Land-use change, ecosystem services, and local livelihoods: ecological and socio-economic outcomes of Payment for Ecosystem Services in Ecuadorian páramo grasslands

A Dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy in Geography

by

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ABSTRACT

Land-Use Change, Ecosystem Services, and Local Livelihoods: Social and Ecological Outcomes of Payment for Ecosystem Services in Ecuadorian Páramo Grasslands.

by

Leah Lodge Bremer

This dissertation examines the socio-economic and ecological outcomes of emerging payment for ecosystem services (PES) programs targeting highland Andean grasslands (páramos) in Ecuador. While PES programs, in general, and in Ecuador in particular, are increasingly advocated as a way to link conservation and rural development, there is a noted lack of empirical research on the social and ecological outcomes of these initiatives. The primary objective of this research was to contribute to filling this gap.

Chapter 2 focuses on Ecuador’s SocioPáramo program, a national-scale PES program targeting carbon, water, biodiversity, and poverty alleviation páramo grasslands. Participation resulted in gains in financial and non-financial capital, but outcomes depended on the context under which PES occurs. In many cases, PES strengthens adaptive capacity by providing a more diversified income source, but, in some cases, participation may increase vulnerability due to reduced access to permanent and seasonal grazing lands.
Chapters 3 & 4 address changes in carbon storage and plant diversity under afforestation and burn exclusion, the two main land-use changes currently promoted by PES programs targeting páramos. Pine afforestation and burn exclusion increased aboveground carbon storage and had small, but variable, influence on soil carbon storage. Results suggest little immediate impact of fire on soil carbon storage, but that burn exclusion can lead to small increases in soil carbon storage, at least when some tussock cover is maintained. In both study areas, intermediate levels of burning maximized species richness, but results suggest that a mosaic of burn histories likely enhances landscape level plant diversity and richness. Pine afforestation led to a dramatic decrease in species richness in one field site, but supported a high diversity of species in another. However, in both sites, plant composition was dramatically different under pine than in native grasslands.

These results constitute a significant step forward in better understanding PES in an applied context and are relevant for PES program development, particularly for programs targeting páramo grasslands. These findings can contribute to the development of more equitable and effective PES programs that help to protect the páramo for its ecological, cultural, and economic value.
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CHAPTER 1

Introduction

1. Research Context

Linking conservation and rural development goals has been an important concern and challenge for conservation over the last century (Adams et al. 2004, Sunderland et al. 2007, Redford et al. 2008). However, researchers have noted a lack of critical research and paucity of evidence regarding whether such initiatives can jointly reach social and ecological goals (Agrawal and Redford 2006). More recently, payment for ecosystem services (PES) has been advocated as a more efficient means to achieve conservation than Integrated Conservation and Development Projects (ICDPs) and as more equitable and inclusive than traditional protected areas (Rosa et al. 2004, Tallis et al. 2008, Farley et al. 2010, Muradian et al. 2010). Through direct monetary and/or non-monetary compensation, PES programs promote conservation or sustainable land-use practices that seek to maintain or enhance one or more targeted ecosystem service while also providing important revenue for landowners (Wunder 2005, Daily and Matson 2008, Muradian et al. 2010, Kinzig et al. 2011). While considered more directly focused on ecological outcomes than ICDPs and other joint conservation-development initiatives, PES is also often expected to contribute to poverty alleviation and rural development (Grieg-Gran et al. 2005, Wunder 2006).

However, whether poverty alleviation and rural development should be considered primary goals or secondary objectives remains a topic of debate and
depends on the way PES is conceptualized (Rosa et al. 2004, Wunder 2008, McAfee and Shapiro 2010, Muradian et al. 2010). Diverging expectations of how PES programs can contribute to social as well as environmental goals echo the wider, hotly debated issue of whether and how rural development and poverty alleviation concerns should be incorporated into conservation policy, research, and funding (Sanderson and Redford 2004, West and Brockington 2006, Gockel and Gray 2009).

While the prioritization of social outcomes of PES varies, there is widespread interest in understanding PES impacts, both positive and negative, on the poor (Landell-Mills and Porras 2002, Miranda et al. 2003, Pagiola et al. 2005, Wunder 2008). This relates both to concerns over the equity of PES, as well as to increased recognition that conservation and ecosystem services programs are unlikely to gain support without demonstrating the value of these programs to human welfare (Gockel and Gray 2009, Luck et al. 2009).

However, as with other efforts to link conservation and development, social and ecological outcomes of PES remain poorly understood (Ruffo and Kareiva 2009, Brockington 2011). In particular, researchers have noted a paucity of empirical research examining the social outcomes of PES, both in terms of whether PES programs are desirable and accessible to the poor and whether participation in PES reduces or exacerbates poverty and social inequality (Kosoy et al. 2008, Wunder et al. 2008, Brockington 2011, Farley et al. 2011). At the same time, the science linking land use/cover to ecosystem services lags far behind program implementation, leading to uncertainty whether promoted land uses/covers actually protect or enhance
targeted services (Armstrong et al. 2007, Ellison 2009). In addition, there is debate over the extent to which ecosystem services programs complement biodiversity conservation or potentially promote contradictory land uses or compete for critical conservation funds (Bekessy and Wintle 2008, Goldman and Tallis 2009, Lindenmayer et al. 2012). Improved understanding of PES outcomes, based on empirical data regarding effects on land use, ecosystem services, biodiversity, and local livelihoods, is critical to evaluating and enhancing the effectiveness and equity of these programs.

With increasing international interest in carbon sequestration and growing water demand in urban areas, carbon- and water-focused PES projects constitute a growing driver of land-use change in highland Andean grasslands (páramos) (Wunder and Alban 2008, Paramundi 2009, Albán 2011). While, worldwide, the majority of carbon-based PES projects have focused on afforestation, reforestation, and more recently on avoided deforestation, there is increasing recognition of the critical importance of the protection and sustainable management of biodiverse non-forested ecosystems that store large amounts of carbon belowground as soil organic matter (Lal 2004). Páramo grasslands are an example of such a system, as they support impressive levels of endemic plant and animal diversity and store an extremely large amount of soil carbon, making these highland ecosystems an important carbon sink and biodiversity hotspot (Sklenar and Ramsay 2001, Buytaert et al. 2005b, Buytaert et al. 2006a).
Over the past decade, a number of payment or compensation for ecosystem services programs directed at protecting páramo grasslands have emerged in Ecuador (Farley et al. 2011). Collectively, ecosystem services projects in Ecuador are compensating landowners to either plant pine, plant regionally native species, or alter traditional burning and grazing regimes (Farley et al. 2011). The first PES programs in the country specifically targeted carbon sequestration through pine afforestation projects associated with the Kyoto Protocol’s Clean Development Mechanism (CDM) and run through PROFAFOR (Programa FACE de Forestacion del Ecuador) (Wunder and Alban 2008). In addition, several urban areas, including Quito and Cuenca, have developed water funds to finance conservation programs in páramo headwaters that promote the alteration of traditional burning and grazing regimes or planting regionally native tree species (Farley et al. 2011). As pine afforestation projects were found to decrease water yield (Buytaert et al. 2007) and soil carbon (Farley et al. 2004), PROFAFOR’s carbon sequestration efforts now include planting regionally native species with the assumption that this will have improved ecosystem outcomes (Farley et al. 2011).

Launched in June 2009, SocioPáramo, the only national-scale PES program in Ecuador, departs from a focus on a single ecosystem service, instead targeting carbon, water, and biodiversity, as well as poverty alleviation (de Koning et al. 2011, Farley et al. 2011). SocioPáramo is a chapter of the larger SocioBosque program, which targets forests and other native ecosystems with high carbon storage potential, as part of Ecuador’s Reducing Emissions from Deforestation and Forest Degradation.
(REDD) readiness program (de Koning et al. 2011). SocioPáramo promotes conservation of already well-conserved páramos as well as reduced grazing and burn cessation (Farley et al. 2011). Land-use regulations were developed in response to research demonstrating the detrimental environmental effects of frequent and repetitive burning coupled with intensive grazing (Poulenard et al. 2004), however, there has been virtually no research on the ecological outcomes of long-term burn exclusion in the páramo. SocioPáramo program officials recognize that these land-use regulations were made without adequate scientific study and have expressed interest in understanding how páramo ecosystems will respond to burn exclusion and other incentivized land-use changes (Farley et al. 2011).

In order to enhance or protect that production of ecosystem services while also alleviating poverty, SocioPáramo uses “conservation incentives” of up to $30 USD per hectare annually paid to communities and individuals entering into 20-year conservation agreements (MAE 2009, Farley et al. 2011)

Communities who enroll in the program with collective land must create an investment plan detailing how they will use program payments in a way that benefits the community at large. Whether or not SocioPáramo will achieve its goal of poverty alleviation will depend on the extent to which communities and individuals voluntarily choose to take part in the program and how livelihoods change with participation in the program. Evaluating how participation in the program will affect local livelihoods requires an understanding of

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1 Since ending my fieldwork, payments have increased to $60 per hectare of páramo for individuals with less than 20 ha in their land title. Payments have increased to $60 for the first 50 ha and $40 for 50-100 ha for communities, regardless of land holding size.
how it affects financial, social, human, physical, and natural capital (Miranda et al. 2003, Grieg-Gran et al. 2005).

2. Páramo ecosystems

Páramos are high elevation ecosystems in the northern Andes mountain range that occur between the upper forest line (approximately 3000-3200 m) and the permanent snowline (about 4700 m) (Luteyn 1992). They range from 11° north to 8° south, spanning from Venezuela to Peru with small patches in Costa Rica and Panama (Luteyn 1992, Buytaert et al. 2006a). Most páramos are dominated by tussock grasses, along with giant rosettes, acaulescent rosettes, cushion plants, and sclerophyllous shrubs (Acosto-Solís 1984, Ramsay and Oxley 1997) with páramo landscapes constituting a heterogenous mix of lakes, peat bogs, wet grasslands, shrublands, and forest patches (Buytaert et al. 2006a, Keating 2007).

Due to proximity to the equator, solar radiation is nearly constant throughout the year, but with marked daily temperature variations of up to 20°C; this temperature regime is an important factor differentiating tropical from temperate alpine ecosystems (Buytaert et al. 2006a). Precipitation varies greatly in the páramo and generally ranges from 700 mm to 3000 mm (Luteyn 1992) with large-scale precipitation patterns determined both by the Amazon and Pacific basins (Buytaert et al. 2006a). The study regions in this dissertation are located in the inter-Andean valleys between the western and the eastern mountain ranges and are subject to variable influence from both oceanic and continental air masses leading to a bimodal
seasonal precipitation distribution (Buytaert et al. 2006a). These large-scale factors, combined with smaller scale patterns derived from variations in wind speed and direction, as controlled by topography, lead to highly variable weather conditions at local scales (Celleri et al. 2007).

Páramo history began in the Pliocene over four million years ago (van der Hammen and Cleef 1986) when the large upheaval of the Andes created the high altitude montane environments where páramo vegetation evolved (van der Hammen 1974). Numerous glacial and inter-glacial cycle persisting into the late Pleistocene (~126,000-11,800 B.P.) led to continuous shifts in vegetation cover and the treeline, corresponding with expansion and contraction of the páramo belt during glacial and interglacial cycles, respectively (van der Hammen and Cleef 1986, Jantz and Behling 2012). Estimates of the area covered by páramo grasslands range from 35,000 km² to 77,000 km² with discrepancies in estimates related to uncertainties regarding the lower limit of the páramo and the difficulty, in some cases, of distinguishing between natural and artificial grasslands given high degrees of anthropogenic modification near the treeline (Buytaert et al. 2006a).

Diverging estimates of the extent of páramo grasslands forms part of a long-standing debate concerning the extent to which páramo grasslands are considered natural or created by anthropogenic disturbance, particularly fire (Luteyn 1992; Keating 2007). Some authors contend that high elevation forest fragments (including those occurring above 4300 m in elevation) represent remnants of a far more extensive forest cover of the past (Sarmiento 2002). However, recent palynological
studies have not indicated that forests covered all the highlands (Willie et al. 2002), but rather that fire may have prevented the expansion of shrub páramo and montane forest and favored the wider distribution of grass páramo (Rodriguez and Behling 2011). Given the large number of endemic herbaceous species in the páramo (Jorgenson and León-Yanez 1999), it is clear that some páramo has been present in the northern Andes for thousands of years, but it is thought that human activities, including burning and forest clearing, may have lowered the páramo-treeline boundary by up to 50-200 meters (Sarmiento 2002, Wille et al. 2002). However, in some regions, the opposite trend is currently occurring in that the treeline is advancing with the removal of fire (Jokisch and Lair 2002).

Humans are an integral part of páramo ecosystems and have shaped and continue to shape a dynamic cultural landscape (Luteyn 1992, Keating 2007). The livelihoods of many communities and individuals who live in or below páramos are based on varying degrees of use and management of these highland systems (Mena and Hofstede 2006). Humans have used páramos for at least 7000-8000 years, with activities likely consisting mainly of low-frequency burning and grazing prior to Spanish colonization (Luteyn 1992, Buytaert et al. 2006a, Jantz and Behling 2012). Grazing with sheep, cattle, and horses began in the 1500s with European colonization, and hacienda owners began to burn large extensions of páramo to improve the land for grazing (Hofstede 2001, Harden 2006). Cultivation and grazing pressure strongly increased by the 1970s, attributed to population growth, commercial development, and agrarian reforms (Luteyn 1992, Poulenard et al. 2003). Currently,
the most common land uses and sources of livelihoods in the páramo are burning coupled with livestock grazing, agriculture, and pine plantations (Buytaert et al. 2006a).

Regardless of whether classified as natural or semi-natural, the páramo is considered the richest tropical mountain flora in the world, and the northern Andes are considered one of the world’s hotspots for biodiversity (Sklenar and Ramsay 2001). Ecuadorian páramos occupy less than 2% of the land area in Ecuador, yet support an incredible array of plant diversity, with over 2000 species of vascular plants (Mena et al. 2001). Due to its geographic isolation and an abundance of microhabitats, endemism is also high and is estimated at 60% (Buytaert et al. 2006a). Páramos also support a diversity of birds, small mammals, and insects, as well as the spectacled bear, mountain tapirs, and pumas (Mena et al. 2001). In addition, páramos represent an important cultural resource in the form of useful and medicinal plants (Vasconez and Hofstede 2006). As such, biodiversity, as valued by scientific and traditional knowledge systems, is a critical ecosystem service in páramos and is an important component to consider in any evaluation of the biophysical outcomes of changes in land use and land management (Luteyn 1992).

In addition to rich biodiversity, the main ecosystem services identified in páramo ecosystems are carbon storage and water regulation, in part, derived from the unique properties of páramo soils (Torn et al. 1997, Farley et al. 2004, Buytaert et al. 2006a). The majority of páramo soils are volcanic in origin and classified as Andisols, although Histisols, Entisols, and Inceptisols are also present (Poulenard et
al. 2003). Soil depth ranges from several centimeters to a few meters depending on location (Buytaert et al. 2006a), and one or more paleosols from previous ash deposits are commonly found (Zehetner et al. 2003, Buytaert et al. 2006a, Tonneijck et al. 2008). Páramos in the study regions in this dissertation are Andisols and, given that páramos are dominated by this soil order, the following section focuses on andic properties.

A combination of the cold and wet climate, the formation of organo-mineral or organo-metallic complexes (Al and Fe) that resist microbial breakdown, physical protection caused by a large micro-porosity, and indirect protection through low soil pH facilitate high soil organic matter (SOM) accumulation in páramo soils (Poulenard et al. 2003, Buytaert et al. 2006b, Tonneijck et al. 2010). Andisols, in general (Torn et al. 1997), and particularly in the cold and wet environment of the high Andes (Buytaert et al. 2006b), store twice as much soil organic carbon (as a major component of soil organic matter) as any other soil order besides Histisols (Batjes 1996). High soil organic matter stabilization in Andisols is, in part, related to the formation of organo-mineral or organo-metallic complexes through mechanisms that are still poorly understood (Shoji et al. 1993, Tonneijck et al. 2010). Active Al and Fe are found in the clay-size fraction of Andisols as noncrystalline minerals including allophane, imogolite, and ferrihydrite, or as Al- and Fe-humus complexes (Shoji et al. 1993). Two types of Andisols have been described (Shoji et al. 1993, Tonneijck et al. 2010). This includes “allophanic Andisols” which are dominated by short-range order amorphous aluminosilicates (e.g. allophane and immogolite) tending to form at pH
levels of 5-7 and relatively low soil carbon contents. In contrast, “non-allophanic” Andisols tend to form at pH <5 and with higher soil carbon contents, with the categorization as “non-allophanic” associated with the formation of organo-metallic complexes considered to have an anti-allophanic effect (Shoji et al. 1993, Tonneijck et al. 2010); however, there is some discrepancy over the utilization of these categories. Non-allophanic Andisols are thought to accumulate more soil organic carbon than allophanic Andisols due to the high levels stabilization of organic matter in organo-metallic complexes (Shoji et al. 1993, Poulenard et al. 2003, Buytaert et al. 2006b, Tonneijck et al. 2010).

The majority of soils in the Ecuadorian páramo have been classified as non-allophanic Andisols (Buytaert et al. 2005a). Organic C contents can reach 40%, or 100 g/kg, in highly weathered Andisols almost devoid of allophane (Buytaert et al. 2005a). However, in locations with relatively dry climates and high volcanic ash deposits, allophanic Andisols form with lower soil carbon contents, typically between 2-10% (Podwojewski et al. 2002, Zehetner et al. 2003). Accordingly, while climate and parent material lead to substantial variation in carbon storage in páramo soils, these ecosystems represent an important carbon sink that is increasingly valued in an era of climate change (Farley 2007, Tonneijck 2009). As páramo ecosystems are important socio-economic and cultural landscapes (Mittermeier et al. 1998, Vasconez and Hofstede 2006), a biodiversity and carbon hotspot (Mittermeier et al. 1998, Tonneijck 2009), and the water source for Andean rural areas and cities (Buytaert et al. 2006a), improved understanding of the causes and consequences of land
management change related to PES program development is of critical importance
from the global to local scales.

3. Dissertation research

This dissertation research responds to the need for empirical research on the
social and ecological outcomes of PES, in general, and of emerging PES programs
targeting páramo grasslands in particular (Brockington 2011, Farley et al. 2011).
While conceptualized in different ways in the literature, I employ the definition of
PES used by Muradian et al. (2010: 1205) as “a transfer of resources between social
actors, which aims to create incentives to align individual and/or collective land use
decision with the social interest in the management of natural resources.” My
research incorporates hybrid human and physical geography research methods to
better understand the social and ecological dimensions of emerging PES program in
Ecuador (Figure 4).

Chapter 2 presents research on livelihood outcomes associated with the first
1.5 years of Ecuador’s SocioPáramo program. This research draws on interviews
carried out with 19 community participants and 5 neighboring non-participant
communities, 45 individual participants and 4 neighboring non-participating
individuals, 4 program extension agents, 3 program officials, and 5 NGO
representatives. I chose to focus on SP as it is the largest and only national-scale,
government-run PES program targeting páramos in Ecuador. Analysis of the program
at its nascent stage is timely and important as the program moves forward even in the
absence of baseline data, and this research provides policy-relevant information that can be useful in developing and adapting the program.

Chapters 3 and 4 of this dissertation examine the outcomes of burn exclusion and afforestation with *Pinus* spp. and *Polylepis racemosa* in terms of carbon storage and plant diversity. These land uses were chosen in broader consideration of land uses currently incentivized by all PES programs targeting páramo grasslands. Fieldwork was conducted in three field sites (Figure 5; Figure 6). The first, and primary, field site is Mazar Wildlife Reserve (MWR) in Cañar province in Southern Ecuador (3299-3453 m). This site includes páramos with a variety of burn histories, including recently burned sites and sites last burned 25 and over 45 years ago, as well as páramo planted with *Pinus patula*. The second field site is the páramo managed by the community Zuleta, in Imbabura province in Northern Ecuador (3518-3655 m). This site includes recently burned páramos and páramos protected from burning for 9-15 years as well as páramo planted with *Polylepis racemosa* and *Pinus radiata*. The third site is in the páramo of the community of Salinas in Bolivar province in central Ecuador (3757-3829 m). This site contains the oldest *Polylepis racemosa* plantations I could identify in the country as well as extensive areas planted with *Pinus patula*. Despite widespread promotion of burn exclusion and afforestation with *P. racemosa*, there are few areas where the ecological outcomes of these land uses can be evaluated, making these study sites unique and important to improving understandings of links between ecosystem services, biodiversity, and land use in Ecuadorian páramos.
Using available meteorological station data (INAHMI; Instituto Nacional de Metrologia e Hidrologia; http://www.inamhi.gob.ec/) all three study areas have similar mean annual precipitation (MAP) values of 1281-1306 mm; however, according to TRMM Satellite data (averaged from 1998-2009) (Bookhagen in review), sites ranged from driest (Zuleta; 855 mm) to wettest (MWR; 1595 mm). The closest INAMHI meteorological station (Rio Mazar Rivera; M0410; 2°34’ S, 7°39’ W; 2450 m) to MWR measured MAP from 1964-2011 at 1325.9 mm. However, of note is that this station is approximately 1000 m below the MWR study area. To obtain another value of precipitation data, I estimated MAP at 1595 mm using TRMM satellite data (Bookhagen in review); this value is similar to 2010 precipitation (1503 mm) measured in MWR by Fundación Cordillera Tropical (FCT), suggesting that this may be a more accurate estimate of MAP for MWR. In Zuleta, MAP is 1344 mm based on 1964-1992 measurements from the closest INAMHI station (Zuleta; M0316; 0°12’ N, 7° 5’ W; 2901 m); this station is approximately 600 m below the Zuleta study area. MAP in Zuleta, according to TRMM data, is 855 mm, substantially lower than the value obtained through INAMHI (Bookhagen in review). MAP in Salinas is 1303 mm using INAMHI data (1971-2011) at a nearby station with similar elevation to the study area (Salinas-Bolivar; M0385; 1 24 N S, 79 1 W; 3600 m); this is similar to the 1281 mm obtained from TRMM data (Bookhagen in review).
Figures

Figure 1. Burning is often used as a land management strategy to improve forage for cattle and sheep (and, to a lesser degree, alpacas and llamas). Photo below shows a small-scale burn typical of many páramo fires.

Figure 2. Extensive cattle grazing is among the most common páramo land use.
Figure 3. Agricultural expansion and pine plantations are among the major land-use changes affecting páramos. The yellow areas are páramo grasslands, the bright green exotic pasture, the pink agriculture, and the trees pine.

