be conserved for its important role in providing water for agricultural and household use. The pro-conservation attitudes by these communities was enhanced by the monetary incentive for conservation, even though 15 out of 18 participating communities had established some form of conservation prior to enrolling in SocioPàramo. (Bremer et al, 2013).

Conclusion

The Ecuadorian pàramo, consists consisting of plains, glacial valleys, and a wide variety of lakes, marshes, and wet meadows. The soils of the pàramo are mostly Andisols, which have a high organic matter content, open pore structure, and large volume of mesopores and micropores to contribute to the high water retention. It provides key ecosystem services such as high levels of biodiversity, high amounts of carbon sequestration, and water storage and regulation. In an attempt to store more carbon, the creation of the Clean Development Mechanism (CDM), has lead to an increase in the establishment of exotic pine plantations in Ecuador. Studies have shown that pine plantations diminish the ecosystem services provided, and transfer carbon from belowground where it is stable, to above ground where it is less stable. More sustainable methods of preserving the pàramo and enhancing its ecosystem services came about in the form of Payment for Ecosystem Services, such as SocioPàramo. SocioPàramo has a goal of protecting 800,000 ha of unprotected pàramos while contributing to poverty alleviation.

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