Figure 4. Conceptual framework used to identify the underlying conditions that constrain or facilitate participation in PES and to evaluate the socio-economic and ecological outcomes of PES. PES program outcomes can be evaluated in terms changes in land use and associated ecosystem services and biodiversity, as well as changes in local livelihoods associated with the program.
Figure 5 (left). Map of study areas where the ecological portion of this research took place. Areas shaded in gray indicate the location of páramo grasslands.

Figure 6 (right). Map of study areas and associated mean annual precipitation (SIISE, 2001).
Literature cited


MAE. 2009. Acuerdo Ministerial No. 115. MAE, Quito, Ecuador.


Paramundi. 2009. in PARAMUNDI, segundo Congreso Mundial de Páramo, Quito.


CHAPTER 2
Can Payment for Ecosystem Services contribute to poverty alleviation? A sustainable livelihoods approach to understanding Ecuador’s SocioPáramo program

Abstract
Payment or Compensation for Ecosystem Services (PES or CES) programs are being implemented in a wide variety of settings, but little is understood about how participation affects local livelihoods and whether such programs facilitate equitable rural development. This paper evaluates whether and how SocioPáramo (SP), a national-scale PES program targeting Andean grasslands, contributes to poverty alleviation and rural development in highland Ecuador. Through in-depth structured interviews with program participants and non-participants, I examined how participation affects “equity in outcome” through effects on financial, natural, social, human and physical capital. I found substantial positive outcomes of PES participation on financial, natural, social, and human capital, particularly where there was pre-existing capital, corroborating the adage that it takes capital to make capital for PES programs like SP. Results also suggest that the context in which PES transactions occur remains a critical determinant of PES outcomes. I found that participation in SP often strengthens adaptive capacity by providing a more diversified, stable income source and by enhancing social, natural, and human capital. However, in some cases, it also reduces access to seasonal and permanent grazing lands, which may increase vulnerability of participants to biophysical and economic
stressors. This research contributes to a better understanding of the conditions under which PES and other conservation incentives have potential to contribute to improved livelihoods and the findings can help guide development of these programs.

1. Introduction

Despite considerable debate surrounding the efficacy of joint conservation and development initiatives to simultaneously meet biophysical and socio-economic goals (Adams et al. 2004, Agrawal and Redford 2006, Brockington et al. 2006), payment or compensation for ecosystem services (PES/CES) initiatives are increasingly advocated as a way to enhance one or more ecosystem service and to improve human well-being (Wunder 2008, Luck et al. 2009, Muradian et al. 2010). As these programs continue to grow, a number of competing conceptualizations of PES have emerged, each advocating different primary program goals and measures of program success (McAfee and Shapiro 2010, Muradian et al. 2010). The first conceptualization, categorized as “conservation efficiency PES” by McAfee and Shapiro (2010: 583), focuses on poverty alleviation and social equity as potential side benefits rather than primary program goals (Pagiola et al. 2005, Engel et al. 2008, Wunder 2008). A second conceptualization, particularly prevalent in the developing world, is classified by McAfee and Shapiro (2010: 583) as “pro-market, pro-poor PES,” which strives to combine ecological and social criteria with the goal of creating PES programs that are “win-win mechanisms for both environmental protection and poverty alleviation” (Muradian et al. 2010: 1203). Finally, a third conceptualization, frequently referred to
as compensation for ecosystem services, focuses on social inequity as one of the “driving forces of environmental degradation” (Rosa et al. 2003: 2) and on the potential of PES to support rural land stewards in areas important for ecosystem services production (Rosa et al. 2003, Rosa et al. 2004).

Within these three conceptualizations of PES, increasing effort has been dedicated to measure PES success in terms of ecological and socio-economic outcomes. Ecological measures of success include whether PES agreements are ecologically effective, in that they lead to ‘additional’ protection or enhancement of targeted ecosystem services, and whether PES agreements result in transfers or ‘leakage’ of environmentally degrading activities from one area to another (Asquith et al. 2008, Engel et al. 2008). Measures of social outcomes of PES agreements, on the other hand, focus on how accessible and desirable PES programs are to the poor – “equity in access” – and how participation affects livelihoods – “equity in outcome” (Brown and Corbera 2003: S46, Corbera et al. 2007b, Kollmair and Rasul 2010). In this paper, I evaluate social outcomes of SocioPáramo, a national-scale PES program in Ecuador. Specifically I ask how PES program participation affects livelihoods in terms of financial, social, human, physical, and natural capital. I review previous accounts of PES social outcomes on multiple forms of capital, introduce an integrated framework for evaluating equity in PES agreements, and discuss this in the context of my research with SocioPáramo participants in its first year and a half of operation.
1.1 PES and Livelihoods

How PES participation contributes to poverty alleviation or development goals among participants depends upon the extent to which livelihoods and well-being change as a result of program participation (Landell-Mills and Porras 2002, Miranda et al. 2003, Grieg-Gran et al. 2005). PES participation can directly affect financial capital in two main ways: through changes in land use or management related to participation and through investment of cash flow from incentive payments. Jack et al. (2008) note that PES is most likely to contribute to poverty alleviation when areas with the poorest landowners have the lowest opportunity costs and also highest potential of service provision. However, for PES programs to contribute to poverty alleviation, they would have to compensate landowners substantially more than landowners could have made without PES participation. Some have argued that PES agreements can “trap” poor landowners if payments are lower than actual or potential earnings from productive land uses (Wunder 2008: 287). However, others argue that there is little evidence for this and that, in many cases, whether or not payments strictly match opportunity costs, they are more stable than existing or potential income sources and an important means of income diversification (Grieg-Gran et al. 2005, Wunder et al. 2008, Kollmair and Rasul 2010).

While financial capital is the most obvious way to evaluate PES effects on livelihoods, impacts on non-financial assets, particularly natural capital (shifts in land use or management that affect biodiversity and ecosystem goods and services), human capital (health and basic services, access to education and training), and social
capital (land tenure, social organization, community institutions and associations, kinship ties) have been identified as important motivators for and outcomes of PES participation (Grieg-Gran et al. 2005, Zbinden and Lee 2005). Participation can have an important non-monetary or intangible influence on livelihoods, both positive and negative, through, for example, impacts on land tenure, social organization, and natural capital (Miranda et al. 2003, Grieg-Gran et al. 2005, Kosoy et al. 2007). Kosoy et al. (2007) identify such intangible benefits as an explanation for why some landowners participate in PES programs when opportunity costs exceed incentive payments, underscoring the importance of considering a range of livelihood outcomes beyond financial capital.

The extent to which PES costs and benefits are equitably shared among community members when collective land is enrolled and the effects this has on social organization is another important concern in evaluating equity outcomes. Some have pointed to the potential of PES to strengthen community-based organizations, inter-institutional coordination, and forest management efforts (Grieg-Gran et al. 2005, Kollmair and Rasul 2010), while others have pointed to the potential of PES to increase inequality, leading to a decrease in social cohesion, and crowd out local rules and social norms due to PES markets (Grieg-Gran et al. 2005, Clements et al. 2010, Muradian et al. 2010). Farley et al. (2011) note the importance of pre-PES income generation from the enrolled area, finding that, where production value of land is low and inequitably distributed prior to PES participation, PES can contribute more equitably to development goals. A number of researchers have also pointed to the
importance of pre-existing political and social capital, in the form of strong institutions and social organization, as key determinants of PES outcomes in this regard (Corbera et al. 2007a, Jack et al. 2008).

1.2 Socio Páramo

In this paper, I evaluate the social outcomes of participation during the first 1.5 years of the Ecuadorian government’s SocioPáramo program (hereafter, SP). SP forms part of the wider SocioBosque program established by the Ecuadorian Ministry of the Environment (MEA) in November 2008 with the goal of protecting the country’s remaining privately and communally owned forests (de Koning et al. 2011). In July 2009 the MEA launched SP by extending SocioBosque to include highland native grasslands (páramos) with the goal of protecting biodiversity, carbon, and water while also reducing poverty in 800,000 hectares, or 80% of currently unprotected páramos, via direct payments to community and individual landowners (Farley et al. 2011).

Páramo grasslands, ranging from 3,200 to 4,700 m above sea level are increasingly valued for their high levels of endemic plant and animal diversity, large soil carbon stores, and role in regional hydrology (Sklenar and Ramsay 2001, Buytaert et al. 2005, Buytaert et al. 2006). At the same time, communities that own or rely on the páramo remain among the poorest and most marginalized in Ecuador. A growing population and unequal land distribution have led to increasing agricultural
expansion into these highland grasslands, threatening the sustainability of water supply for urban and rural areas (Buytaert et al. 2006)

SP is described as a “conservation incentive” program that seeks to balance environmental goals and poverty alleviation, while recognizing the role of rural communities and individuals in protecting valuable ecosystems (de Koning et al. 2011: 539). The program aims to accomplish its stated goals through incentives of up to $30 USD per hectare annually to communities and individuals entering into 20-year conservation agreements (de Koning et al. 2011). Payments are equal across ecosystem types, but decrease as the area enrolled increases, with the goal of attracting small landowners (Farley et al. 2011). As of October 2010, 19 communities and 67 individuals had joined the program. As with many other PES programs around the world, poverty alleviation is a central objective and is given equal weight to the three priority ecosystem services in the prioritization scheme (MAE 2009).

While several studies evaluate the social goals and outcomes of these programs generally (de Koning et al. 2011, Farley et al. 2011), no study of which I am aware has addressed these human dimensions through a detailed study of how participation is affecting local livelihoods among those who have enrolled. I use a conceptual framework adapted from the Sustainable Livelihoods Approach (SLA), that considers the factors facilitating or constraining participation in PES and how participation strengthens or diminishes financial, natural, human, social, and physical

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2 Payments have since increased to $60 per hectare of páramo for individuals with less than 20 ha in their land title and to $60 for the first 50 ha and $40 for 50-100 ha for communities, regardless of land holding size.
capital among program participants (Chambers and Conway 1992, Landell-Mills and Porras 2002, Miranda et al. 2003, Grieg-Gran et al. 2005) (Figure 1). I integrate this with the equity framework developed by Brown and Corbera (2003: S45), focusing on “equity in access” and “equity in outcome.” This paper focuses specifically on “equity in outcome” by evaluating how participation strengthens or diminishes financial, natural, social, human, and physical capital. While individual categories of capital are interrelated (Angelson and Wunder 2003), the SLA provides a way to comprehensively assess the risks and benefits associated with PES participation that moves beyond financial capital to include broader effects on livelihoods and well being (Miranda et al. 2003, Grieg-Gran et al. 2005, Corbera et al. 2007b). Accordingly, this paper addresses the following research question: In what ways does participation in SP strengthen or reduce financial, social, human, natural, and physical capital?

2. Methods

This research integrated structured, in-depth interviews with program participants and several non-participants, participant observation, and document analysis. I interviewed all of the community landowner participants (19 of 19) and the majority of individual landowner participants (45 of 63) who entered SP by October 2010 as well as two communities that enrolled by May 2011 (Table 1).

Interviews were designed to examine: 1) participant characteristics and reasons for joining SP; 2) land-use history and páramo land-use/management before
and after joining SP; and 3) use of SP funds and perceived benefits and drawbacks of the program. Interviews included both closed- and open-ended questions and typically lasted between one and four hours. In addition, I interviewed five neighboring non-participant communities and four neighboring non-participant individuals. For non-participants, I modified questions slightly, focusing on current land use and future land use plans, whether they were aware of SP, and whether they would be able to or desire to participate in the program. Appendix 2.1 provides further information on the approach utilized and details of the interview design.

I also attended several community and SP workshops and conducted semi-structured interviews with SP program representatives, including four regional program promoters who are responsible for implementing the program on the ground, and with five NGOs who opposed or supported the program. Finally, I examined community investment plans, a requirement of SP, in which communities create a budget and describe how they plan to use program incentives. I talked with representatives from all 19 communities about the process of organizing and completing their community’s or association’s investment plan, reviewed 13 investment plans in the SocioBosque office, and attended several workshops sponsored by a local NGO on developing investment plans and budgets.

3. Results and Discussion

Community participants comprise mainly rural indigenous or peasant cooperatives or associations that own collective land in the highland areas, while
individual participants are a mix of smallholders (defined as owning <50 hectares, which is the smallest land holding category in the SP payment structure), medium-sized farmers, and larger urban landowners (Table 1; Figures 2 & 3). Medium-sized farmers and larger urban landowners are discussed as larger landowners (owning >50 ha). Here, I describe the impacts that SP participation is having on these groups’ livelihoods in terms of financial, social, human, natural, and physical capital in order to answer the question of whether SP is contributing to poverty alleviation and/or rural development (“equity in outcome”) among participants.

3.1. Impacts on Financial Capital

Annual incentive payments to individuals ranged from $118.20 to $24,819.50 (median = $1,066.50) and to communities from $2,661 to $39,415 (median = $14,881). While individual participants are required to submit an investment plan, community participants are required to create much more detailed investment plans that outline and budget for proposed activities (Figure 4). Communities, like individuals, decide how to invest funds, but must track expenses, and demonstrate that planned activities benefit the entire community; accordingly, community contracts do not provide a direct income source to any individual community member. It should be noted here that my analysis is limited to evaluating early program investment plans and talking with representatives about how funds are spent; I was not able to evaluate the reports submitted by the communities and, in some cases, I interviewed representatives before the communities had enacted their
investment plans. While I gathered data from both community and individual participants regarding use of incentive payments, my review of community investment plans allowed me to obtain more detailed information on community use of funds.

Participants generally reported moderate, but positive effects on financial capital. While all participants expressed that SP funds were relatively limited, they also viewed them as “the first assistance” used for community projects, household expenses, taxes, health, education, and food costs (Table 2). Additional financial benefits identified by participants include land tax exemptions associated with enrolling land and improved access to loans. However, participants indicated generally poor understanding of these tax and loan benefits and asserted that improved training about these benefits remains essential.

As with the majority of other PES programs (Wunder 2008), SP payments are not based on calculated opportunity costs, and few participants thought that the incentive was sufficient to cover the opportunity cost for the most productive land uses (potato farming, intensive grazing, etc.). However, the actual opportunity costs associated with entering SP were relatively low since the majority of participants either did not change their land use or did not change their land use in ways that significantly reduced income. The majority of participants (53% of communities, 52% of larger landowners, and 53% of smallholders) were not utilizing the páramo enrolled prior to entering SP and so did not need to make any land-use changes. Another group of participants (26% of communities, 16% of larger landowners, and
5% of smallholders) utilized the enrolled páramo for extensive grazing deemed acceptable by SP and also did not change their land use in any way. This, in part, is due to the design of SP, which allows participants to enter part of their land, which generally lies outside of the most productive areas (Figure 5).

Others landowners (21% of communities, 36% of larger landowners, and 47% of smallholders,) are changing land use, with varying levels of financial impact. Where land-use changes are required, SP regional extension agents generally require burn cessation and advocate a reduction in grazing (mainly cattle) according to what is economically feasible for the landowner. As use of the páramo was lower than other land areas due to biophysical, socio-economic, or political constraints on land use in the páramo and access to other livelihood sources, these changes usually had little financial impact. This remained the case for the majority of larger landowners who moved animals from the páramo, with little impact on household income. Likewise, participant communities required to reduce grazing were already in a process of reducing grazing levels due to a combination of economic factors and an increasing desire to manage the highlands for water conservation (Figure 6). These communities viewed protection of the páramo as important for overall community goals, supporting the idea that rural development may benefit where ecosystem services production is high, but land productivity is low and unequally distributed (Farley et al. 2011).

There are, however, instances where SP land-use restrictions reduce financial capital among smallholders and medium-sized farmers who live within protected
areas or areas regulated by municipal ordinance, where grazing is legally restricted but had not been previously enforced (Figure 7). In these cases, participation in SP reduces access to seasonal or permanent grazing areas. While income from grazing in the enrolled páramo was considered secondary, smallholders and medium-sized farmers reducing their grazing, with few exceptions, considered the SP payment less than or equal to what they gained through grazing. One medium-sized farmer who relied heavily on his páramo for seasonal grazing, for example, explained that, due to a municipal ordinance, his land use was severely restricted; this landowner did not distinguish between SP regulations and those enacted through the municipal ordinance, complaining that, under SP, “nothing is permitted,” requiring him to remove his cattle from the enrolled area into a lower pasture. He explained that this lack of access to seasonal grazing could be a major hardship, exclaiming, “What would I do if there was a dry summer?” However, in this and other cases, there are legal restrictions on land use, with or without SP, and it is unclear whether SP, with limited monitoring capabilities, will actually give these regulations more teeth.

In several cases individual participants indicated that, without SP, they would have intensified land use, but that SP represented a less risky and more stable income source. The most striking case was a medium-sized farmer in the process of creating a work-group to convert his páramo to exotic pasture, but decided to enroll in SP instead. While explaining that he could earn more money from this conversion than from SP, he indicated that SP was a more stable income source associated with less risk. There is, however, the potential that at some point in the next 20 years
community members or individual landholders may wish to utilize the area entered into SP for production, but will not be able to. This may also be the case for neighboring communities and farmers whose access has been restricted through improved monitoring of the area. While, in some cases, more stable payments were seen as a benefit of the program, some smallholders said that less frequent payments (compared with grazing earnings) were a hardship. In this case, SP may involve cases of “winners and losers” where land security and conservation are improved, but some lose access to former grazing lands (Jack et al. 2008: 9467, Wunder and Alban 2008).

Among individual landowners, smaller landowners viewed the incentive payment as an important contribution to the household budget. For smallholders who were not required to change their land use or were able to move their animals to other available areas, SP incentives are providing the most significant income supplements (in relation to overall cash income), which are being used for food, healthcare, education, and other basic needs. Incentive payments are not necessarily removing participants from poverty and are viewed by participants as “small, but an important support,” but are nonetheless exceeding opportunity costs, which, due to labor or biophysical constraints, are low. A regional program promoter explained that, “participants cannot live on incentive payments, but they are important in the most difficult times of the year.” In cases where land-use changes are small to none, this can constitute an important contribution to the household budget. In one case, a smallholder earned $35 per week from agricultural labor outside of his property; this landowner’s $800 per year PES incentive payment, accordingly, constitutes nearly
half of the landowner’s non-PES income. While this does not include the income he generates from his 20 sheep, PES payments clearly represent much more than the 5% of smallholder household income reported by Miranda et al. (2003), supporting Wunder (2008)’s findings that PES payments often constitute 10-50% of household income.

In contrast, community and larger individual landowners generally viewed payments as a “support” for continuing with current land use that they would likely continue without payments or as a “reward” for conserving, rather than as a significant portion of their income. One medium-sized farmer, for example, who had managed his páramo for conservation since he purchased the land, explained that the main benefit of SP, was it, “recognized the work he had already been doing… the money is more of a prize than an incentive.” Likewise, one community expressed a typical sentiment that, “I have been taking care of the páramo for a long time. Now I have a little compensation for that work.”

This idea of PES payments as a “reward” or “support” rather than opportunity cost payment has been reported in other assessments of PES in Latin America (Kosoy et al. 2007, Garcia-Amado et al. 2011). However, there were two large landowners that stand out among the rest in terms of the size of their incentives ($24,000 and $19,000, with the next highest incentive $9000) and its role in their overall income. The landowner with the highest incentive included a group of 7 siblings who entered their inherited property (4163 ha), which they were not utilizing primarily due to accessibility and protected area constraints, as one unit; accordingly, split among 7
families, this incentive would be less than $4000 per family. The representative of the family said that each sibling’s family was utilizing the incentive for food and basic household needs. Given that the siblings were all employed in blue-collar positions including taxi and bus drivers and did not have to give up any income generated from their land upon entering SP, the incentive is likely an important supplement to household income. The other large landowner had bought his land as an investment and was utilizing part of the property (500 ha) for production, part for forestry with exotic species (2000 ha), and enrolled the rest into SP. This landowner had not decided exactly how he planned to utilize the incentive, but said it would likely be invested in developing an ecotourism business. In both of these cases the incentive represented an important income source and contributed to the livelihoods of these participants (Table 2).

Communities generally view SP payments as small, but important in enabling development of community projects. The majority are using at least part of their incentives to support or begin agricultural or ecotourism projects that will serve to increase income generation for the community. Activities include purchasing seeds and fertilizer, financing organic agriculture and agroforestry projects, ecotourism development, aquaculture development, and paying for a corral and a caretaker house for community alpacas (Table 2). Communities investing funds for future ecotourism have focused on building trails and refuges, which they also see as an important step towards improved land security and conservation. In addition, a number of communities are using funds to directly pay community administrative costs, and one
community is using all of the funds to start a small community bank (Table 2). One community, for example, allocated 39% ($4563) of the incentive to the objective of “Increas[ing] income generation of organization through optimization and diversification of productive activities through sustainable use of páramo resources.” Under this objective, the community plans to utilize funds to construct a corral for the community’s alpacas, purchase 2 new alpacas, and construct several aquaculture pools in 20 ha of páramo that has been converted to exotic pasture below the area entered in SP.

3.2. Impacts on Social and Political Capital

I identified impacts on social and political capital in terms of land security, enhanced community organization, and community pride (Table 2). Both communities and individuals often cited improved land security as a major driver of participation. Participants cited benefits in terms of formalizing the protection of their highlands through a government affiliation and through obtaining funds to secure and patrol their land. For example, communities are investing funds in a variety of ways including paying park guards and improving their boundaries with neighboring lands, which some expressed as important steps to protect their land and “to gain the respect of their neighbors.” While communities expressed that their use of part of their SP funds strengthened land security, individual landowner participants rarely used funds for this purpose. Several individuals indicated that they had “conversed with their neighbors about land-use restrictions,” However, few have taken any concrete actions
to prevent outside use, with many noting the difficulty of this task, particularly in cases where the landowner does not live on the property.

Half of community representatives identified improved community organization as a major benefit of SP and no community representative indicated that participation had divided the community at this stage (Table 2). Several communities explained that enrolling in the program had increased community membership, including one cooperative that attributed the enrollment of 19 new members to SP, which was attractive to young people in the community who had not previously joined the cooperative. Four participant communities indicated that SP had helped create an “alliance of four communities for water conservation.” A number of communities are utilizing funds to improve communal meeting areas and to organize community meetings and events. Others indicated that workgroups organized to carry out activities in the investment plan had also led to improved social cohesion and community organization. In addition, one representative explained that he thought the work projects organized with SP funds were helping to “improve self esteem” in the community. Communities also are investing funds in activities aimed at improving community administration and leadership. This supports other research that has found that PES has the potential to enhance social and political capital through increased land security and strengthening of community-based organizations and sustainable resource management efforts (Grieg-Gran et al. 2005, Kollmair and Rasul 2010).

Although I generally found positive impacts on social and political capital, there are several examples of reduced social and political capital (Table 2). While the
majority of participants cited improved land security as an important benefit, some noted a decrease in land security, with one individual landowner explaining that now neighbors thought of his land, “as part of the State, and so invade more.” There is also the potential that increased monitoring and security of the páramo could cause conflict among community members and between neighbors if land use restrictions are felt unevenly. While I found no evidence of this in community contracts, some individuals entering individually-held land from a single community described a growing conflict regarding restricting land use in the highlands for 20 years when the lower area was already regulated through its location inside of a protected forest. In the view of one NGO, which has expressed firm opposition to payment for ecosystem services programs in general, a major disadvantage of SP is that communities “monitor their own people,” potentially damaging social relations and community cohesion.

While no participant community indicated that SP participation caused major internal conflict, one community representative suggested that the former president had mismanaged program funds. In many cases, communities did not have a copy of their investment plans and lacked a well-organized plan for spending money and tracking expenditures. While the investment plan and monitoring of funding is designed, in part, to counter corruption or mismanagement, conflict may be difficult to avoid in some situations. An NGO working with communities entering SP, for example, explained that they do not encourage communities with high levels of
conflict among community members to enter the program since managing communal funds could escalate existing conflicts.

I found no evidence of major conflicts among community members over creation of investment plans. However, some communities expressed discontent with the outcomes of investment plans organized by a Quito consulting company, which has since been discontinued. A number of representatives explained that prioritizing activities and creating a budget were significant challenges given relatively limited funds. One community, for example, found it difficult to prioritize activities as different groups wanted different things, ranging from improving the water supply to building a soccer field to improving the community church. Well-organized communities, with existing community development or land management plans, often made in association with NGOs, generally found prioritization easier. While I found that participation in SP often strengthens community organization and stewardship over the páramo, participating communities generally were well-organized and interested in conservation prior to entering the program. This supports the idea that pre-existing social capital is a key determinant of program outcomes (Corbera et al. 2007a, Clements et al. 2010).

3.3 Impacts on Natural capital

I observed several ways participation is linked to enhanced natural capital, including reduced burning and grazing, which is thought to be linked to increased water supply; payments for park guards and environmental workshops aimed at
improving conservation efforts; and agroforestry projects in non-enrolled areas that may reduce pressure on the highlands (Table 2). An important perceived benefit of participation is reduced use of the páramo, which is commonly linked to improved water supply, and in some cases, biodiversity and air quality. If it is the case that reduced burning and grazing increases water supply, biodiversity, and other ecosystem services – a relationship that is still not well understood – SP agreements can be seen as increasing natural capital where these types of land-use changes occurred. However, an important constraint on understanding how participation in SP affects natural capital is the poor understanding of the links between land use and ecosystem services production in páramos (Farley et al. 2011), including water quality and quantity, which are among the most valued by program participants. SP has recognized the need for further study, but prohibits burning under the assumption that this is the best way to protect water, carbon, and biodiversity. This practice of basing land use regulations on assumed relationships between land use and ecosystem services production is common in PES programs around the world, particularly in data poor regions (Muradian et al. 2010).

Half of the communities are investing part of their incentives in activities directly aimed at improving conservation and security of their highlands. These include activities aimed at improving agricultural production in lower elevation areas, park guards and community work groups to protect the enrolled areas, ecotourism development, environmental education, and trash clean-ups (Table 2). SP considers efforts to improve land security as a conservation activity, demonstrating the
perceived importance of improving the capacity of communities to protect and monitor their land from prohibited land uses by outsiders and by community members themselves, although some interviewees also pointed out the difficulty of preventing accidental fires.

Many communities described strong links among financial, social, and natural capital and saw SP as a way to strengthen these interlinked assets. Investment in improved production in areas outside of reserves, for example, is seen by many as the most effective and equitable way to conserve the highlands and many communities have undergone a process of land zonification setting aside lower areas for production and higher elevation areas for conservation or sustainable use (Figure 8). One community leader explained that his community placed a high value on “self-sustainability,” stressing the importance of improving organic agricultural production in lower areas to take pressure off of the páramo, which in turn would also lead to protection of water supplies and increased agricultural production. When one community that had established a reserve in the 1990s was asked about the best way for páramos to be managed, a representative said, “giving support to communities in their productive activities in the lower part of their land; with this, they will no longer go up [to the páramo].” Many communities suggested that improved capacity to sustainably manage their natural resources strengthened rather than weakened their development goals, contradicting the idea that PES may “‘bring back the fences’ by decoupling conservation from development” (Wunder 2005: 2).
Other communities discussed the intricate connection between land rights, land security, and conservation. One community worked with an NGO to gain land tenure and to develop agroforestry activities in lower elevation areas with the goal of reducing pressure on highlands and ensuring continued protection of their lands. Community members emphasized that the national park that now includes their communal lands is managed poorly and needs local land stewards. The community is using SP funds in part to “develop a management and monitoring plan for the highland zone (forest and páramo) to ensure its integrity over time,” with planned activities including a community monitoring plan and building a trail and refuge for possible future ecotourism projects. Others are using some of the funds to pay for park guards, organize community work groups, and install signs indicating the protected status of their páramo. Thus, while land use did not change in many of the community conservation agreements, SP funds are being utilized in many cases to strengthen conservation and enhance stewardship.

Several individual participants explained that they were using all or some of their SP funds to finance conservation activities, including fence building either on their own accord or as a requirement based on their affiliation with the local water authority (Table 2). However, none indicated that this significantly increased their capacity to manage or protect their land. While some suggested that improved land security and less burning and grazing would improve water supply, for the most part, individuals did not express the same perception of the connection between land management in the highlands and water supply for consumption and agriculture in the
lower area, in part because individuals rarely had landholdings as large as communities. However, several individual participants who were already conserving their land prior to entering SP saw sustained conservation, viewed often for its intrinsic values, as an important benefit of participation.

While interviewees indicated overwhelming positive effects on natural capital, there is also the potential for environmentally degrading land uses to be moved to other areas or for incentive funds to be utilized for activities that degrade natural capital (Table 2). Leakage, or the transfer of environmental problems from one place to another as a result of PES participation (Asquith et al. 2008), was not an issue for community and individual landowners who were not utilizing their land prior to participation. For those participants who were required to change their land use by participating in SP, on-farm leakage was not an issue when they sold their animals, but off-farm leakage could occur if animals were sold to other páramo landowners. On the other hand, those that moved their animals to lower areas intensified use in already utilized areas. In most of these cases, animals were moved to lower areas that were already converted to artificial pasture, reducing the risk of leakage in terms of further conversion of páramo. However, in the case of some smallholders, those who lowered or sold their animals likely have more resources and time to work lower properties, which included substantial amounts of páramo grasslands and shrublands. It is unclear whether this will involve more clearing of the land not entered into SP, but in some cases pressure taken off the upper páramo could be transferred to the
lower areas, constituting on-farm leakage that could diminish natural capital in these areas.

3.4 Impacts on Human Capital

The majority of individual participants indicated that they were utilizing their incentive payment to improve human assets such as supplementing educational, food, health, and household expenses. Likewise, most communities also dedicated a significant portion of funds to improving health, education, and access to basic services. This includes projects to improve nutrition of elderly community members, improved potable water systems and latrines, establishment of community medical funds and pharmacies, training for community members in sustainable agriculture and livestock grazing, and improved access to social security benefits. One community for example, included the objective to “improve health and water supplies,” under which they are establishing an emergency health fund and improving water capture tanks and distribution in the community. Likewise another community is utilizing funds to help incorporate all community members into the rural social security fund and also to “develop agriculture and livestock grazing to improve nutrition among families.” Other communities are using funds to organize training workshops in agriculture, natural resource management, and community development with the joint goals of improving health, education, and economic production (Table 2).

However, despite these positive projects, a number of communities expressed that funds remained insufficient to cover the most urgent projects, including
renovating community meeting areas, installing irrigation systems, roads, and improving access to potable water. Similarly, a number of smallholders suggested that the “funds were important, but that they are small,” falling short of meeting all of their health, education, and nutrition needs. In some cases, communities are utilizing funds to cover a portion of priority projects such as building several latrines at a time. While contributing to improvements in basic services is seen as a major strength of SP by a number of communities and NGOs, an NGO that opposes SP contested this, explaining that “it is the government’s obligation to provide basic services – health, education, roads – and communities should not have to enter into a contract with SocioBosque to be provided with basic services” (Table 2).

### 3.5 Impacts on Physical Capital

Due, in part, to the limited size of the incentives, investment plans do not include large-scale infrastructure projects. However, communities are using funds for smaller scale projects, including irrigation systems, latrines, potable water systems, a machine to process achira (a type of starch), and community centers. In addition, a number of communities are investing funds in building trails and small access roads to the highland areas for improved monitoring and ecotourism development (with potential negative impacts on natural capital; Table 2). In many cases, communities are funding pieces of larger projects, such as purchasing materials for renovating the community center in the first year, which will be followed by construction in later
years. In contrast, fences were the only enhancement of physical assets identified among individual participants (Table 2).

4. Policy Recommendations and Conclusions

This paper discussed social outcomes of SocioPáramo in terms of how the program is affecting local livelihoods and rural development efforts (equity in outcome). Among those participating, I found positive influences on social, human, natural, and financial capital, particularly among communities who utilized their funds for collective projects that fit into wider conservation and development strategies. Results concur with Rosa et al. (2003: 10)’s assessment that PES cannot be seen as a “panacea for combating rural poverty and environmental degradation,” but if situated as part of wider strategies, can “serve as valuable instruments for strengthening and diversifying community livelihood strategies.”

I also found, that, particularly in the case of community participants who were already managing or in the process of transitioning to managing their highlands as a reserve for water supply or other forms of natural capital, PES can play an important role in strengthening local conservation and sustainable development initiatives. Particularly in a context of a paucity of funding for protected areas, the idea that a centralized, national-level program may facilitate less centralized resource management with greater participation from local people is an important finding of this study. While land use did not change in many of the community conservation agreements, SP funds are clearly being utilized to strengthen conservation and
enhance stewardship and may constitute one of the more efficient uses of
conservation funds. Contrary to ‘mainstream’ PES conceptualizations that suggest
that “the ideal ES seller is, if not outright environmentally nasty, then at least
potentially about to become so,” (Wunder 2005: 12), I argue that utilizing PES funds
to support environmentally friendly ES providers also has value in the resulting
strengthening of environmental stewardship, with the benefit of enhancement of
natural capital for participants and non-participants (Rosa et al. 2003).

Vulnerability constitutes an important dimension of poverty, which, with few
exceptions (Landell-Mills and Porras 2002, Miranda et al. 2003), has been given little
attention in the literature on the social outcomes of PES. Allison et al. (2006: 757-
758) define vulnerability as, “a function of the risks to which people may be exposed,
the sensitivity of their livelihood system to those risks, and their ability to adapt to,
cope with, or recover from the impacts of an external shock to their livelihood
system.” Given that the livelihoods of rural landowners often depend upon the ability
to adapt to environmental and socio-economic change, understanding how PES
participation strengthens or diminishes adaptive capacity is an important component
of understanding effects of PES on poverty. As stated by Milder et al. (2010: 7), “an
important aspect of pro-poor benefit is the extent to which participation enhances or
undermines the broader livelihood strategies for service providers.” In the case of SP,
payments can be expected to enhance livelihoods and increase adaptive capacity
when payments exceed, or are more stable, than income lost from required land-use
changes, or when funds are used to stimulate economic activities, such as agricultural
production or ecotourism. Conversely, SP could reduce adaptive capacity if land-use regulations reduce access to productive lands and if payments do not sufficiently compensate for lost income.

Overall, I found little evidence that participation in SP makes landowners more vulnerable to environmental or economic change. Rather, in the majority of cases conservation opportunity costs remain low, so incentives provide a stable income source and a diversification of income, with potential to increase adaptive capacity. All participants concentrated production in areas outside of their enrolled land and, where possible, SP promoters allowed for continued seasonal grazing. As participants relying on their land for agricultural production also did not enter their most productive land, the risk of the poor becoming specialized in ecosystem services production at the expense of food production (Muradian et al. 2010) is low. Likewise, with few exceptions, results do not support the idea that PES can “trap” landowners into agreements that compromise their livelihood source (Wunder 2008: 287). Exceptions to this include the medium-sized farmers and some smallholders whose land use in the páramo is now restricted, but who rely on it for pasture, particularly during the dry months. Several small and medium-sized farmers, for example, expressed concern over what they would do if there was a dry summer and they needed the páramo. In these cases, strict land-use regulations were a result of their position within a protected area; where participants are not in a protected area, seasonal grazing is often permitted. Thus, rather than SP itself undermining livelihood strategies, the program can be seen as the “carrot that makes the stick of
regulation more palatable” (Engel et al. 2008: 669). This also suggests that regulations associated with protected areas may need to be reevaluated if social equity concerns are to be fully addressed (Brockington et al. 2006, Keating 2007).

Results also point to the importance of consulting and including the perspectives of SP participants and collaborating agencies in program development, which constitutes Brown and Corbera (2003: S45)’s third category of equity, “equity in decision making.” While communities and individuals maintain autonomy over how payments are spent, SP participants have had relatively little participation in the planning of the program, falling short of the CES idea that, “compensation strategies planned and implemented from the perspective of indigenous and peasant communities can contribute to strengthening their livelihoods and to the improved management of rural spaces” (Rosa et al. 2003: 3). Throughout the interviews, a number of suggestions for improvement were provided by participants and could be incorporated into program planning. These include improving communication between SP staff and participants, clearer land-use regulations, clearer descriptions of eligibility for tax breaks, fewer delays in payments, and assistance in protecting the areas entered into SP. Several participants suggested that SP should provide more opportunities for loans associated with sustainable production outside of the area entered into SP as well as projects such as alpaca or llama rearing within the páramo, in order to make participation in the program more economically viable and effective.

Overall, rural participants opined that payments would be enhanced through a more comprehensive approach that included education, agricultural development, and
capacity building. Findings support the contention of Milder et al. (2010) that PES can be seen as a part of a wider strategy that includes both environmental stewardship and sustainable livelihoods. Likewise, findings buttress Schloegel’s (2010: 3) focus on payments as part of a wider conservation strategy; she notes that, “In isolation, education in the absence of economic alternatives may not be able to achieve lasting conservation outcomes, nor will the presence of economic alternatives in the absence of education.”

This research also suggests that entering communal land has strong potential to enhance community organization, while individual agreements among multiple community members may have more potential to cause conflict. This may be an artifact of the communities entering already demonstrating strong organization, but the requirement that the investment plan be used to benefit the entire community facilitates collaboration in fund allocation. While PES incentives may provide a mechanism for increased cooperation in managing community lands, for PES to meet its poverty reduction and equity goals it is also important to ensure that risks and benefits are shared equally (Munoz-Pina et al. 2008). SP has held a number of investment plan development workshops aimed at increasing participation in the process, but, as with any rural development plan, maximizing participation among all community members remains an ongoing challenge (Corbera et al. 2007a, Gockel and Gray 2009).

This study highlights the importance social capital, in the form of community organization and networks with NGOs and other organizations, in facilitating positive
PES outcomes (Corbera et al. 2007a). These findings point to the value and importance of strengthening existing collaborations and forming new ones with NGOs and community institutions who work locally with communities and smallholders. This further supports the idea that PES should be considered one strategy in a toolbox of approaches rather than a stand-alone approach (Kollmair and Rasul 2010, Muradian et al. 2010).

According to these findings, it is evident that the socio-economic and biophysical context under which PES transactions occur remains a critical determinant of program access and outcomes, highlighting the importance of mediating factors depicted in the conceptual framework (Figure 1). Where social networks are strong and where alternative economic opportunities, biophysical constraints, and/or a desire to protect water supplies constrained páramo land use prior to program enrollment, SP contributes to sustainable livelihoods through strengthening financial and non-financial capital. Accordingly, to improve equity in outcomes, PES programs may collaborate with government and community organizations to strengthen social networks and develop sustainable economic alternatives, which lay the groundwork for PES to strengthen livelihoods and adaptive capacity.

This research has three important limitations that could be fruitfully reconciled in future research. First, SP is a new program so this research focuses on the preliminary stages of program outcomes; following up with these participants in 5-20 years and also exploring how outcomes change with new participants in
subsequent years is imperative to a more complete understanding of program outcomes. Second, interviews with community participants focused on community leaders and representatives; to more adequately understand equity in outcome in terms of how costs and benefits are shared among community members, further research could employ a more comprehensive study of outcomes at the household level. Finally, the analysis of experiences of non-participants is limited; longitudinal research pairing changes in livelihoods of participants vs. non-participants would help to illuminate the role of PES in contributing to sustainable development. Findings suggest that advancing PES research promises to pay considerable dividends towards global investments in sustainable and equitable resource use.

Acknowledgements
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Tables

Table 1. Number of contracts (as of May 2011 for communities and as of October 2010 for individuals) and number of participants interviewed. *19 communities enrolled in the program, but one has since left; **67 individual contracts, representing 63 families/land managers and 49 individuals were interviewed representing 45 families/land managers.

<table>
<thead>
<tr>
<th>Participant group</th>
<th>Number of contracts</th>
<th>Number interviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communities</td>
<td>18</td>
<td>18*</td>
</tr>
<tr>
<td><strong>Rural cooperatives/associations</strong></td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td><strong>Potable water organization</strong></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Individuals</td>
<td>63**</td>
<td>45**</td>
</tr>
<tr>
<td><strong>Smallholders (&lt;50 hectares)</strong></td>
<td>31</td>
<td>20</td>
</tr>
<tr>
<td><strong>Larger landowners (medium-sized farmers and urban-dwelling landowners)</strong></td>
<td>36</td>
<td>25</td>
</tr>
</tbody>
</table>

Table 2. Strengthened and reduced financial, human, natural, social and political, and physical capital among community and individual SP participants.

<table>
<thead>
<tr>
<th>Capital</th>
<th>Strengthened</th>
<th>Reduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td>Communities:</td>
<td>Communities:</td>
</tr>
<tr>
<td></td>
<td>➢ Improved agricultural production (funds used to purchase seeds and fertilizer; to finance planting and transport to agricultural areas)</td>
<td>➢ In some cases, reduced access to páramo for grazing by community members and outsiders.</td>
</tr>
<tr>
<td></td>
<td>➢ Agroforestry, organic agriculture, livestock raising, aquaculture, and irrigation development</td>
<td>➢ Future losses in production from restrictions on land use.</td>
</tr>
<tr>
<td></td>
<td>➢ Corral and caretaker house for community alpacas</td>
<td>Individuals</td>
</tr>
<tr>
<td></td>
<td>➢ Microbusiness for raising and commercializing trout</td>
<td>➢ Lost income from reduced grazing in some cases</td>
</tr>
<tr>
<td></td>
<td>➢ Ecotourism development – building of trails and refuges</td>
<td>➢ Future losses in income due to restrictions on land use</td>
</tr>
<tr>
<td></td>
<td>➢ Female agricultural seed fund</td>
<td>➢ Less frequent income seen as a disadvantage by some</td>
</tr>
<tr>
<td></td>
<td>➢ Purchase land for agricultural production in</td>
<td></td>
</tr>
</tbody>
</table>

56
<table>
<thead>
<tr>
<th>Human</th>
<th>Communities:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>➢ Nutrition fund for elderly community members</td>
</tr>
<tr>
<td></td>
<td>➢ Improved potable water systems and latrines</td>
</tr>
<tr>
<td></td>
<td>➢ Medical fund and community pharmacies</td>
</tr>
<tr>
<td></td>
<td>➢ Training of community healthcare worker</td>
</tr>
<tr>
<td></td>
<td>➢ Workshops on health, agricultural production, community development, and environmental management and conservation</td>
</tr>
<tr>
<td></td>
<td>➢ Training for community member in sustainable agriculture and livestock grazing, natural resource management, ecological restoration, and improved seedstock.</td>
</tr>
<tr>
<td></td>
<td>➢ Pay for education promoters from the community</td>
</tr>
<tr>
<td></td>
<td>➢ Improve access to health insurance.</td>
</tr>
<tr>
<td></td>
<td>➢ Improve health through seed fund for agricultural improvement and environmental protection</td>
</tr>
<tr>
<td></td>
<td>➢ Seed fund for females in community for agricultural production</td>
</tr>
</tbody>
</table>

<p>| None identified |</p>
<table>
<thead>
<tr>
<th>Individuals:</th>
<th>Communities:</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ Incentives used for education, food, health, and household expenses</td>
<td>➢ Use of funds to buy chemical fertilizers and plow land outside of reserved area</td>
</tr>
<tr>
<td>Natural</td>
<td>➢ Potential leakage to other areas outside of the area protected</td>
</tr>
<tr>
<td>➢ Reduced burning and grazing linked to improved water supply</td>
<td>➢ Potential negative environmental impacts increased foot traffic resulting from building trails</td>
</tr>
<tr>
<td>➢ Increased patrolling of protected area by volunteer and paid park guards</td>
<td>and small access roads.</td>
</tr>
<tr>
<td>➢ Work groups for páramo trash clean-up</td>
<td>➢ Movement of animals into other areas</td>
</tr>
<tr>
<td>➢ Signs indicating reserved area and fences to control what are regarded as environmentally</td>
<td>➢ Increased use of lower elevation areas</td>
</tr>
<tr>
<td>unfriendly land uses</td>
<td></td>
</tr>
<tr>
<td>➢ Workshops on environmental themes (fire control, water quality and quantity)</td>
<td></td>
</tr>
<tr>
<td>➢ Agroforestry and organic agriculture development to take pressure off the highlands and reduce</td>
<td></td>
</tr>
<tr>
<td>environmental impact</td>
<td></td>
</tr>
<tr>
<td>➢ Development of monitoring and management plans for reserved areas</td>
<td></td>
</tr>
<tr>
<td>➢ Improved community access to highlands as a means to increase awareness and conservation</td>
<td></td>
</tr>
<tr>
<td>➢ Ecotourism development</td>
<td></td>
</tr>
<tr>
<td>➢ Training in reserve management and conservation</td>
<td></td>
</tr>
<tr>
<td>➢ Contracting of a conservation promoter and administrator of community reserve (considered important for</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ombores of the area protected</td>
</tr>
<tr>
<td><strong>Social and Political</strong></td>
<td><strong>Communities:</strong></td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td><strong>Indians:</strong></td>
<td>• Increased land security (paying for transport of community members and park guards to secure land, improved boundaries between communal land and neighboring land)</td>
</tr>
<tr>
<td></td>
<td>• Consolidate community territory by redefining limits of community</td>
</tr>
<tr>
<td></td>
<td>• Improved community organization with increased participation in community projects</td>
</tr>
<tr>
<td></td>
<td>• Improvements to communal meeting areas</td>
</tr>
<tr>
<td></td>
<td>• Improved capacity to manage community finances and paperwork through training, supply purchase, and accountants</td>
</tr>
<tr>
<td></td>
<td>• Increased enrollment (19 new community members)</td>
</tr>
<tr>
<td></td>
<td>• Sense of pride at being involved in a conservation program</td>
</tr>
<tr>
<td></td>
<td>• Pay community administrative costs</td>
</tr>
<tr>
<td></td>
<td>• Investment in improving community meetings and general assemblies</td>
</tr>
<tr>
<td></td>
<td>• Formed a group of 7 community members</td>
</tr>
<tr>
<td>Physical</td>
<td>Communities:</td>
</tr>
<tr>
<td>----------</td>
<td>--------------</td>
</tr>
<tr>
<td></td>
<td>- Irrigation system</td>
</tr>
<tr>
<td></td>
<td>- Improvement of potable water and latrines</td>
</tr>
<tr>
<td></td>
<td>- Machine for processing achira</td>
</tr>
<tr>
<td></td>
<td>- Fences</td>
</tr>
<tr>
<td></td>
<td>- Community centers</td>
</tr>
<tr>
<td></td>
<td>- Highland refuges</td>
</tr>
<tr>
<td></td>
<td>- Access trails</td>
</tr>
<tr>
<td></td>
<td>- 5 km of access roads to agricultural areas</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physical</th>
<th>Communities:</th>
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Figures

Figure 1. Factors affecting participation in PES (“equity in access”) and changes in capital associated with participation (“equity in outcome”).

<table>
<thead>
<tr>
<th>Socio-economic, political, environmental, and cultural conditions</th>
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<tr>
<td>Influence eligibility, accessibility, and desire to participate</td>
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<tr>
<td>PES participation (“equity in access”)</td>
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<tr>
<td>Change in financial, natural, social, political, human, and/or physical capital (“equity in outcome”)</td>
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Figure 2. An individual participant (right) shows us the páramo in our area. This participant lives in an urban area, but purchased páramo in surrounding highlands.
Figure 3. Family members of individual smallholder participants who enrolled páramo above their community.

Figure 4. A community workshop sponsored by a local NGO to create a community investment plan and budget detailing how SP incentives will be spent.
Figure 5. Páramo enrolled in SP is most often areas not utilized or areas used for extensive grazing. The above photo shows the páramo enrolled by a community of smallholder individual landowners. The area below the pines was left out of SP for production purposes.

Figure 6. Sign describing a community alpaca project used as an environmentally friendly alternative to cattle grazing in a community that had managed their páramo for water protection prior to SP.
Figure 7. Sign created by the Ministry of the Environment to encourage protection of the páramo owned by smallholder individuals who enrolled in SP. This is an example of an area where land enrolled in SP overlapped with a protected area.

Figure 8. Map made by a community participant in SP showing how they had zoned their land into productive areas (zona de Ganado (cattle), zona trabajos), a buffer zone (zona amortiguamiento), and a conservation area in the highlands (bosque primario, pajonal). Pajonal = páramo; bosque primario= primary forest. A number of community participants had undergone a similar zonification of their land prior to enrollment in SP.
Literature cited


MAE. 2009. Acuerdo Ministerial No. 115. MAE, Quito, Ecuador.


Appendix 2.1. Methods supplement

1. Introduction

The discussion of livelihood outcomes of SocioPáramo (SP) presented in chapter 2 is based on interviews with program participants, non-participants, program directors, program extension agents, and NGOs as well as participant observation and document analysis. Research was conducted during July 2009, from January-September 2010, and in July 2011. Here, I discuss the critical need for research on this topic, the use of qualitative methods, generally, and the methods used for this research, specifically, and my positionality as a researcher.

2. Research focus

Despite the rapid growth of PES programs and fierce debate surrounding their effectiveness in jointly reaching conservation and development goals, empirical research on PES remains limited (Brockington 2011). This dissertation research, accordingly, responds to a critical need for in-depth study of the social and ecological outcomes of PES programs. During July 2009, I worked as part of field team to conduct a pilot study surveying PES (or compensation for ecosystem services – CES) programs targeting Ecuadorian highland grasslands (páramos) (Farley et al. 2011a). Páramos are both highly valued for ecosystem services provision and are also owned or managed by some of the most marginalized rural communities and smallholders, which has led to a variety of PES efforts, often with joint social and ecological goals (Farley et al. 2011a). The pilot study research included semi-structured interviews
with 25 project personnel, policy makers, and others involved in the development and implementation of PES programs targeting páramo grasslands (see Interview 1 below). We interviewed representatives of every PES program targeting páramo grasslands; this included interviews with non-governmental organizations (NGOs), local government agencies, and community leaders involved with the design and implementation of PES projects targeting páramo grasslands.

These interviews allowed me to choose a PES program to focus on for my dissertation research and helped to guide the design of the structured interviews used in interviews with SP participants. A number of programs included joint social and ecological goals, but SP was unique in its focus on and prioritization of multiple ecosystem services (carbon and water) and biodiversity as well as poverty alleviation (Farley et al. 2011a). Moreover, SP is the only national-scale, government run program targeting páramo grasslands and provided a unique opportunity to evaluate how this program was playing out on the ground in terms of participation, land use, and livelihood outcomes in multiple regions.

In July 2009, at the time of interviewing the SP program director in the Ministry of the Environment, two communities and four individuals had joined the program, but additional contracts were in the development stages. By October 2010 and May 2011, respectively, 67 individuals and 19 communities\(^3\) were enrolled with many more contracts in development. The program targets poverty alleviation and multiple ecosystem services and biodiversity, but no empirical research on the social

\(^3\) The 67 individuals represented 63 families/land management units. Nineteen communities enrolled in the program, but one has since left the program.
and ecological outcomes of this program had been conducted. I encountered similar enthusiasm and hostility towards PES noted by Brockington (2011), and SP in particular, also in a context of a paucity of empirical research. There was a clear need to understand the socio-economic dimensions of SP as a new and rapidly growing program. This information could then be complemented with my data on páramo land use and carbon storage and biodiversity, which responds to another gap in PES knowledge regarding whether incentivized land uses produces desired outcomes, in order to evaluate PES outcomes in a holistic, rather than piecemeal way.

3. Approach

My central research questions centered on understanding why landowners are joining SP and how participation affects land use and local livelihoods; analysis in chapter 2 focuses specifically on livelihood outcomes. In addition to my pre-determined research objectives, I also aimed to understand the viewpoints and perspectives of participants and discover the issues and topics most relevant to their experiences. To answer these questions and also provide space for interviewees to elaborate on their own topics of interest, my research employed qualitative methods, and, in particular, structured, in-depth interviews conducted with program participants. Qualitative methods are well suited for my research question of how participation affects local livelihoods, as this is fundamentally a process and a cause question, which is most effectively addressed through qualitative methods (Sayer 2000). Qualitative interviews have been used in similar studies of PES programs
Interviews are considered a powerful way of studying social phenomena and gaining access to events, opinions, and experiences most relevant to those interviewed (Dunn 2005, Fontana and Frey 2008, McDowell 2010). Dunn (2005: 80) identifies four major reasons for utilizing research interviews. First, “to fill a gap in knowledge that other methods such as observation or the use of census data, are unable to bridge efficaciously;” second, “to investigate complex behaviours and motivations;” third, “to collect a diversity of meaning, opinion, and experiences…,” and finally, “when a method is required that shows respect for and empowers those who provide the data.” Even more critically, in the absence of thousands of multiple time series observations, qualitative research is the only way to understand process and illuminate causation (Sayer 2000). In the case of my research with SP, existing census data are too coarse and not recent enough to answer my research question of how and why livelihoods change with PES programs. Moreover, interviews allowed me to collect data on the diverse experiences and opinions of SP participants and non-participants, which would not have been possible with another approach. While I included some closed-ended questions typical of quantitative surveys, many questions were open-ended in order to allow participants (and non-participants) to focus on aspects of their experience most important to them and to address relevant new
themes that might not have emerged had I focused exclusively on close-ended questions.

The purpose of this research was to provide a case study of PES as observed on the ground, and qualitative interviews were essential to explore the processes and causes central to my research questions. Allowing participants to elaborate on their experience with the program enhanced my research question regarding livelihood outcomes of SP. This included participants identifying the advantages and disadvantages or risks and benefits of participation, which could only have been done through qualitative methods. Quantitative methods are used to address patterns or relations, but only qualitative methods can address processes and causes in social science (Pratt 1995, Sayer 2000), which were most central to my research questions. Rather than seeking to discover an objective “truth,” qualitative researchers recognize that human behavior and social phenomena are complex and that results should be interpreted as representations rather than a single objective and verifiable truth (Davies and Dwyer 2007, Denzin and Lincoln 2008). Nevertheless, qualitative methods provide a deeper and more nuanced understanding of the processes and causes behind social phenomena in ways that quantitative methods could not (McDowell 2010, Cheong et al. 2012). In some cases, qualitative methods are combined with quantitative methods to provide both intensive and extensive understanding of phenomena, but this is only possible where large data sets are available to allow for both types of analysis (Sayer 2000, Creswell 2009, An and Lopez-Carr 2012). With the relatively limited program size at the time of research,
quantitative analysis was not deemed appropriate for the most compelling question of how and why program participation is influencing local livelihoods. As SP grows, quantitative analysis could be usefully integrated with qualitative data, which provides context, validity, and explanation to patterns documented with quantitative methods (Creswell 2009, Cheong et al. 2012).

Other research methods that were considered include remote sensing, one of the primary methods of studying land-use change over time, which also has been used to evaluate changes in land use or avoided land-use change associated with PES and other policies (Sanchez-Azofeifa et al. 2007, Brannstrom et al. 2008, Scullion et al. 2011). However, in the case of SP, the program is new, with land-use changes in the process of occurring or being mandated for future implementation. Land-use changes are also relatively subtle, involving changes in grazing practices that would be difficult to accurately assess with remotely sensed data. Field observations and remote sensing may be effective tools in the future to more accurately measure on-the-ground changes in land use with time. However, human-environment researchers in PES and beyond have noted the importance of field interviews to understand land-use changes detected in satellite imagery (Lambin and Meyfroidt 2010, Scullion et al. 2011, Cheong et al. 2012). In particular, field interviews are needed to understand whether land-use changes or avoidance of land-use change are actually due to the PES program itself or, alternatively, whether they would have occurred in the absence of the program (Scullion et al. 2011).

Utilizing qualitative methods requires reflection on my own “positionality” as
a researcher and how it affects my collection and interpretation of data (Dunn 2005, Fontana and Frey 2008, McDowell 2010). The collection and analysis of qualitative data is inherently subjective and my status as a white, graduate student from North America brought situated understandings of my interviews, as did my collaboration with Ecuadorian community development workers. However, throughout the research process, I acknowledged these issues and engaged in continuous critical reflexivity regarding how my positionality influenced interviewees’ responses and my interpretation of responses (Dowling 2003). While my position as a North American graduate student and cultural outsider may have influenced what people chose to tell or not to tell me, others have argued for the benefits of outsider status in helping to provide a different perspective from that of insiders (Wolf 1996, Swanson 2008). While my research findings are subject to the bias of my own interpretation and influence of my position as a foreigner, I believe that my collaboration with local assistants and my position as a student helped to establish trust with the majority of interviewees. Collaboration with local assistants also reduced misinterpretations of interviews due to language limitations. While I am fluent in Spanish, it was invaluable to have local assistants to review data collected and who were able to rephrase questions where they were not fully understood. In general, questions were not threatening or very personal and, with few exceptions, interviewees seemed comfortable to share their experiences. There were several important exceptions with some smallholder rural individuals who were notably uncomfortable in the interview; I made note of this and in these cases avoided the most sensitive questions and
generally focused on asking key questions in multiple ways to ascertain how reliable gathered data was. In these cases, I also discussed key issues related to the landowners’ participation with the associated program extension agent or affiliated NGO to verify and compare information sources. While I do not claim to have found an objective, replicable, and verifiable truth about SP or PES in general, I believe my research provides an important view into how this growing approach to conservation is playing out on the ground.

4. Interview structure and process

Given the relatively small number of program participants (63 individuals, 19 communities), I conducted a near census of participants, interviewing 45 of 63 individuals and 19 of 19 communities who had joined the program by October 2010 and May 2011 respectively. I obtained the list of SP participants and contact information through the SocioBosque office. Where appropriate, I also interviewed neighboring non-participants in order to understand how participants differ from non-participants and how this relates to the ability and desire to participate as well as to livelihood and land-use change outcomes. I used a ‘snowball’ technique (Hay 2005) to recruit non-participants by asking participants if they could recommend a neighboring or nearby, non-participant landowner to interview. Given that land title of páramo grassland is a key program requirement, I had set land title and ownership of intact páramo as part of my selection criteria for non-participant subjects. However, recruitment of non-participants proved difficult for several reasons. First, in
many cases, neighbors did not have land title. Second, in the case of many individual landowners, they lived in areas distant from their páramo and often did not know or have contact information for their neighbors. Third, in cases where landowners lived near their páramo and did know their neighbors, participants rarely had contact information for often distant neighbors. Nonetheless, I located and interviewed three individuals who met the criteria for inclusion and also included one individual neighboring landowner who had land title but had recently converted his páramo to crops and exotic pasture. I included three non-participant communities in the same region as four of the participating communities; although none of these communities had land title, two were in the process of obtaining it with the aim of enrolling in SP. According to an NGO working in the region, few communities had land title in this area so I included these communities to gain their perspective. The other two non-participating communities were in the adjacent province to three participating communities, but neither of these communities had land title. Accordingly, while I was not able to interview an equal number of non-participants as participants, I was able to gather information on non-participants in order to gain perspective on differences and similarities between participants and some non-participants as well as shed light on factors facilitating and constraining participation.

I conducted structured, in-depth interviews with the above-described participants and non-participants (see Interviews 2-5 below). Structured interviews follow a predetermined and standardized list of questions which are normally asked in the same way and in the same order (Dunn 2005). While following this format, I also
encouraged interviewees to discuss issues most pertinent to them either as part of their responses to pre-determined questions or in response to more open-ended questions. I designed interviews using a funneling technique, asking general questions first as a “warm-up” and then moving towards more specific questions about SP and livelihood and land-use change outcomes (Dunn 2005: 92). Utilizing funneling in interview design has long been seen as an effective strategy to building trust during an interview, given that interviews begin in a more relaxed manner with more specific and potentially sensitive questions held to the end (Sudman and Bradburn 1982). While my interviews did not include highly sensitive questions, I still structured the interviews in a way that allowed for specific questions most important to the outcomes of my study to come after more general, warm-up questions.

I obtained approval for my research from the Institutional Review Board (IRB) at both San Diego State University and the University of California, Santa Barbara, which required that I keep interview notes and data confidential and anonymous. Per my IRB approval, I also obtained verbal consent prior to interviews, explaining to interviewees that I was a student conducting research on páramo grasslands and was interested in their opinions and experiences with páramo land management. Written consent was waived in my IRB approval as it would not have been culturally appropriate, and, in some cases, interviewees were not literate.

I designed structured interviews following a summer of fieldwork in which I interviewed policymakers and program officers about existing PES programs in Ecuadorian páramos. I then conducted interviews with several communities and then
revised questions to be more effective and clear for my interviewees. In the revision phase, I recruited the help of a community worker associated with a local NGO with extensive experience working with communities. This helped to restructure questions in a way that made more sense to local people. Incorporating feedback from key informants who are ‘culturally qualified’ has been identified as an effective way for improving interview outcomes (Dunn 2005). In the following sections, I describe my rationale for the questions I included and those that I chose to not include.

Interviews 2-5 (below) are templates for interviews with individual and community participants and non-participants. Community and individual interview templates are similar, but adapted to whether land enrolled was individual or collective, and community interviews included additional questions related to the ownership of collective land. The first four communities I interviewed were in Loja province and all worked with a local NGO, Nature and Culture International. I contacted this NGO and asked if one of their community workers (técnicos) could help me to get in contact with these communities. A técnico agreed and took me out to visit the four communities and conduct the interviews. I always introduced myself as a student studying the páramo and páramo land use and asked for verbal consent per my IRB approval. As this NGO had a long history of working with the communities, community representatives were willing to talk to me and were more trusting of me than they would have been if I had called them directly. While being associated with this NGO may have brought its own set of biases, bias in interviewing is inevitable, and I believe, in these cases, approaching these communities through
this gatekeeper was the most effective way of conducting the interviews.

The técnico who introduced me to the four communities in the Loja province then helped me to revise my interview questions towards language that would be better understood and received by interviewees. This técnico had nearly 10 years of experience working with rural communities so I hired him to assist me with interviews with the remainder of participants who had joined in the first year (11 communities and 14 individuals). He contacted participants by phone and explained that he was helping a North American student conduct her thesis research on the páramo and that he would like to set up an interview. We then set up a meeting place, usually at the participant’s residence, and drove to meet them. Given the national-scale of the program, this involved driving from the border with Perú to the border with Colombia. At the start of the interview, the técnico explained again that I was a North American student studying the páramo and that he was a técnico with Nature and Culture. He was open that he had helped communities enroll in SP in Loja, but we made it explicit that we did not in any way represent SP.

While my association with a conservation NGO, and the fact that I received participants’ contact information from SP, may have influenced the responses given to some questions, this was the most effective way for me to conduct interviews as a foreigner. At first I was reluctant to have my assistant share his experiences with SP and with communities in Loja with participants in other areas, but soon I discovered that this type of “empathetic” interviewing led to greater levels of trust between us (the interviewers) and the interviewees, which I believe led to a more honest and open
interview process (Oakley 1981 and Douglas 1985 in Dunn 2005). While it is important to reflect upon my own positionality as a researcher and how this affects my results, I believe our interview team collected data reflective of participants’ views and experiences with the program. I am confident of this because working with a técnico with experience working with communities facilitated trust between us and interviewees, interviewees seemed to understand the purpose of the study as part of my education and thesis requirement, and finally, most participants seemed eager to share their experiences and provided both positive and negative information on the program, suggesting that they did not feel pressure to portray the program in one way or another. The second set of interviews (those who joined between December and May 2010; 8 communities; 31 individuals) were conducted in part with the same técnico and, in part, with another assistant who also had extensive experience working with rural communities. The first técnico also conducted several additional interviews independently and reported back results.

I chose to take notes rather than to record interviews as I felt being recorded could be threatening to those being interviewed. In some cases, I took detailed notes where the interviewee appeared comfortable with me doing so, while in other cases, I chose to listen carefully and record notes after the interview. My assistants also took notes and we followed each interview with a debriefing session to compare notes, discuss the interview process, and verify that we had recorded the same information. We also discussed how our own positionality as researchers with potential ties to conservation, in general, and the SocioPáramo program, specifically, might have
affected interview outcomes. In accordance with IRB approval, I did not disclose the names of any of those interviewed in my analysis of interview data.

The following section discusses the specific questions below with references to the actual instruments used, which are included in this methods supplement. The first set of questions, #1-14 for community interviews (Interview 2) and #1-8 for individual interviews (Interview 3), focused on community or individual landowner characteristics. These questions were used as warm-up questions as well as to gather basic information on participant characteristics related to community or family size and age demographics, access to basic services and education, and primary livelihoods. I also included two questions regarding whether the community or individual landowner had worked with a governmental or non-profit organization as well as whether there had been previous conservation or development efforts (including protected areas) directed at their páramo (#11-13 in community interviews (Interview 2), #9-10 in individual interviews (Interview 3)). These questions were included to understand how participation in SP fit into the wider context of páramo conservation and development initiatives as well as legal constraints on land use (through, for example, overlap of land with a protected area).

For community interviews, I also included a question in the introductory section regarding the frequency and purpose of community meetings and events (#3, Interview 2), which I used as a proxy for community organization. In community interviews, I also included a question regarding what were considered the most important goals or necessities (#9, Interview 2), which I used to understand the extent
to which incentive payments were being used to meet identified needs. Question #4 in community interviews (What product or products is this community known for?) was used to first focus on community assets prior to community needs. Finally, I included a question regarding the communities’ experiences managing financial resources (#14, Interview 2) in order to understand whether managing SP funds was the first major experience managing financial resources.

I chose not to ask interviewees about their income directly as I was concerned this would compromise trust since this is a very direct and personal question. For the majority of rural landowners, income is inconsistent and variable since few held employment with salaries, but rather relied on selling agricultural products. Moreover, in many cases, actual income is not necessarily a good measurement of wealth or poverty as the extent to which a community or family produces their own food are also important to consider. I included this aspect of how much food is produced versus purchased in question #5 in community interviews and question #6 in individual interviews. I also included questions regarding employment and principal livelihoods in the introductory section, which together with other questions, were used for a qualitative understanding of socio-economic conditions of participants.

The second, third, and fourth sections focused on páramo land-use history and current management (#16-29, Interview 2, #12-22, Interview 3). These questions were designed to understand how the páramo enrolled in SP was utilized and the extent to which the enrolled páramo contributed to the economy of the community or
individual landowner. In most cases, I asked the interviewee to draw a map of their property, although, where time was limited or where the interviewee preferred not to, section 2 was dropped. The property or community map provided a visual device for discussing land use of the enrolled páramo in the context of land use of surrounding areas. This often led to discussions of páramo land use and value in ways I did not initially anticipate and provided for a more in-depth understanding of páramo land use.

The third section complemented the second and focused on land use and management of the páramo, including enrolled and non-enrolled areas. Question #18/13 (Interview 2/Interview 3) was used to understand the accessibility of the páramo and, in conjunction with questions regarding the use of the páramo and the productivity of the páramo compared with other lands, was used as a proxy for biophysical opportunities and constraints on páramo land use. Question #21 in the community interview (Interview 2) regarding whether the communal páramo had been divided into individual plots was used along with an earlier question on individual landownership (#17) to shed light on the relative importance of the communal páramo compared with individually held land for production and livelihoods. Questions on páramo land use as well as the question regarding how the páramo was contributing to the economy of the community/family were used to evaluate the contribution of the páramo to livelihoods of participants. This information was then combined with later questions on changes in land use related to participation to understand changes in livelihoods associated with participation.
The fourth section (Interviews 2 and 3) focused on the use of a time line to understand current páramo land use in the context of long term land-use history, and in the case of communities, a history of the community and their ownership of the land. This device was suggested by an NGO contact as a way to interactively discuss the history of the páramo and understand factors leading to changes in land use and management.

The fifth and final section (Interviews 2 and 3) focused on the individual’s or community’s experience with SP including reasons for joining the program, challenges in enrollment, and changes in land use and livelihoods associated with program participation. Questions in this section began with how the individual or community heard of the program and why they decided to enroll. The direct question of why participants decided to enroll and how difficult the process of enrollment was (#31/#24, Interviews 2/3) was used in combination with earlier questions to understand factors leading to the ability and desire to participate in the program. Questions #32-36/#25-29 (Interview 2/Interview 3) focused on what portion and what quality of land was enrolled in SP and how participation in SP influenced (or did not influence) land use in these areas. Question #37-38/#30-31 (Interview 2/Interview 3) were chosen to assess future land use plans and whether enrolling in SP would influence these plans, while question #39/#32 (Interview 2/Interview 3) focused on whether land uses had changed in areas not enrolled in SP (assessing potential

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4 It should be noted that communities in SocioPáramo often referred to the program as SocioBosque as they often enrolled both páramo and forest lands and, in general, on the ground the program is referred to as SocioBosque rather than SocioPáramo since SP falls under the umbrella of SocioBosque.
Changes in livelihoods associated with incentive payments were assessed through questions #40-42/#34 (Interview 2/Interview 3), which asked about how payments were being utilized. I asked specifically about whether payments were sufficient to cover opportunity costs for any land-use change or avoidance of land-use change required. This was a difficult question as most participants said payments were too low regardless of whether any land-use changes were required. The low reliability of asking directly about the value of payments relative to opportunity costs has been noted in other PES studies (Kosoy et al. 2007b, Garcia-Amado et al. 2011).

In the case of communities, I also inquired about the process of putting together the investment plan and whether the community had assistance in the process or difficulties in prioritizing activities. The final two questions focused on general advantages and disadvantages of the program and provided interviewees with the opportunity to respond in an open way.

Non-participant interviews (Interviews 4 & 5) were identical to participant interviews with the exception of questions related directly to participation outcomes of SP. Instead, the last section of the interviews focused on whether the non-participants had heard of SP, whether they were thinking of joining, and how participation would likely affect their land use and livelihoods. These questions were used to assess awareness, ability, and desire to enroll in the program among non-participants and to identify potential constraints on participation.

Interviews lasted between 1-4 hours. In some cases we followed the questions
exactly, while in others interviewees discussed issues tangential to interview questions. Some of my most interesting results and insights came from these tangential conversations, which is an important benefit of qualitative methods. This adds depth and validity to the data gathered as the causes and processes behind the data are explored. Where possible, we visited the participant’s páramo to verify land-use descriptions, but many participants enrolled páramo at a far distance from their residences, making site visits difficult. In the case of community participants, interviews were generally done with community representatives, but where possible I talked with multiple community members to gain a broader perspective and to verify data collected. In the case of several smallholders with limited time available, abbreviated interviews were conducted which focused on key questions regarding land use of the páramo, land-use changes required, and use of incentive payments.

I also conducted semi-structured interviews (Interview 6) with all four regional program promoters responsible for implementing the program on-the-ground. These interviews focused on the promoters’ duties and experiences in implementing the program including factors facilitating and constraining participation in the program, biophysical goals, socio-economic goals, monitoring, and major challenges. These interviews were also useful to compare with information gathered during interviews with participants.

In addition, I conducted interviews with NGOs who supported or opposed SP, including two NGOs who had signed contracts to work with SP to enroll landowners, two NGOs who worked in páramo conservation but not with SP directly, and one
NGO in opposition to PES in general. These interviews were semi-structured and were adapted to the relationship the NGO had with SP (see Interview 7 below).

I was also able to review community investment plans for all of the enrolled communities who had submitted them (five of the communities had not completed their investment plans by July 2011 when I conducted my final month of fieldwork). Communities are required to submit investment plans detailing how they plan to utilize their incentive payments in a way that benefits the entire community. I recorded activities planned and noted the relative percentages of funds designated for each project. During this analysis I was aware that these were the communities’ first investment plans and some communities were in the process of revising plans. This data was combined and compared with information collected during interviews.

Finally, I engaged in participant observation (Hay 2005), including community planning meetings and meetings between SP and participants. This included observing five communities in the process of creating their investment plans with the assistance of an NGO. This provided me with a greater understanding of the dynamics of creating an investment plan and the role that outside assistance can play in directing the final plan. Similar participant observation methods have been utilized to study social outcomes of PES and other conservation and development initiatives (Bebbington 2000, Carr 2006, Corbera et al. 2007b, Himley 2009, Walters and Vayda 2009).

To analyze the data collected both from interviews and document analysis, I created a spreadsheet with the following categories (information was not available for
all participants and depended, in part, on elaborations from core questions):

- Community/family size
- Land owned/% of land enrolled
- Incentive payment
- Reason for joining program
- How found out about program
- Biophysical conditions
  - Distance to/accessibility of páramo from residence
  - Perceived productivity of páramo compared to other lands owned
- Socio-economic conditions
  - Principle livelihood
  - Basic services
  - Education
  - Food production
  - Identified most urgent needs (communities only)
  - Pre-PES employment/economic value of enrolled páramo
  - Post-PES employment/economic value of enrolled páramo
- Political/institutional conditions
  - Land tenure and time on land
  - Protected area/environmental mandate affecting land use
  - Partitions of community land (community interviews only)
  - Private land ownership (community interviews only)
  - NGO/government organization contact
  - Community organization (community interviews only)
  - Páramo community land-use regulations (community interviews only)
  - Prior conservation efforts
- Cultural conditions
  - Perceptions of burning and forestation
  - Perceptions of conservation
  - Perceptions/value of páramo
- Demographic conditions
  - Age of community members/family
  - Time on land
- Land-use and land-use history
  - Description of past land use
  - Last burn
  - Perceived land-use regulations
  - Land use páramo prior to SP enrollment
  - Land-use change with SP enrollment
  - Land use of páramo not enrolled in SP pre- and post-enrollment
  - Additionality
  - Leakage
• Livelihoods
  o SP activity enhancing or reducing?
  o Lost livelihood?
  o Use of incentive funds
  o Assistance with investment plan/community map
  o Perceived benefits
  o Perceived drawbacks
• Program logistics
  o Greatest challenge in joining or participating in program
  o Monitoring/contact with SP
• Interesting notes

These databases were then used to discuss participation outcomes in terms of conditions behind the ability and desire to participate, land-use change, additionality, leakage, and livelihood outcomes in terms of financial, social, natural, human, and physical capital. Non-participant interviews were similarly evaluated and used as a point of comparison.

**INTERVIEW 1 (Semi-structured): Program Directors: SocioBosque, Capítulo Páramo (SocioPáramo)**
(Based on Tallis et al. 2009 and used to compile a data base of all Payment for Ecosystem Services projects in collaboration with Dr. Kathleen Farley and William Anderson of SDSU)

1) Basic project information
   a. Project start date and expected length
   b. Land ownership in project location(s)
   c. Project partners (national government, regional government, local government, non-profit, education, corporate, other)
   d. Project funding sources (national government, regional government, local government, non-profit, education, corporate, other)

2) Project goals
   a. Target ecosystem services
   b. Scale of target services (local, regional, national, global)
   c. Priority ecosystem services
   d. Pre-project land cover
   e. Target land cover
   f. Pre-project land use
   g. Target land use
   h. Synergies or tradeoffs among ecosystem services with target land use
   i. Other biophysical goals
j. Socioeconomic goals
k. Differences in goals among project partners

3) **Project tools**
   a. Land management tools/approaches used
   b. Person/group implementing land management
   c. Prohibited land uses or activities
   d. Finance tools used
   e. Who pays for the services?
   f. Who receives payment for the services?
   g. Legal or policy tools used
   h. Level of community involvement

4) **Valuation/analysis**
   a. Was an economic valuation of services done for the project?
   b. If so, when (pre, during, post-project)?
   c. What type of valuation was done?
   d. Which services were valued?
   e. Was a policy analysis done to evaluate policies existing or required for project goals to be met?
   f. Was an ecological analysis done to determine past and current conditions?
   g. How was the target land cover/use determined/chosen?

5) **Monitoring**
   a. Is any project monitoring done to assess how well objectives are being met?
   b. If so, what is being monitored?
   c. How is it being monitored?
   d. In which locations and with what frequency is monitoring done?
   e. Who collects and analyzes the data?
   f. What is the source of financing for monitoring?

6) **Challenges/lessons**
   a. Main challenges in setting up and/or implementing the project
   b. Institutional challenges
   c. Economic challenges
   d. Political challenges
   e. Challenges in working with project partners and/or local landowners
   f. Data that were needed but unavailable
   g. Science needed to make the project better
   h. Lessons learned

**Interviews: Community and Individual Participants and Non-Participants in SocioPáramo (translated)**

Introduction and informed consent (used with all community and individual land owner interviews):
My name is Leah Bremer and I am a graduate student in the Geography department at San Diego State University in the United States. I am studying land use change in páramos of Ecuador. Part of my study involves talking with people about páramo land use and management and how and why land use has changed and may change in the future. Because you are involved with páramo land use and management I wonder if you would be interested in talking with me about how and why land use and management has changed over the years and how it may change in the future. The interview should last about an hour depending on your preference. Your participation in my study is completely voluntary. Any information you give me will be anonymous meaning that it will not be linked to your personal information. Do you wish to participate?

**INTERVIEW 2 (structured): Community Participants in SocioPáramo**

1. **Community information**
   1) How many members are there in the community? How many are female and how many are male?
   2) What is the age range of heads of households of community members?
   3) How often, and for what purpose, does the community have meetings or community events?
   4) What product or products is this community known for?
   5) What products does the community purchase in the city? What products are produced in the community for consumption?
   6) What services are available in this community (water, electricity, telephone, sewage)?
   7) Where does the water used in this community for drinking and for irrigation come from?
   8) How many children of school age (7-12 years) attend primary school? How many do not? How many attend high school? How many do not? Is there anyone in the community who has gone to college?
   9) What do you consider to be the most urgent goals or necessities of this community?
   10) What type of work or jobs do community members do? Females? Males?
   11) Are there community members who have left the community to work or study abroad or in other areas in Ecuador?
       a. If yes how many people and what type of work (or study) are they dedicated to? How much time do they work away from the community?
       b. How does this affect the community?
   12) Has the community worked with a non-profit or governmental organization? If yes, which, when, and in what capacity? How often?
   13) Has there been any conservation or development program focused on the páramos of this community?
   14) Is there a national park or protected area near the community?
       a. How does this affect the community?
   15) Does the community have experience managing financial resources? If yes, since when?

2. **Community map**
   In order to better understand land use, particularly of the communal páramo, would you please draw a map of the community?
   16) What is the area of the community in total? What is the area of communal páramo and of communal forest? Does the community have land tenure of all communal lands?
17) How much private land does each family in the community have on average? How are families using their private land? Are there differences in the quality or quantity of private lands between families? What are the three largest and three smallest private land holdings in the community?

3. Communal páramo land use and management
18) How much time does it take to travel to the communal páramo from the community? What is the most common mode of travel (on foot, horse, car) to get to the communal páramo? Is there a road or trail that goes to the páramo?
19) Does the community obtain anything from the communal páramo? If so, what? What is the communal páramo utilized for?
20) Is, and how is, land use regulated in the communal páramo? If yes, it is written or known by everyone?
21) Have there been repartitions of communal land into private ownership? If so, could you please explain the history of these repartitions?
   a. If the communal páramo has been repartitioned: How are families using the land? Are there differences in the quality or quantity of private lands between families? What are the three largest and three smallest private land holdings in the community?
22) Does the community have crops in the communal páramo?
   a. If yes, how many hectares and what type of crops?
   b. How long has this area been cultivated?
23) Does the community have tree plantations in the communal páramo?
   a. If yes, how many hectares and of what species? Why did the community decide to plant this species?
   b. When did the community plant the plantations?
24) How much of the communal páramo is used for grazing and for what type of animals?
   a. How many animals (cows, sheep, alpacas, llamas) can each community member graze in the communal páramo? How many community members currently use the communal páramo for grazing? How many months per year do they use the communal páramo for grazing?
   b. Are there people who are not community members who use the communal páramo for grazing? If so, how many people and how many animals? How many months per year do they use the páramo for grazing?
   c. What management techniques does the community use to improve the land for grazing? In the case of burning – What is the reason for burning? At what frequency does the community normally burn the páramo?
25) Does the community use páramo plant or animal species for medicinal purposes? If yes, which ones and for what purpose?
26) Is the communal páramo contributing to the economy of this community?
   a. If yes, how? (Agriculture, forestry, grazing, tourism, etc.)
   b. How many people in the community work permanently in the communal páramo? Is there anyone who works there temporarily? What type of work do they do?
27) Are there any people from outside of the community who use the communal páramo of this community? If so, who, and what do they use it for? What effect does this have on the páramo?
4. Land use history of the communal páramo
This part focuses on the land use history of the communal páramo and how land use may change in the future.

28) How was the communal páramo used in each time period (before and after the community formed, before an after the agricultural reforms, other time periods defined by events important to the community, etc.)? (Grazing, agriculture, forestation, conservation, cultural and religious activities, etc.). How often was the páramo burned in each time period? What was the purpose of burning?

**Time Line **

1) Event Year Páramo land use and management

29) When was the last burn in the communal páramo? How much area was burned and what was the purpose of burning? Was it on purpose or an accident?

5. Experience with SocioBosque, Capítulo Páramo (SocioPáramo)

30) How did the community know about SocioBosque/SocioPáramo?

31) Why did the community decide to participate in SocioBosque/SociPáramo? Was it the decision of the entire community or one or several representatives?
   a. Were there people in the community who did not want to participate in the community? If so, how many? What were the reasons for not wanting to participate?
   b. Was it easy to enroll in the program? Was there any additional cost to enrolling? Did you receive any assistance in completing the required documents? What was the most difficult aspect of enrolling in the program?

32) How much area of communal páramo did the community enter? How much communal forest and communal scrubland was entered? (Using the community map—ask whether the community was able to enter páramo with plantations, agriculture, or grazing). How did the community decide what, and how much, land to enter?
   a. Does the community plan to enter more communal páramo in SocioBosque/SocioPáramo in the future?

33) How are the communications with SocioBosque/SocioPáramo? How many times have they visited the community? Have they seen your communal forest and communal páramo entered into the program?

34) What are the regulations concerning land use of páramo entered into SocioBosque/SocioPáramo.
   a. What activities are prohibited? What activities are promoted or permitted?

35) Which of the permitted or promoted activities are important for the community? (Tourism? Grazing (type of animal and amount of animals?), conservation)? Are these activities new for the community since joining SocioBosque/SocioPáramo?

36) Has the community had to change land use as a result of SocioBosque/SocioPáramo regulations (in terms of grazing, forestation, etc.)? If yes, what type of changes?
   a. Are you in agreement with SocioBosque/SocioPáramo regulations? Is there anything you would like to change?

37) What changes do you anticipate in the communal páramo entered in SocioBosque/SocioPáramo? (After 20 years)
38) If the community had not entered SocioBosque/SocioPáramo, how would the communal páramo be managed or used in the future?
   a. What would happen in terms of páramo land use and management if the government decided to terminate the program prior to the 20-year agreement?
39) Have there been any land-use changes in communal páramo or privately owned páramo that was not entered in SocioBosque/SocioPáramo since the community entered other lands into the program (*increased grazing intensity, agriculture, etc.*). If yes, what type of land-use or management changes?
   a. How will communal and privately owned Páramo that was not entered into SocioBosque/SocioPáramo be managed in the future?
40) How did the community put together the investment plan and community map for SocioBosque/SocioPáramo? How did the community prioritize projects to include in the plan? Was there a vote?
41) What project or activities did the community include in the 2009-2010 Inversion Plan? What has been completed?
   a. What other ideas did the community have in terms of activities to include, but that, in the end were not included? Why did the community decide on final activities?
   b. How does the community plan to put together the investment plan for the next year? What will future resources from SocioBosque/SocioPáramo be used for?
   c. Do you think the funds are sufficient (*to serve as an opportunity cost, to complete activities that you would like to include in the investment plan*)?
42) How is the community putting together the required expense reports to SocioBosque/SocioPáramo? Has the community received any assistance with this? Who is in charge of managing expenses?
   a. What would be helpful to the community to help better manage expenses and paperwork?
43) What are the advantages of participating in SocioBosque/SocioPáramo?
   a. Has participation in the program strengthened the community? If so, how?
44) Are there any disadvantages?

**Conclusion (used with all community and individual land owner interviews):** *Thank you very much for your assistance with this study. Your participation in this interview is very important for this study, which aims to improve understanding of land use and management in páramos.*

**INTERVIEW 3: Individual Participants in SocioPáramo**

1. **General information**
   1) What type of work do you do the majority of the time? Your husband or wife?
   2) Do you or your family belong to a community, association, or other type of organization? If yes, which?
   3) How old are you? Your partner?
   4) How many people currently live in your household?

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5) Do (or did) your children attend primary school? High school? University? If your children are adults, what type of work do they do?
6) What products do you buy in the city? What do you produce at home for consumption?
7) What type of services do you have in the home? (Water, electricity, telephone, sewage?)
8) Have you or anyone in your family left to work away? If so, where? How long did you or your family member work away?
9) Have you or your family worked with an NGO or a governmental organization? If so, which, when, in what capacity, and with what frequency?
10) Has there been any conservation or development project in your family’s páramo?
11) Is there a national park or protected area close by? Does this have any affect on your family?

2. Map of property
12) What is the area of your land in total? How much of your land is in the páramo? In the forest? How long have you had land tenure over your property?

3. Páramo land use and management
13) How long does it take to travel to your páramo from where you live? What is the most common mode of travel (on foot, horse, car) to get to the páramo? Is there a road or trail that goes to the páramo?
14) Does your family obtain anything from the páramo? If so, what? What does your family use the páramo for?
15) Are there crops in your family’s páramo?
   a. If yes, how many hectares and what type of crops?
   b. How long has this area been cultivated?
16) Are there tree plantations in your páramo?
   a. If yes, how many hectares and of what species? Why did your family decide to plant this species?
   b. When were the plantations established?
17) How much of your páramo is used for grazing and for what type of animals?
   a. ¿How many animals (cows, sheep, alpacas, llamas) does your family have in the páramo and for how many months per year?
   b. Are there people outside of your family who use your páramo for grazing? If so, how many people and how many animals? How many months per year do they use the páramo for grazing?
   c. What management techniques do you or your family use to improve the land for grazing? In the case of burning – What is the reason for burning? At what frequency do you normally burn the páramo?
18) Do you or your family use páramo plant or animal species for medicinal purposes? If yes, which ones and for what purpose?
19) Is the páramo contributing to the economy of your family?
   a. If yes, how? (Agriculture, forestry, grazing, tourism, etc.?)
b. How many people permanently in your páramo? Is there anyone who works there temporarily? What type of work do they do?

20) Are there any people from outside of the community who your páramo? If so, who, and what do they use it for? What effect does this have on the páramo?

4. Land use history of the páramo

21) How was your páramo used in each time period? (Grazing, agriculture, forestation, conservation, cultural and religious activities, etc.). How often was the páramo burned in each time period? What was the purpose of burning?

**Time line **

22) When was the last burn in your páramo? How much area was burned and what was the purpose of burning? Was it on purpose or an accident?

5. Experience with SocioBosque/SocioPáramo

23) How did you or your family find out about SocioBosque/SocioPáramo?

24) Why did you or your family decide to participate in SocioBosque/SocioPáramo?
   a. Was it easy to enroll in the program? Was there any additional cost to enrolling? Did you receive any assistance in completing the required documents? What was the most difficult aspect of enrolling in the program?

25) How much area of your páramo did your family enroll? How much of your forest and scrubland was entered? How did you or your family decide what, and how much, land to enter?
   a. Do you plan to enter more land in SocioBosque/SocioPáramo in the future?

26) How are the communications with SocioBosque/SocioPáramo? How many times have they visited your páramo?

27) What are the regulations concerning land use of páramo entered into SocioBosque/SocioPáramo.
   a. What activities are prohibited? What activities are promoted or permitted?

28) Which of the permitted or promoted activities are important for you or your family? (Tourism? Grazing (type of animal and amount of animals?), conservation)? Are these activities new for you or your family since joining SocioBosque/SocioPáramo?

29) Has you or your family had to change land use as a result of SocioBosque/SocioPáramo regulations (in terms of grazing, forestation, etc.)? If yes, what type of changes?
   a. Are you in agreement with SocioBosque/SocioPáramo regulations? Is there anything you would like to change?

30) What changes do you anticipate in your páramo enrolled in SocioBosque/SocioPáramo? (After 20 years)?

31) If you had not entered SocioBosque/SocioPáramo, how would your Páramo be managed or used in the future?
   a. What would happen in terms of páramo land use and management if the government decided to terminate the program prior to the 20-year agreement?

32) Have there been any land-use changes in your páramo that was not entered (if it exists) in SocioBosque/SocioPáramo since your entered other lands into the program (increased grazing intensity, agriculture, etc.). If yes, what type of land-use or management changes?
a. How will páramo that was not entered into SocioBosque/SocioPáramo be managed in the future?

33) How did your or your family put together the property map for SocioBosque/SocioPáramo?

34) What are you or your family using SocioBosque/SocioPáramo funds for?
   a. What will future resources from SocioBosque/SocioPáramo be used for?
   b. Do you think the funds are sufficient (to serve as an opportunity cost, to complete activities or projects you would like to invest funds in)?

35) What are the advantages of participating in SocioBosque/SocioPáramo?

36) Are there any disadvantages?

**INTERVIEW 4: Community Non-Participants in SocioPáramo**

1. Community information
   *Same as community participant interview (Questions 1-15)*

2. Community map
   *Same as community participant interview (Questions 16-17)*

3. Management and use of communal páramo
   *Same as community participant interview (Questions 18-27)*

4. Land use history and changes in land use in the communal páramo
   *Same as community participant interview (Questions 28 and 29)*

30) How do you think the community will utilize the communal Páramo over the next 20 years?

5. Experiences with SocioBosque/SocioPáramo
   31) Has the community heard of SocioBosque/SocioPáramo? If so, how did the community learn of the program?
   32) Is, or has, the community thought of entering the program? Are there people in the community who would like to participate? Are there others who do not want to participate? What are the reasons for wanting and not wanting to participate?
   33) Would the regulations of SocioBosque/SocioPáramo (no burning, no intensive grazing, no forestation) require the community to change land use or management practices?
   34) What changes in the páramo would you anticipate if you decided to enroll in the program?
   35) What would the community utilize SocioBosque/SocioPáramo funds for if you decided to participate?
   36) Do you think SocioBosque/SocioPáramo incentives would be sufficient to serve as an opportunity cost for any changes you would need to make in land use or management? Would funds be sufficient to complete projects or activities you would ideally like to complete with SocioBosque/SocioPáramo funds?
INTERVIEW 5: Individual Non-Participants in SocioBosque/SocioPáramo

1. General information
   Same as individual participant interview (Questions 1-11)

2. Property map
   Same as individual participant interview (Question 12)

3. Páramo land use and management
   Same as individual participant interview (Questions 13-20)

4. Páramo land-use history
   Same as individual participant interview (Questions 21-22)

23) How do you think you or your family will utilize the páramo over the next 20 years?

5. Experiences with SocioBosque/SocioPáramo
   24) Have you heard of SocioBosque? If so, how did you or your family hear of the program? Have you or are you thinking about joining the program? Why or why not?
   25) Would the activities not permitted by SocioBosque/SocioPáramo (no burning, no intensive grazing, no forestation) require you to change land use or management of your páramo?
   26) What changes would you anticipate in your páramo if you joined the program (after 20 years)?
   27) What would utilize SocioBosque/SocioPáramo resources for if you decided to participate? Do you the funds would be sufficient to serve as an opportunity cost for required land use or management changes?

INTERVIEW 6 (semi-structured): Regional promoters of SocioBosque, Capítulo Páramo (SocioPáramo):

1) What does your work as SocioBosque/SocioPáramo promoter consist of?
   a. Name?
   b. How long have you worked in this position?
   c. What region or regions are you responsible for?
   d. How do you meet and recruit communities and individuals to participate in the program? Do you work with a governmental or non-governmental organization?
   e. How do communities and individuals enroll in the program? What are the reasons for wanting to enroll?
   f. Have you met with communities or individuals who do not desire to or are not able to participate? What are the reasons for not wanting to or not being able to participate?
   g. How often do you have contact with the communities and individuals who have enrolled in the program? In what capacity (verification, monitoring, capacitating, etc.)?

2) Biophysical goals
   a. What are the biophysical goals of SocioBosque/SocioPáramo?
b. What type of páramo can and cannot enter into the program (planted with what species? Time since last burn? Burn frequency? Number and type of animals?). What is the process of verification of eligible land uses?

c. What land uses are prohibited in SocioBosque/SocioPáramo agreements? What land uses are permitted or promoted? What is the reason for these regulations?

d. Has land use changed in the SocioBosque/SocioPáramo community and individual agreements in your area? If so, how? How was land used prior to entry and how has it changed?

e. How often did the communities and individuals burn their páramo prior to entering the program? What do you think of the current regulation of no burning?
  a. What type of grazing did the communities and individuals have prior to entry (type and animals per hectare)? Have grazing practices changed? Have any individuals or communities in your area been required or chosen to lower the quantity of animals? If so, where were they moved?
  b. Do the community and individual participants have tree plantations in their páramo? What species (pine, Polylepis racemosa, etc.). Were these planted before or after entry into the program?

3) Socioeconomic goals
  a. What are the socioeconomic goals of SocioBosque/SocioPáramo?
  b. How are the communities putting together their inversion plans? What do you think is the most complicated part of the inversion plan?
  c. How are the communities putting together their financial reports?
  d. Do you think the funds are sufficient to serve as an opportunity cost? To help alleviate poverty?

4) Monitoring
  a. Is there any type of monitoring in SocioBosque/SocioPáramo agreements? If so, what type and who is responsible for the monitoring?
  b. How frequently is monitoring completed?

5) Challenges and lessons
  a. What are the primary challenges related to implementing this program?
  b. What type of institutional, economic, and political challenges have you had? What about challenges in related to land owners?
  c. Is there anything you would like to change or improve about the program?

INTERVIEW 7 (semi-structured): NGOs

1) What types of projects does the organization have in relation to páramo conservation or development?
  a. What are the socioeconomic and biophysical goals of these programs?
  b. Does your program promoter or prohibit particular land uses? If so, which, and why?
  c. What do you consider the most important risks to the páramos of this region?
  d. Beyond SocioBosque/SocioPáramo, has there been any payment for ecosystem services programs in the communities or individuals you work with?
2) **For organizations with relationships with SP: what is the nature of your organization’s position as a SocioBosque/SocioPáramo program partner?**

   a. How long has your organization had this partnership?
   
   b. How long, and in what capacity, do you work with participating communities and individuals? Do you assist in the recruiting process?
   
   c. Have you met with communities or individuals who do not desire to or are not able to participate? What are the reasons for not wanting to or not being able to participate?
   
   d. How often do you have contact with the communities and individuals who have enrolled in the program in what capacity (verification, monitoring, capacitating, etc.)?
   
   e. Do you consider SocioBosque/SocioPáramo a tool for conservation of biodiversity and ecosystem services? For development and poverty alleviation?

*The rest of the interview follows sections 2-5 from the SP promoters interview (see interview 1)*
Literature cited:


Davies, G. and C. Dwyer. 2007. Qualitative methods: are you enchanted or are you alienated? Progress in Human Geography 31:257-266.


CHAPTER 3

Changes in carbon storage with burn exclusion and afforestation in páramo grasslands

Abstract

Highland Andean grasslands (páramos) are highly valued for their role in regional water supply, and increasingly for their large soil carbon stocks. A number of Payment for Ecosystem Services (PES) programs targeting páramos have emerged promoting either afforestation or an alteration of traditional burning and grazing regimes, often under the assumption that these land uses will maximize carbon storage. However, understanding of how these land-use changes affect carbon storage, particularly in the soil pool, is limited. This paper evaluates how burn exclusion and afforestation with Pinus patula and Polylepis racemosa affect carbon storage in páramo grasslands in two study areas in Ecuador. The results support previous findings that aboveground carbon storage is enhanced by afforestation, and, secondarily, by burn exclusion. While regional differences in soil carbon storage between study areas far outweigh variation in soil carbon storage due to land-use change, several small but significant land-use effects were found. Plantations, of both Pinus patula and Polylepis racemosa, stored slightly more soil carbon in one area than a nearby unplanted site, while in the other study area afforestation with Pinus patula had mixed effects on soil carbon storage depending on whether interpretation focused on surface samples or on surface to greater depth sample ratios, which were used to normalize data for underlying environmental variation. Changes in soil carbon
storage with varying burn frequencies were small, with no direct effect of fire detected. However, results suggest that burn exclusion can increase soil carbon storage, with the caveat that this trend may reverse where there is a transition to complete woody dominance. However, results also demonstrate complexity of land-use change effects on soil carbon storage in Andisols, which are characterized by soil organic matter that is structurally and chemically linked to soil material. Results also point to the potential difficulties of operationalizing land-use prescriptions in PES programs to maximize overall ecosystem carbon storage, particularly when such programs target large, environmentally variable regions.

1. Introduction

Payment for ecosystem services (PES) approaches are increasingly advocated as ‘win-win’ mechanisms for poverty alleviation and ecosystem services protection, despite uncertainty over whether land uses incentivized will produce desired ecosystem services (Wunder 2005, Ellison 2009). Such initiatives provide incentives to landowners to manage land in a way that ideally protects or enhances one or more ecosystem service (Zbinden and Lee 2005, Muradian et al. 2010, Kinzig et al. 2011). While PES targets a wide variety of services, the most common initiatives focus on carbon sequestration and storage, watershed protection, landscape beauty, and biodiversity protection (Wunder 2006). Carbon-focused PES projects, in particular, are rapidly growing with elevated international interest in reducing greenhouse gas emissions and increasing carbon sequestration through land management (Wunder
2006, Trabucco et al. 2008). While efforts to enhance carbon storage have primarily focused on aboveground biomass through afforestation, reforestation, and avoided deforestation (Gibbon et al. 2010), changes in soil carbon are also important to consider when evaluating the effects of land use on overall carbon storage (Lal 2004, Farley et al. 2012). However, land-use change effects on soil carbon stocks are often poorly understood and difficult to generalize across environmentally variable regions given that the effect of land-use change on soil carbon storage varies with soil properties and environmental conditions (Hofstede et al. 2002, Holmes et al. 2006). Accordingly, studies illuminating the effect of land use on soil carbon storage under the environmental conditions targeted by PES programs are urgently needed.

With increasing international interest in carbon sequestration and growing water demand in urban areas, carbon and watershed protection PES projects constitute a growing driver of land-use change in highland Andean grasslands (páramos) in Ecuador (Wunder and Alban 2008, Farley et al. 2011). In addition to rich biodiversity, páramo grasslands are valued for their high carbon storage and water regulation, in part derived from the unique properties of páramo soils (Farley et al. 2004, Buytaert et al. 2006a). Andisols, which dominate páramo soils, stabilize large amounts of soil organic matter through direct protection in organo-mineral complexes or of organo-metallic (Al-humus) complexes, through indirect protection through low soil pH and toxic levels of Al, and through physical protection related to large micro-porosity (Shoji et al. 1993, Batjes 1996, Torn et al. 1997, Tonneijck et al. 2010). Páramo soil organic carbon (SOC) storage is higher than most Andisols due to
the cold and wet climate as well as the high organic matter inputs of páramo vegetation (Zehetner et al. 2003). SOC concentrations have been found to reach 40% in highly weathered soils in wet areas (annual precipitation >900 mm) (Buytaert et al. 2005a). However, soils with more frequent ash deposits, and therefore younger soils, have been found to have lower SOC concentrations of about 4-10% (Zehetner et al. 2003).

Ecosystem services projects targeting páramo grasslands in Ecuador compensate landowners to either afforest with pine or regionally native species (most commonly Polylepis racemosa, a small evergreen tree native to the Peruvian Andes), or to alter or eliminate traditional burning and grazing regimes, often with the aim of increasing carbon storage (Farley et al. 2011). The first PES program targeting páramo grasslands, PROFAFOR (Programa FACE de Forestacion del Ecuador), an Ecuadorian company working as an extension of the Forests Absorbing Carbon Dioxide Emissions (FACE) consortium, funded by Dutch electricity companies’ carbon offsets, was established in 1993. PROFAFOR focuses on carbon sequestration through afforestation, primarily with Pinus species. Since, 1999, however, PROFAFOR has been experimenting with regionally native species, including Polylepis racemosa. The Ecuadorian government’s newly-launched SocioPáramo, a chapter of the wider SocioBosque program, is another important PES effort targeting páramo grasslands. In contrast to earlier carbon projects, SocioPáramo focuses on multiple ecological and socio-economic goals by compensating landowners to exclude burning and alter traditional grazing regimes with the goals of enhancing
carbon storage, biodiversity, and water provision and contributing to poverty alleviation (de Koning et al. 2011, Farley et al. 2011).

As with PES programs around the world, however, the science linking land use and land cover to targeted ecosystem services lags far behind program implementation, leading to uncertainty regarding whether promoted land uses actually protect or enhance targeted services, highlighting the need to quantify these links (Armsworth et al. 2007, Daily et al. 2009, Ellison 2009). In the case of páramo grasslands, improved understanding of the outcomes of afforestation with multiple species and of altered burning and grazing regimes is urgently needed if PES programs are to be successful in protecting or enhancing targeted services. One potential source of long-term funding of SocioPáramo (in conjunction with the wider SocioBosque) program is through carbon-offset projects. Obtaining funding through carbon markets, however, requires a clear understanding and quantification of the effects of land-use change on carbon stocks. In the case of páramos, understanding changes in soil carbon stocks is particularly important given that the majority of carbon is stored in this pool and land use effects on soil carbon storage remain poorly understood (Farley et al. 2004, Buytaert et al. 2006b, Farley et al. 2012). Moreover, given that carbon storage in Andisols is unique due to the sorption of organic matter in organo-metallic or organo-mineral complexes (Shoji et al. 1993, Tonneijck et al. 2010), it is critical to understand how these soils may respond differently to land-use change than other soil types.
While afforestation of grasslands with exotic and native tree species has been used as a means to increase carbon sequestration through accumulation of carbon in aboveground biomass, outcomes for soil organic carbon following afforestation are mixed, with one global synthesis finding either increases or decreases in SOC (Paul et al. 2002), and a more recent synthesis finding clear decreases, particularly in the case of pine (Berthrong et al. 2009). Others have emphasized the influence of mean annual precipitation (MAP) on afforestation outcomes, suggesting that afforestation of wet grasslands tends to result in decreases in SOC, while afforestation in drier areas leads to no change or increases in SOC (Guo and Gifford 2002, Berthrong et al. 2012). Guo and Gifford (2002) identified the division between wet and dry grasslands at 1200 mm MAP, while Berthrong et al. (2012) placed it at 600 mm MAP. Given that the majority of Ecuadorian páramos have precipitation levels above 1000 mm, decreases in soil C would be expected with afforestation based on global trends. Several studies have found decreases in carbon storage in Ecuadorian páramos with pine afforestation (Farley et al. 2004; Farley et al. 2012). Hofstede et al. (2002), in a regional study of afforestation of páramo grasslands, found a similar tendency toward lower levels of soil organic matter under pines, but concluded that substantial regional variability makes generalizations difficult (Hofstede et al. 2002). However, it has also been suggested that pines may tend to be planted in degraded areas, and thus may not always be the driver of lower soil carbon contents (Chacón et al. 2009).

The length of time that vegetation has affected the soil clearly influences soil properties (Jenny 1980), but outcomes of plantation effects on soil carbon storage are
varied with one synthesis finding no effect of plantation age (Guo and Gifford 2002) on carbon stocks and another finding recovery of lost carbon stocks after 20-30 years (Berthrong et al. 2012). Recovery of carbon stocks with time has been explained as a function of the multi-decadal reductions in organic inputs with plantation establishment that recover with age (Berthrong et al. 2012; Paul et al. 2002). However, available studies on afforestation of Ecuadorian páramos with Andisol soils suggest decreased carbon storage with plantation age and do not point to recovery of carbon stocks with age (Farley et al. 2004; Farley et al. 2012). In northern Ecuador, Farley et al. (2004) found decreasing SOC content in the top 0-10 cm with increasing age of pine planted in páramos, but the oldest plantations were 25 years old. More recently, Farley et al. (2012) found lower soil carbon under 40 year old pine compared with unplanted páramo sites, but no effect of young *Polylepis racemosa*, possibly due to the small size (<400 cm) of the *Polylepis* trees.

A number of mechanisms behind changes in soil carbon storage with afforestation have been proposed, including accelerated decomposition rates due to reduced soil moisture (Farley et al. 2004) and a shift from extensive fine roots systems of grasses with high turnover rates to longer-lived, coarser tree roots that contribute less organic matter (Post and Kwon 2000, Guo and Gifford 2002). Litter quality has also been shown in some studies to have an important influence on the rate at which litter is decomposed and incorporated into SOM (Quideau et al. 2001, Guo et al. 2006). Higher C:N ratios, indicative of lower quality litter, in pine litter compared with grassland litter have been associated with delayed incorporation of
litter into the mineral soil under pine compared with grasslands (Quideau et al. 2001, Farley et al. 2004, Guo et al. 2006).

Afforestation is also expected to result in acidification of grassland soils (Jobbagy and Jackson 2003, Farley and Kelly 2004, Berthrong et al. 2009). In Andisols, forest cover has been shown to contribute to acidification more than grasslands, which has important implications for soil properties related to pH (Tonneijck et al. 2010). Jobbagy and Jackson (2003) propose that soil acidification with grassland afforestation can result from three mechanisms: increased production of organic acids, soil respiration, or sequestration and redistribution of cations. Studies in páramo grasslands have attributed changes in pH related to afforestation (or forest vs. grassland vegetation) to the first and the third explanations, rather than to soil respiration, despite documented changes in soil carbon storage with afforestation (Farley and Kelly 2004, Farley et al. 2004, Tonneijck et al. 2010). Given that soil acidity plays an important role in soil fertility and other important biogeochemical processes, understanding of land-use change effects on pH is critical (Jobbagy and Jackson 2003).

Even less is understood about the effects of fire frequency on carbon storage in páramo grasslands. While reduced burning frequency likely increases aboveground carbon storage, the relationship between fire, in particular fire exclusion, and soil carbon storage in páramo grasslands and other ecosystems remains unclear. Globally, fire has been shown to have variable effects on soil organic matter, with burning found to increase, decrease, or have no influence on the amount of soil organic matter
depending on fire intensity, environmental conditions, soil properties, and the degree to which organic matter is combusted during a fire (Gonzalez-Perez et al. 2004). Fire regimes can alter soil organic matter content directly by altering organic inputs and decomposition rates and through transformation of aboveground and belowground carbon into more stable char compounds (black carbon) (Gonzalez-Perez et al. 2004, Knicker 2007) and indirectly through controls on species composition (Jackson et al. 2002). Frequent burning, coupled with intensive grazing, has been shown to decrease SOC in páramo grasslands (Podwojewski et al. 2002), but there is little evidence of burning alone influencing organic matter content in these ecosystems (Hofstede and Rossenaar 1995, Suarez and Medina 2001).

Beyond direct effects of burning, fire regime can influence species composition, and, in particular, whether grass-to-shrub transitions occur. Burn exclusion in grassland ecosystems can lead to woody encroachment, with variable outcomes for SOC storage (Jackson et al. 2002, Neff et al. 2009). Jackson et al. (2002), comparing grass to shrubland transitions across a precipitation gradient, concluded that woody encroachment leads to SOC gains in dry sites (<600 mm) and losses in wet sites (>600 mm), mirroring findings of Berthrong et al. (2012) in regards to afforestation. Similarly, grassland versus forest cover has been associated with differences in the amount and vertical distribution of SOC in Andisols (Shoji et al. 1993, Tonneijck et al. 2010). Shoji et al. (1993) attribute altered vertical distributions of organic matter to different mechanisms of organic matter input between forest and grassland ecosystems, where organic matter is primarily added to
the top of the soil surface in forests, while inputs in grasslands include belowground root turnover and aboveground inputs. Similar mechanisms have been attributed to changes in organic matter distribution and quantity in woody and grass vegetation across a range of soil types (Jobbagy and Jackson 2000, Guo and Gifford 2002). Understanding the ecological outcomes of such transitions has important implications for SocioPáramo and other emerging PES programs targeting páramo grasslands.

Although soil carbon storage below 30 cm is over half of total soil carbon storage in most soils (Batjes 1996, Jobbagy and Jackson 2000), the vast majority of soil carbon studies and inventories focus on the surface 10 cm or 30 cm, as this is where land-use change has the most direct influence on soil properties (IPCC 2003, Farley et al. 2004, Jones et al. 2005, Poeplau et al. 2011). However, land-use change can also influence carbon storage at greater depths through the translocation of dissolved organic carbon (DOC) (Marin-Spiotta et al. 2011) or through input from deeper roots (Jobbagy and Jackson 2000). While vertical transport of DOC is expected to be insignificant in Andisols due to the sorption of organic C (Kramer et al. 2012), Marin-Spiotta et al. (2011) documented such translocation of DOC in Hawaiian Andisols. Wider C:N ratios with depth, can be an indicator of stabilized organic matter translocated from surface horizons. (Marin-Spiotta et al. 2011). Thus, while the greatest effects of land-use change are most likely found in the surface soils, this study also includes greater depth samples. The inclusion of greater depth samples recognizes the potential for land use change to affect deeper soil horizon, but, alternatively, can be used to normalize surface samples for background
environmental variation if the assumption is made, based on previous research, that land-use change impacts tend to be limited to surface horizons (Jones et al. 2005; Berthrong et al. 2009; Poeplau et al. 2011; Turner and Kelly 1985).

This study evaluates the outcomes of afforestation and fire regime on carbon storage. To do so, I calculated the aboveground and soil carbon storage of nine sites within two study regions, one in the Cañar province in the south of Ecuador and one in Bolivar province in central Ecuador. Sites included a chronosequence of burn histories as well as sites afforested with Pinus radiata, Pinus patula and Polylepis racemosa. I collected 0-10, 10-20, 20-30, and 30-60 cm soil samples and discuss these results in terms of whether differences in carbon among land uses and between study regions are due to underlying environmental variation or to land use and management. I focus on afforestation and burn exclusion as two land use or management practices promoted by current and emerging PES programs targeting páramo grasslands, with the aim of contributing to discussions on the effectiveness of these programs and strategies for improvement.

Specifically, this study addresses the following research questions:

1. How does afforestation affect aboveground and soil carbon storage in páramo grasslands?

2. How does burn history affect aboveground and soil carbon storage in páramo grasslands?
2. Methods

2.1. Study Areas

This research took place in two study areas, one in Cañar province in south central Ecuador, and the other in Bolívar province in central Ecuador (Figures 1 & 2). The first study area is Mazar Wildlife Reserve (MWR) (2° 56’-2° 57’ S, 78° 74’ W), an 1800 hectare forest and páramo reserve within Sangay National park managed by Dr. Stuart White and the NGO Fundación Cordillera Tropical. The closest INAMHI (Instituto Nacional de Meterologia e Hidrologia) meteorological station (Rio Mazar Rivera; M0410; 2° 34’ S, 7° 39’ W; 2450 m) to this site measured mean annual precipitation (MAP) from 1964-2011 as 1326 mm; however, of note is that this station is approximately 1000 m below the MWR study area. Mean annual precipitation (MAP) in MWR (based on TRMM time series data from 1998-2009; Bookhagen in review) is 1595 mm per year; this value is similar to 2010 precipitation levels (1503 mm) measured in MWR by Fundación Cordillera Tropical (FCT), suggesting that the TRMM and FCT measurements may be more representative of actual field conditions. The second study area, Salinas, is managed by the Grupo Juvenil de Salinas, in Bolívar province in central Ecuador (1° 36’-37’ S, 79° 00-01’ W). The Salinas study area was originally grass páramo, but has been converted, for the most part, to *Pinus patula* plantations and exotic pasture with patches of native grass páramo and plantations of *Polylepis racemosa*. MAP in Salinas, is 1303 mm as measured from 1971-2011 at a nearby INAMHI meteorological station with similar elevation to the study area (Salinas-Bolivar; M0385; 1° 24’ N S, 79° 1’ W; 3600 m).
This is similar to the 1281 mm MAP obtained using TRMM data from 1998-2009 (Bookhagen *in review*).

Mazar Wildlife Reserve is a mixed-use reserve, with 350 of the 1800 ha used for alpaca grazing, with a maximum of 160 alpacas over 350 hectares (See Appendix 3.1 for site photos). This site was selected for its diversity of burn histories, ranging from a recently burned area to an area burned over 45 years ago, along with 22 year old *Pinus patula* plantations. Native vegetation includes montane forests, grass páramo dominated by tussock grass (*Calamagrostis intermedia*) and *Puya clava-herculis*, and shrubby páramo dominated by a mix of *C. intermedia, Puya clava-herculis* with shrub species including *Morella parvifolia, Gynoxys cuicochensis, Brachyotum jamesonii*, and *Valeriana hirtella*. Páramos range from approximately 3200-3600 m in this region. The reserve is located at the southern end of the Cordilleras and is farther away from eruptive centers than Salinas (Figure 1) (Poulenard et al. 2003). Soils are classified as Andisols (Soil Survey Staff, 1999). According to Poulenard et al. (2003), these soils are non-allophanic Andisols, dominated by Al-humus complexes.

The Salinas site has been planted extensively with *Pinus patula* and, more recently, with *Polylepis racemosa* in some areas through a contract with PROFAFOR for carbon credits (See Appendix 3.1 for site photos). *P. racemosa* is a small-statured evergreen tree, often with a growth pattern of a large shrub. It is native to Peru, but has been brought to Ecuador for use in reforestation or afforestation and windbreaks and is often referred to as a native species by local communities. There are four native
Polylepis species in Ecuador, which are found up to 5000 m elevation, but these have not been utilized extensively for reforestation/afforestation. The Salinas study region was selected to compare the effects of *P. racemosa*, pine, and unplanted native grass páramo, as the *P. racemosa* plantations in Salinas are the oldest PROFAFOR project utilizing this species so represent one of the only examples of older plantations of this species in the country. Páramos in this area span to higher elevation areas than MWR, with remaining native vegetation, consisting primarily of grass páramo dominated by *C. intermedia*, ranging from 3700-4000 m. Soils in the Salinas site are also classified as Andisols, but are younger, less developed soils, given closer proximity to a greater number of eruptive centers (Figure 1). It is unknown whether these soils are classified as allophanic or non-allophanic Andisols.

Using aerial photos and expert assistance by the 30 year owner and manager of Mazar Wildlife Reserve (S. White, *personal communication*, March 2010), I identified 6 sites within the reserve and one site outside of the reserve with different land-use histories over the past 20-50 years in terms of burn history or afforestation. This included two sites planted with *Pinus patula*, four sites with a chronosequence of burn histories from burned 1 year ago to burned over 45 years ago, and one site with frequent burning (every 3-5 years) and cattle grazing outside of the reserve (MG) (Table 1). The páramos within the reserve have been protected from burning for approximately 20 years; however, in the last 6 years, two large fires (2004 and 2010) have crossed from neighboring properties. Accordingly, I was able to choose sites where the last burn occurred less than 1 year ago (M1Y), 6 years ago (M6Y), 25 years
ago (M25Y), and more than 45 years ago (M45Y), forming a chronosequence of time since the last burn. M25Y and M45Y were both shrubby páramo, with the 45 year site dominated by native woody species. These sites were both grassy páramo in a 1977 air photo and the 45 year site has not been burned in the 30 years since the arrival of the current landowner in 1981, with the 25 year site burned once between 1981 and the time of sampling (Figure 3). Jockish and Blair (2002) documented similar increases in woody cover with burn exclusion in the study area. All sites have similar long-term land-use histories, which prior to the current landowner involved extensive cattle grazing coupled with burning over the last 80 years.

When the pilot phase of this project began in 2009, there were no areas with recent burns (in the past 1-3 years) to include in the study. In order to understand the short-term effect of burning on soil carbon, I carried out a controlled burn in June 2009 over 1 hectare of páramo that had not been burned in 20 years. This site was subsequently burned in November 2009 in an accidental fire. I sampled this site before (M20Y) and after (M1Y) the two burns (only surface soil samples were taken before the burn). Thus, M20Y and M1Y are the same location, but before and after the two 2009 burns.

The two pine sites (MP1 & MP2), planted approximately 22 years prior to sampling, are in their first and only rotation. They are not managed for production, as the goal of planting was to use them to facilitate the recuperation or advancement of native forest. Spacing is approximately 3 m x 3 m. In the first pine site (MP1), several pine trees were harvested during the study for house construction, so one transect
went through disturbed forest. In general, there is little native vegetation cover under the pines, but native trees and shrubs have colonized some areas.

Three sites were chosen in the Salinas study area, including two adjacent sites, one planted with *Pinus patula* (SPp) and one planted with *Polylepis racemosa* (SPr) (Table 2). Both sites were planted 8 years prior to sampling and are second rotation sites, previously planted with pine for one 20 year rotation, which, after harvesting, was left to regenerate to native páramo grassland for 12 years prior to the second rotation. There were no *P. racemosa* plantations that had not been previously planted with pine. Spacing was approximately 3-4 m between trees at both sites, with intermittent larger gaps. In both sites, there was a large amount of native vegetation in light gaps, primarily *C. intermedia* and several other herbaceous and shrubby species. There was evidence of cattle grazing at both the pine and *Polylepis* sites. The third site, an unplanted native grass páramo site (SG), was several hundred meters higher and steeper than the other sites due the difficulty of finding a grass páramo site that had never been planted. This site had not been burned in at least 6 years prior to sampling and is used very sparingly for grazing, which is concentrated in the flatter areas converted to exotic pasture.

Ideally this study would draw on a greater number of sites but MWR is unique in the availability of a long known chronosquence of burn histories adjacent to pine plantations and the Salinas site is unique in being the location of the oldest *P. racemosa* planted in páramo grasslands. While field conditions are not ideal, it is critical to study these available sites given that PES policies are incentivizing burn
exclusion and *P. racemosa* afforestation despite little understanding of the ecological outcomes of these transitions.

### 2.2 Soil sampling

In each site I established three evenly spaced 20 m transects. 20 m transects were used to capture the maximum amount of environmental variation within the often small patch size of land use/management types. Samples were collected from these transects at four depths: 0-10 cm, 10-20 cm, 20-30 cm, and 30-60 cm. 0-10 and 10-20 cm samples were collected every 2 m along each transect (n=33 per site). Three 20-30 and 30-60 cm, litter samples, and bulk density samples (0-20 cm) were taken at 6 m intervals along each transect for a total of nine samples per site at 20-30 and 30-60 cm depths. I focused sampling efforts on surface samples (0-10 and 10-20 cm) collecting >30 samples per site as this is where land-use change effects on soil properties are most expected. Given budget constraints, sample size for greater depth samples (20-30 and 30-60 cm) was lower (n=9), but large enough to conduct non-parametric statistical analysis. One soil pit was also dug in each site, from which I collected two bulk density samples by horizon, which were used to calculate total carbon values for the greater depth samples.

All samples, with the exception of bulk density samples, were air-dried and passed through a 2 mm sieve. Samples were analyzed for pH (H₂O) and pH (NaF) at the soil laboratory at the University of Azuay. Values for pH (NaF), or the pH rise due to fluoride sorption, that are above 9.4 indicate the dominant presence active Al
compounds, including allophane and Al-humus complexes (Wada 1980). Such materials are typical weathering products in volcanic ash soils and play an important role in Andisol properties including water retention capacity and organic matter stabilization (Shoji et al. 1993). pH (NaF) values higher than 9.4 indicate the presence of such materials, but pH (NaF) cannot effectively distinguish between allophanic clays and Al-humus complexes (Wada 1980). Soil texture was not analyzed in the laboratory because mechanical analyses of soil texture in Andisols are considered unreliable because noncrystalline materials present often form stable aggregates that strongly resist dispersion (Shoji et al. 1993). Samples were brought back to the University of California, Santa Barbara soil laboratory for grinding and oven drying (60° C). Samples were then transferred to San Diego State University for carbon and nitrogen analysis using a CHN analyzer. Carbon and nitrogen were the focus of analysis due to the interest in carbon storage by PES programs and the role of nitrogen in SOM structure and dynamics. All samples were run in duplicate and repeated if duplicates differed more than 10%. Samples were then oven-dried at 105°C for 24 hours and percent C values adjusted for remaining water weight. Bulk density samples were dried to a constant weight and used to calculate bulk density values for each depth class.

2.3. Biomass sampling

At Mazar Wildlife Reserve, I established three 10 m x 20 m plots in each site around each soil transect and calculated the biomass of all trees within each 10 m x
20 m plot. Trees were defined as having a height >1.5 m, a diameter at breast height (DBH) >2.5 cm, and not branching at the base. For the pine sites, DBH of all pines were measured within each plot and then used to calculate biomass based on established allometric equations for pines (Ravindranath and Ostwald 2008). For native trees, general tropical forest allometric equations were not appropriate as the DBH range of trees in the burn exclusion sites was below those used to establish these equations. Trees in the MWR study site often branched slightly above the base, making it difficult to rely on established allometric equations based on larger trees with simple architecture. In order to minimize alteration of native vegetation within the reserve, I used a less destructive sampling method adapted from Fehse et al. (2001). I first measured the height and DBH and identified the species of each tree. For species branching at DBH height, the DBH of the largest branch was recorded.

To measure the biomass of the trees, the volume of the bole of the tree was calculated by measuring the diameter and height of each branch of the bole. I then harvested and measured percentage of the crown. To calculate the mass of the bole, a wood sample for wood density was collected and measured for volume through displacement. Mass was then measured by drying to a constant weight at 90°C. The mass of the bowl was then calculated by multiplying the wood density by the volume of the bole. To measure the mass of the crown, 25-30% of the crown was harvested and the wet weight recorded for the entire harvested section. I then collected several subsamples of woody parts and leaves, for which I recorded the wet weight and then dried to a constant temperature at 70°C to calculate the dry/wet ratio. The dry/wet ratio was
then used to calculate the dry weight of the harvested sample and extrapolated to calculate the dry weight of the crown. The bole and crown weight were summed to calculate the mass of the tree. For each species of tree, I sampled all individuals if there were less than three individuals per species and a subset of individuals where there were more than three individuals. Subsets consisted of 2-3 individuals; where there were large differences in height, I sub-sampled within height classes and assigned masses to unsampled trees based on sampled individuals.

To calculate the biomass of shrubs, herbaceous vegetation, and litter, I randomly established three 2 m x 2 m plots with nested 1 m x 1 m plots within each 10 m x 20 m plot. All shrubs were harvested and weighed within the 2 x 2 m plots, and all litter and herbaceous biomass in the 1 m x 1 m plots. For large shrubs and the giant herb *Puya* sp., 25-50% of the individual was harvested and extrapolated to calculate the entire shrub. After weighing all harvested biomass according to type (live shrub, dead shrub, live herbaceous, dead herbaceous, and litter), I collected and weighed 1-2 subsamples per plot divided by vegetation type. Subsamples were dried at 90°C and used to calculate a dry/wet ratio, which was then used to calculate the dry weight of the 2 m x 2 m and 1 m x 1 m plots. Tree, shrub, herbaceous, litter, and total biomass were then extrapolated to calculate biomass (tons/ha) and converted to tons/ha carbon using the estimate that two tons of biomass is equal to one ton of carbon.

No plant harvesting was undertaken at the Salinas site due to time constraints and landowner preference.
2.4 Statistical methods

ANOVA, followed by Tukey Kramer Honestly Significant Difference (HSD) post-hoc tests, were used to compare percent and total nitrogen and carbon, C:N ratios, and pH for surface samples (0-10 cm and 10-20 cm) where sample size was near or above 30. For deeper soil samples and litter samples (n= 7-9) per site, we employed Kruskal-Wallis tests followed by Steel-Dwass all-pairs nonparametric post-hoc tests. Non-parametric tests for the greater depth samples were used given smaller sample size, which precluded adequate evaluation of normality. Aboveground carbon values between sites in each study area were also compared using Kruskal-Wallis tests followed by Steel-Dwass all-pairs nonparametric post-hoc tests.

Another way of interpreting these data is to normalize for environmental variation, which was done by computing surface to greater depth sample ratio for total carbon 3/2* (Tons C ha\(^{-1}\) 0-20 cm/Tons C ha\(^{-1}\) 30-60 cm, hereafter TCR). The ratio of 0-20 cm and 30-60 cm is multiplied by 3/2 in order to calculate surface to greater depth sample ratio per unit area. This is based on previous research finding land-use change effects on carbon storage greater in surface than greater depth samples (Turner and Kelly 1985, Berthrong et al. 2009). The higher the TCR, the higher the relative total carbon values are in surface samples compared with greater depth samples. Using these ratios to normalize the data for environmental variation assumes that land-use and vegetation change affects surface, but not deep samples. If the assumption is made that land use does not affect greater depth samples (30-60
cm), then changes in the relative surface values (expressed as a ratio of surface to greater depth) can provide a way to evaluate changes in carbon storage with land use. Alternatively, if there is dissolved organic carbon (DOC) delivery to lower horizons or input from deeper roots, such ratios are poor measures of changes in carbon storage resulting from land use/vegetation cover. I also computed similar ratios for percent carbon (Percent C 0-20 cm/percent C 30-60 cm) (PCRs) to evaluate these trends for carbon concentrations. TCRs and PCRs between sites were compared using Kruskal-Wallis tests followed by Steel-Dwass all-pairs nonparametric post-hoc tests.

3. Results

While soil carbon storage was high in both study areas, MWR sites (412.0-548.6 tons C ha\(^{-1}\) in 0-60 cm) stored 2 to 2.5 times as much carbon in the top 60 cm as the Salinas sites (206.1-215.0 tons C ha\(^{-1}\)) (Tables 2 & 3). Accordingly, differences between study areas far outweighed differences among sites with different land use and management within these areas. In both areas, and in Salinas in particular, the depth of the A and Bw horizons, with high concentrations of organic matter, far exceeded 60 cm, so these are very conservative estimates of total soil carbon storage (Appendices 3.2 & 3.3). pH (NaF) values ranged from 10.5-11.8 in MWR and 10.3-10.7 in Salinas for all land uses at all depths, indicating the presence of amorphous materials including allophane and Al-humus complexes (Shoji et al. 1993) (Tables 2 & 3). In addition to cool, wet conditions, these mineralogical characteristics likely contribute to high SOC stabilization across both study areas.
I did, however, find changes in aboveground carbon storage as well as small, but significant changes in soil carbon storage attributable to land use differences within study areas. I discuss these for MWR (aboveground and soil carbon) and Salinas (soil carbon) in the following sections.

3.1 Mazar Wildlife Reserve

MWR: Aboveground carbon

As expected, aboveground carbon in MWR was highest in the pine sites and increased with time since last burn in the unplanted grassland sites, ranging from 2.3 tons C ha\(^{-1}\) in M1Y to 122.0 tons C ha\(^{-1}\) in MP2 (Figure 4; Table 5). Aboveground carbon storage in MWR páramo sites ranged from 2.3-23.9 tons C ha\(^{-1}\) in site last burned less than a year ago to over 45 years ago, suggesting approximately 0.5 tons C ha\(^{-1}\) year\(^{-1}\) gain in carbon, which appears to slow somewhat with time (Figure 4; Table 5). With burn exclusion, biomass from shrubs and trees increased and contributions from herbaceous biomass decreased. While M45Y had a mean of 4.5 tons C ha\(^{-1}\) of herbaceous biomass, this was largely from low-lying herbaceous species rather than tussock grasses, which dominated other páramo sites. M25Y, in contrast, while having more shrubs than more recently burned sites, also has a high contribution of biomass from large tussock grasses. In the site last burned less than a year prior to sampling (M1Y), approximately a third of the aboveground carbon came from remaining shrub biomass that had survived the burn so does not represent newly sequestered carbon (Figure 4; Table 5)
The sites afforested with pine clearly stored more aboveground carbon than the unplanted sites. Given that the planted pines were approximately 22 years old at the time of sampling, aboveground carbon sequestration of the plantations can be estimated at 4.5 to 5.5 tons C ha\(^{-1}\) per year, an order of magnitude higher than unplanted sites. While aboveground biomass represents an important carbon sink, it comprised only 1-4% of the carbon storage for unplanted sites and 15-18% in the pine plantations (Table 4). However, although constituting a small portion of overall carbon storage, the greatest absolute change in carbon storage between sites was seen in the aboveground pool (Table 4).

**MWR soil carbon**

In MWR, mean total soil carbon in 0-20 cm ranged from 172.7 tons C ha\(^{-1}\) in one pine site (MP2) to 201.9 tons C ha\(^{-1}\) in M25Y, with small but significant differences among sites in both 0-10 cm and 10-20 cm depths (P<0.0001) (Figure 5; Tables 2 & 4). There were small, but significant differences in soil carbon storage between sites with grassy cover (M1Y\(^5\) & M6Y) and sites with high shrub cover (M25Y & M45Y), but conclusions vary based on interpretation. Using the most straightforward measurement, surface (0-20 cm) total carbon values, results suggest a trend towards higher carbon storage in sites with high shrub cover and the longest time since the last burn (M25Y & M45Y) (Figure 4; Table 2). However, differences between M6Y, M25Y and M45Y are the result of higher bulk density in shrubby

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\(^5\) M1Y can be considered a mixed tussock and shrub system in between M6Y and M45Y given that carbon storage did not change after the recent fires.
sites since carbon concentrations are approximately equal (Figure 6; Table 2). It is unclear whether greater carbon storage in sites with high shrub cover (M25Y and M45Y) represents real increases in carbon storage or whether this can be attributed to compaction or densification with a transition to shrub cover. Total carbon stored in 0-60 cm was higher in the two shrubbiest sites (M25Y & M45Y) than in M1Y and M6Y, but it is difficult to ascertain whether this is due to the influence of land-use change on greater depth samples or underlying environmental variation (Table 4).

Normalizing for environmental variation, using the total carbon surface to greater depth ratio (TCR), leads to a different interpretation of results regarding the effect of burn exclusion on soil carbon storage (Figure 7). While significant differences are few given the small sample size (n= 7-9), the TCR points to higher levels of carbon storage under M25Y and M6Y (M1Y is highly variable) than M45Y. By this measure, M45Y is similar to the two pine sites. Patterns with the PCR show little differences between M45Y and the other unplanted sites, pointing to the important role of bulk density in total carbon values (Figure 8). Assuming no translocation of DOC, TCRs suggests lower carbon storage under the shrubbiest páramo site, dominated by woody vegetation, in comparison to sites with greater herbaceous cover (including M25Y, which has high tussock cover in addition to shrubs). Accordingly, in terms of burn exclusion, the most important difference between focusing on surface samples and the TCR is in the ranking of M45Y, which has among the highest carbon levels in the surface samples and among the lowest...
when judging by the TCR. By either measure, the highest soil carbon storage was found under M25Y.

No difference in total soil carbon was found before and after fire (M20Y and M1Y). Thus, although M1Y is classified as a recently burned site, land-use effects on soil carbon storage are more likely reflective of the mixed shrub and grass cover prior to burning than to the recent burn. The intermediate levels of carbon storage in 0-20 cm (Figure 5; Table 2) in M1Y (and M20Y) fit with the trend seen towards greater carbon storage with burn exclusion. The TCR and PCR for M1Y (Figures 7 & 8) is highly variable due to variation in 30-60 cm total carbon values and, accordingly, difficult to interpret.

In terms of outcomes of afforestation in MWR, the two pine sites were different from each other, in that MP1 stored more soil carbon than MP2 (although only significantly more in 10-20 cm) (Figure 5; Table 2). This translates into significantly less carbon storage in MP2 in 0-20 cm than in M25Y and M45Y, but no significant differences between MP1 and M45Y (or M25Y in 10-20 cm). The TCR of MP1 is also higher than MP2, but not significantly so (Figure 7). The TCRs of both pine sites are similar to M45Y, which are all lower than the sites with greater tussock cover. This again points to greater carbon storage under woody vegetation (or under less tussock cover) if the assumption is made of no translocation of DOC. PCRs are also lowest in the pine sites, with MP1 having a significantly lower ratio than all unplanted sites except M25Y. While not all differences are significant, PCRs suggest lower carbon storage under pines, but not under native woody vegetation (M45Y).
Given that soil carbon storage in 0-20 cm under pine in MWR varied among sites, it is difficult to generalize the effects of afforestation on soil carbon storage in this study area (Figure 5). However, there are some important similarities between the pine sites that differentiate them from the non-afforested sites. The pine sites both have high carbon concentrations (Figure 6) and very low bulk densities for both surface and deep samples (Table 2). The two pine sites also stored more carbon in the top 60 cm than all sites but M45Y, reflective of higher carbon contents in the pine sites and M45Y in 20-30 and 30-60 cm depths (Tables 2 & 4). It is unclear whether this is due to underlying environmental variation or enhanced carbon storage at depth with afforestation.

An important comparison in MWR is between the páramo site dominated by shrubs and trees (M45Y) and the adjacent pine site (MP2) (Figure 4). Percent carbon values were not significantly different between sites in surface layers (0-10 and 10-20 cm) (Figure 6). However, total carbon was significantly lower in MP2 than in M45Y. Given that carbon concentrations were not different, this difference is due to greater bulk density in M45Y (Table 2). Likewise, the TCR of MP2 is slightly lower than that of M45Y, although not significantly so (Figure 7). While more replication is needed to determine the magnitude and significance of this effect, this suggests greater soil carbon storage under native woody vegetation (as a result of 45+ years of burn exclusion) in comparison to an adjacent pine plantation.
**MWR C:N ratios**

C:N ratios ranged from 13.4-14.6 at MWR and increased with depth at all sites. Significant differences were found among sites at all depths (P<0.0001 for 0-10, 10-20, and 20-30 cm and P<0.001 at 30-60 cm). C:N ratios were higher in the pine sites (MP1 & MP2) than the unplanted sites in 0-10 and 10-20 cm, but MP2 C:N ratio was not significantly different than M45Y in 10-20 cm (Table 2). Similar trends were found in 20-30 cm and 30-60 cm, but with fewer significant differences, likely due to the small sample size. C:N ratios of litter samples were also highest in the two pine sites (MP1 & MP2), but ratios were similarly high in M6Y (Table 2).

**MWR: pH (H20)**

pH (H20) ranged from 3.7 to 4.7 in all sites and depths at MWR, with small but significant differences among sites in 0-10 cm and 10-20 cm (P<0.0001) and in 20-30 and 30-60 cm (P<0.001) (Table 2). The two pine sites were slightly, but significantly more acidic than the unplanted sites in 0-10 cm. In 10-20 cm, the first pine site (MP1) was significantly more acidic than all other sites, including the second pine site (MP2), which had the same pH (H20) as M1Y. In 20-30 and 30-60 cm depths, MP1 was consistently the most acidic, while MP2 was similar to the unplanted sites. Overall, M6Y was consistently the least acidic (Table 2).
3.2 Salinas

Salinas soil carbon

Total carbon values were lower at Salinas than MWR, ranging from 122.2 T C ha$^{-1}$ in the unplanted site (SG) to 129.6 T C ha$^{-1}$ in the site afforested with Polylepis (SPr) (Tables 3 & 6). Significant differences were found among sites in 0-10 cm (P<0.0001), but no significant differences were found for 10-20 cm (Figure 8; Table 3). In 0-10 cm, carbon was higher in the two afforested sites (SPp and SPr) than the unplanted site (SG). In contrast, total carbon was higher in SG than in the afforested sites in the 20-30 cm and 30-60 cm depths, with significant differences between SG and SPp at these depths (Figure 9; Table 3).

Variations in bulk density in Salinas had less of an impact on how sites compared in terms of total carbon versus carbon concentration than in MWR. However, higher bulk densities in the unplanted site (SG) narrowed differences between sites in terms of total carbon storage compared with carbon concentrations. (Table 3; Figures 9 & 10). Lower bulk densities in SPr compared to SPp in 0-10 cm also narrowed difference between total carbon values at this depth for the afforested sites. Likewise, the lower BD value for SPp in 30-60 cm led to greater carbon storage at this depth despite similar carbon concentrations (Table 3; Figures 9 & 10).

Evaluating changes in carbon storage using TCRs and PCRs led to similar conclusions as using surface samples in Salinas, as TCR and PCR values were also significantly lower in SG than in the afforested sites (Figures 11 & 12). While the TCR was higher in the pine site (SPp) than the Polylepis site (SPr), the difference was
small and not significant and no difference was found in the PCR. It is important to note that, over the entire 0-60 cm, the unplanted site (SG) stored slightly more carbon than the two afforested sites, reflecting higher bulk densities (Tables 3 & 6). This, again, is likely due to environmental variation resulting in greater carbon storage at depth, but possible land-use effects on greater depth samples cannot be dismissed.

**Salinas C:N**

C:N ratios in Salinas ranged from 14.4 to 15.1. In contrast to the MWR sites, C:N ratios were highest in 0-10 cm and then leveled off with depth (Table 3). There were significant differences in C:N ratios among Salinas sites for 0-10 cm (P<0.01), 10-20 cm (P<0.0001), and 20-30 cm (P<0.01) depths (Table 3). C:N ratios were higher in SG than the afforested sites, but patterns of significance varied. The C:N ratio of SG litter was dramatically and significantly greater than in the afforested sites (54.4 compared to 26.7 and 28.1). This difference is due to low nitrogen levels as carbon is similar among sites (Table 3).

**Salinas pH (H20)**

Due to the small number of samples analyzed for pH (H₂O and NaF) I did not run statistical analyses for these data, but describe general trends. Overall, Salinas soils had slightly higher pH (H₂O) values than the MWR, ranging from 4.8 to 6.0. The afforested sites were slightly more acidic than the unplanted site (SG) at all depths, with the exception of 0-10 cm where pH (H₂O) values were very similar among sites.
4. Discussion

The results of this study provide reliable estimates of carbon stocks in páramo grasslands in two field sites, insights into the relationship between incentivized, yet poorly understood land uses and carbon storage, and also contribute to the development of strategies to evaluate changes in carbon storage where optimal replication is not possible. With findings of between 206.1 and 548.6 tons C ha\(^{-1}\) in the top 60 cm of soil, the study sites provide further evidence of the high soil carbon storage potential of páramo grasslands and support the idea that native grasslands can be an important carbon sink (Gibbon et al. 2010, Farley et al. 2012). In MWR, soil carbon stocks in the top 60 cm accounted for 96-99% of carbon storage in unplanted sites and from 82-85% of carbon stocks in afforested sites, pointing to the relative importance of soil carbon in páramo grasslands, even under afforestation.

4.1. Changes in carbon storage with land-use change

Aboveground carbon

The clearest effect of land-use change in this study is the enhancement of aboveground carbon stocks in the 22 year old pine plantations in MWR, which stored 78.4 - 98.1 tons C ha\(^{-1}\) more carbon aboveground than the unplanted site with the highest biomass (a shrubby páramo site over 45 years old). Planting pine has been seen as an exchange of belowground for aboveground C, which may potentially be true at MWR, but with much less being transferred than reported elsewhere.
(Berthrong et al. 2009; Farley et al. 2012). Previous studies in the Ecuadorian Andes (Farley et al. 2012; Fehse et al. 2002) found larger quantities of aboveground carbon in a 45 year old native *Alnus* stand and a 40 year old pine plantation (241 tons C ha\(^{-1}\) and 279 tons C ha\(^{-1}\), respectively), suggesting that these plantations likely have the potential to sequester more aboveground carbon with age, which could translate into further decreases in soil carbon storage associated with the exchange of belowground for aboveground C. However, aboveground net primary productivity (NPP) is likely to decrease with stand age (Gower et al. 1996, Ryan et al. 2004) and a recent review of afforestation effects on SOC found that plantations left to grow over 20-30 years often recover soil carbon initially lost with plantation establishment (Berthrong et al. 2012). Thus the effect of continued growth of the plantations on soil carbon stocks remains uncertain.

While much lower than pine aboveground C stocks, carbon sequestration in unplanted MWR páramo sites reached up to 23.9 tons C ha\(^{-1}\) (with over 45 years of burn exclusion). This is higher or similar to previous reports of carbon stocks in páramo grasslands (Hofstede et al. 1995; Farley et al. 2012). A recent report estimated aboveground C stocks at 59.3 tons C ha\(^{-1}\) in grass páramo, but values were based on visual, rather than measured estimates (Hofstede et al. 2010). Farley et al. (2012) found up to 22.9 tons C ha\(^{-1}\) in a tussock dominated páramo site with 15 years of burn exclusion, suggesting that grass-dominated páramo, with a much shorter period of burn exclusion, can sequester as much carbon as a shrubby páramo. Thus, while carbon sequestration efforts have primarily focused on afforestation,
reforestation, and avoided deforestation, results provide support for the idea that native grasslands and shrublands can also have value for their aboveground carbon stocks (Bekessy and Wintle 2008). Given that afforestation with pines, in particular, has been associated with decreased runoff (Buytaert et al. 2007b) and threats to native plant diversity (Van Wesenbeeck et al. 2003, Bremer and Farley 2010), a focus on the carbon sequestration potential of native grasslands and shrublands is merited (Gibbon et al. 2010).

**Soil carbon storage**

Transitions from grassland to woody vegetation have been shown to influence soil carbon storage across a wide range of soil types (Guo and Gifford 2002, Jackson et al. 2002), including Andisols (Shoji et al. 1993, Farley et al. 2004, Tonneijck et al. 2010). Results of this study support the idea that vegetation is an important, but moderate, control over SOC storage in páramo soils. However, results also point to the difficulty of operationalizing land-use prescriptions to maximize SOC storage across páramo grasslands as land-use change effects were small and variable.

Based on previous research (Farley et al. 2004, Berthrong et al. 2009, Farley et al. 2012), losses in soil carbon were expected with afforestation, particularly with pine. Drawing on data from both study areas, the effects of afforestation on soil carbon storage were inconsistent with one study area (Salinas) showing small gains of 6.3 to 7.4 T C ha\(^{-1}\) (in the top 0-20 cm) in SOC with afforestation and the second study area (MWR) showing small, but variable outcomes depending on how
variations in greater depth samples were interpreted. Hofstede et al. (2002), in a regional study of pine afforestation effects on soil carbon storage, similarly concluded that the effects of plantations cannot be generalized, as outcomes varied based on environmental factors, land-use history, and plantation management. However, the authors also conclude that plantations “almost never have a positive effect on soils and vegetation” (Hofstede et al. 2002: 165). Results from MWR concur with this statement given negative to neutral effects on carbon storage with afforestation depending on the study site and metric used (surface samples or TCRs), with the caveat of the possibility that pine plantations resulted in a translocation of DOC. In contrast, results from Salinas conflict with this statement, given small but positive impacts of afforestation. However, these plantations were young (8-years old) and had an abundant native tussock understory, which differentiates them from MWR plantations and many other plantations established in páramo grasslands.

The finding of no difference between the *Pinus patula* and *Polylepis racemosa* plantations in Salinas contrasts with other research that has indicated more soil carbon loss under *Pinus* than other species (Berthrong et al. 2009). However, this finding is also difficult to interpret, as the plantations are young and second rotation (with the first rotation *Pinus patula*). A recent study found no effect of *P. racemosa* on SOC compared with unplanted sites, but noted the small size of the planted trees (Farley et al. 2012). *P. racemosa* in Salinas are believed to be the oldest plantations in Ecuadorian páramos at 8 years old and 4-8 m tall, but still do not adequately represent the potential long-term effects of *P. racemosa* afforestation. However, that no
difference was found between the two species is important given that *Polylepis racemosa* is often regarded as a tool for ecosystem restoration and an alternative to pine, despite a lack of evidence of greater environmental benefits (Farley et al. 2011).

Globally, fire suppression followed by woody encroachment has led to mixed outcomes on SOC, ranging from increased to reduced C storage (Jackson et al. 2002, Neff et al. 2009), with decreases expected in humid grasslands (Jackson et al. 2002). Grassland vegetation has been associated with higher SOC and greater incorporation into mineral soils than woody cover in Andisols (Shoji et al. 1993, Tonneijck et al. 2010). Shoji et al. (1993), for example, point to the influence of anthropogenic fires in converting forest vegetation to *M. sinenis* (Japanese pampas grass), which has resulted in higher organic carbon concentrations. Based on surface samples (0-20 cm), results from MWR point to a small increase in soil carbon storage (34 tons C ha⁻¹ maximum in top 20 cm) in the sites with long periods of burn exclusion (M25Y & M45Y). This contrasts with research showing losses in carbon storage with woody encroachment of wet grasslands (Jackson et al. 2002), but the two woody sites in the present study had been under woody cover for a shorter time period than the Jackson et al. (2002) study and the site last burned 25 years ago still contained a large percentage of herbaceous cover. However, while results are statistically insignificant, the surface to greater depth sample ratio (TCR) was lower in the site last burned over 45 years ago than the more recently burned sites with greater tussock cover. This suggests that SOC storage may decline with a shift away from tussock-dominated towards shrub- and tree-dominated vegetation, providing support for previous
research indicating greater carbon storage under grasslands than woody vegetation in both Andisols and other soil types (Shoji et al. 1993; Tonneijck et al. 2010; Jackson et al. 2002).

While changes in vegetation cover moderately influenced SOC storage, no direct and immediate impact of fire on soil carbon storage was detected. This finding concurs with past research on fire and SOC in páramo grasslands, which suggests little direct influence of fire on SOC storage (Hofstede 1995, Suarez and Medina 2001). Although aboveground carbon stores decline with burning, this is largely offset through carbon sequestered during regeneration (Bowman et al. 2009). Thus, while burning will, at least temporarily, reduce aboveground carbon storage, it seems to have relatively small immediate impacts on SOC levels, at least in the context of the time period studied. However, this finding does not preclude the influence that fire regime could have on SOC in páramo grasslands. In other regions, fire has been shown to have the potential to directly alter SOC content through altering aboveground carbon inputs and belowground decomposition rates, and through transforming aboveground and belowground carbon into more stable char compounds (black carbon) (Gonzalez-Perez et al. 2004, Knicker 2007). The possible contribution of black carbon to páramo carbon storage is, accordingly, a fruitful area for future research.

It is important to note that, in most cases, burning as a land management strategy in páramos is used in conjunction with cattle, sheep, and, increasingly, alpaca and llama grazing (White and Maldonado 1991, Keating 2007). Sites at MWR were
used for alpaca grazing and in Salinas for occasional cattle grazing, but these sites are not as heavily grazed and frequently burned as many páramos in Ecuador. I gathered one transect of surface (0-20 cm) samples from a site adjacent to MWR which is burned every 3-5 years and used weekly for cattle grazing (MG). This site had higher total carbon levels than all other sites except the two sites with the longest period of burn exclusion (Table 2). Bulk density in this site was similar to the afforested sites and site last burned 6 years ago (Table 2), contrary to expectations that bulk density would be higher in grazed sites due to compaction (Hofstede 1995). While difficult to draw definitive conclusions based on a small sample size and absent 20-30 or 30-60 cm depth samples, these results suggest that grazing effects on soil carbon also merits further research before drawing firm conclusions.

4.2 Mechanisms of change in soil organic carbon with land-use change

Andisol chemical and physical properties have been found to be susceptible to land-use change, including afforestation, intensive grazing, and agriculture (Shoji et al. 1993, Podwojewski et al. 2002, Poulenard et al. 2003). However, in considering changes in SOC in Andisols with land-use change, it is important to note that much of the soil organic matter is sorbed and chemically linked to soil materials via the formation of organo-metallic and organo-mineral complexes (Shoji et al. 1993, Tonneijck et al. 2010). Buytaert et al. (2007) found few land-use change effects in recently cultivated Andisols dominated by organo-metallic complexes, indicating that soil properties may facilitate resistance to some forms of land-use change at least over
relatively short time periods. pH (NaF) values above 9.4 in both Salinas and MWR indicate the presence of active Al, either allophane of Al-humus complexes, suggesting that a large portion of organic matter is likely structurally linked to the soil material which may translate into greater resistance to land-use change. However, in a study of organic matter stabilization of Andisols in northern Ecuador, Tonnejick et al. (2010) concluded that over half of soil organic matter is stabilized indirectly through low soil pH and Al toxicity and through physical protection by the large micro-porosity of Andisols, rather than to stabilization by organo-metallic complexes. Accordingly, while all SOC is not necessarily structurally linked to the soil matrix, Andisols may be more resistant to land-use change than other soil types, which may, in part, explain the relatively moderate changes in SOC with land-use change detected in this study.

Potential mechanisms behind changes in SOC with plantation establishment and woody encroachment include changes in litter quality (Quideau et al. 2001, Guo et al. 2006), an alteration in the quantity of organic matter inputs (Post and Kwon 2000, Guo and Gifford 2002, Jackson et al. 2002), and reduced soil moisture leading to accelerated decomposition (Farley et al. 2004). C:N ratios in pine litter compared with grassland litter, indicative of lower quality litter, can delay incorporation of litter into the mineral soil under afforestation (Quideau et al. 2001, Farley et al. 2004, Guo et al. 2006). In MWR, pine litter C:N ratios were higher than all but one unplanted site (M6Y), which suggests that litter quality may play a role in reduced carbon storage in pine (based on interpretation of TCRs). In turn, the lower litter C:N ratio in
the woody-dominated site (M45Y) than the adjacent pine site (MP2) may explain greater carbon storage under native woody vegetation than pine in surface samples.

In contrast to MWR, litter in the Salinas unplanted site had much a much higher C:N ratio than the afforested sites, which may, in part, explain higher soil carbon values under plantations in that study area. This pattern of C:N ratios is surprising given that grass litter normally has lower C:N ratios than forest litter (Jobbagy and Jackson 2000, Farley et al. 2004). However, it is unclear whether the lower litter C:N ratios found in plantations compared with the grassland sites are due to differences in grass C:N ratio between sites or the fact that plantation litter is constituted by a mix of inputs from grasses and trees.

Continued input of grass litter and roots in Salinas plantations could explain differences between this study area and MWR, and potentially points to the value of maintaining understory vegetation for soil carbon storage (Berthrong et al. 2009). With afforestation, grasses generally become shaded out by trees as the plantation ages leading to a shift from the fine root-system of grasses associated with high turnover and organic matter inputs to tree roots with lower organic matter input (Guo and Gifford 2002, Farley et al. 2004). This was the case in MWR and is reflected in differences in soil consistency and structure under pines (Appendix 3.2). In contrast to MWR and other studies of páramo afforestation (Farley et al. 2004; Farley et al. 2012), plantations in Salinas were characterized by high tussock cover, as the sites had not been burned in over 20 years and were not burned at the time of plantation establishment. Since the trees were relatively young (8 years), the plantations also did
not shade out the majority of the grasses, so soils continue to have substantial inputs from tussock grass vegetation in addition to the planted trees. In addition to the native understory, both Salinas plantations contained substantial pine debris from the first rotation. In combination with continued organic inputs from the native tussock understory, may have tempered the effects of harvesting, which can disturb soils and decrease SOC storage (Hofstede et al. 2002, Berthrong et al. 2009).

An additional possible source of differences between the planted and the unplanted sites in Salinas is environmental variation, given that the only available unplanted site was 200 m higher in elevation and on a steeper slope than the afforested sites. While it is difficult to ascertain whether higher carbon levels were due to the trees or to environmental conditions, normalization through TCRs suggests that differences are due to land-use change rather than environmental variation if the assumption is made that there is no translocation of DOC. While translocation of DOC cannot be dismissed, little transport of DOC is supported by decreasing C:N ratios with depth (Marin-Spiotta et al. 2011).

Another important mechanism of change in SOC with afforestation is a change in evapotranspiration and soil moisture content, with implications for decomposition rates (Farley et al. 2004, Berthrong et al. 2009). Lower soil moisture levels would be expected to accelerate decomposition of SOM under afforestation given that high moisture levels constrain decomposition in páramos (Farley et al. 2004, Berthrong et al. 2009). In MWR sites, Harden et al. (in review) found lower soil moisture levels under both pine sites than unplanted sites, with MP2 significantly
drier than MP1, in accordance with patterns seen in SOC storage. If evaluated in the context of TCRs, assuming no translocation of DOC, lower soil moisture, accordingly, may be one factor contributing to a decrease in total carbon values in surface samples relative to greater depth samples under pine. Likewise variation in soil moisture may explain greater carbon storage in 0-20 cm samples in M45Y compared with the adjacent pine site (MP2) as MP2 was significantly drier (Harden et al. in review).

However, it is important to note that TCR values are driven largely by greater carbon storage in 30-60 cm samples. Assuming that 30-60 cm samples are unaffected by the land-use changes evaluated, greater carbon storage at this depth is reflective of underlying environmental variation rather than land-use change and total carbon stock estimates should be interpreted accordingly. However, an alternate explanation is that greater carbon in pine sites and M45Y at 30-60 cm is due to translocation of SOC to greater depths. While highly reactive SRO minerals and metallic nanoparticles characteristic of Andisols easily sorb OC and would be expected to minimize translocation of dissolved organic matter (Kramer et al. 2012), Marin-Spiotta et al. (2011) found evidence of such delivery of DOC along preferential flow paths in Hawaiian Andisols. C:N ratios increased with depth at MWR in all sites, which is unusual particularly for non-allophanic Andisols, under which MWR soils are classified (Buytaert et al. 2006b, Marin-Spiotta et al. 2011). Widening C:N ratios with depth can be indicative of translocation of DOC, but can be attributed to a wide variety of processes that lead either to a depletion in nitrogen or SOM protection from
normal decomposition which depletes C relative to N (Marin-Spiotta et al. 2011). Future research on land-use change effects on soil carbon in páramo grasslands should address whether such changes influence carbon storage below 20 cm, as the interpretation of varying SOC contents at depth has an important influence on conclusions drawn regarding the effect of land-use change on SOC stocks.

It is also important to note that carbon concentrations under pine in MWR were higher than unplanted sites, pointing to the role that bulk density plays in determining total carbon stocks. However, given that PCRs (surface to greater depth ratios for carbon concentrations) also were lower (although not always significantly so), relative decreases in surface compared with deeper soil C also held true for carbon concentration, which is independent of bulk density. Yet, this study, particularly in MWR, clearly demonstrates the importance of considering the role of bulk density in driving differences in SOC with land-use change.

4.3. Regional differences in soil carbon stocks

While changes in carbon storage due to land-use change are the focus of PES programs, given that this is where such programs can influence carbon sequestration, it is important to consider large regional differences in soil carbon storage between the two study areas. The major large-scale controls on soil carbon storage in páramo Andisols can be related to volcanic ash deposits, parent material, and climate (Buytaert et al. 2007a). Soils in Salinas are in closer proximity to eruptive centers than MWR (Figure 1) and, accordingly, would likely have more abundant ash
deposits with lower levels of weathering than MWR (Buytaert et al. 2005b). An abundance of non-crystalline minerals (allophane, imogolite, and ferrihydrite), which are products of weathering of volcanic ash, and the associated formation of organo-mineral complexes, have been found to increase carbon stabilization (Torn et al. 1997). However, in Ecuadorian páramos, the majority of Andisols have been classified as “non-allophanic” Andisols where active Al is primarily in the form of Al-humus (organo-metallic) complexes (Buytaert et al. 2006b, Tonneijck et al. 2010). In drier areas with more recent ash deposits, allophanic Andisols develop with associated lower soil carbon contents (Buytaert et al. 2007). While Andisols are by far the dominant soil order in Ecuador, and in particular ‘non-allophanic’ Andisols in the South of the country, Histisols, Umbrisols, Inceptisols, and Entisols evolve (Buytaert et al. 2006a). For example, Buytaert et al. (2007) note that some páramo soils are Histisols with negligible ash deposits and owe their high carbon storage exclusively to the cold and wet climate, rather than to soil physical properties that facilitate SOM stabilization.

pH (NaF) values above 9.4 are indicative of significant levels of amorphous materials, including allophane and Al-humus complexes (Wada 1980), but cannot be used to distinguish between allophane and Al-humus complexes (Shoji et al. 1993). In this study pH (NaF) values were between 10.5-11.8 in MWR and between 10.3 and 10.7 in Salinas for all land uses at all depths, indicating high levels of active Al in both study areas, but with somewhat higher levels in the MWR. However, pH (H₂O) values can be indicative of whether soils are dominated by allophane or Al-humus
complexes. According to Shoji et al. (1993), ‘allophanic’ Andisols, dominated by short-range order amorphous aluminosilicates (such as allophane and imogolite) form at pH (H$_2$O) of 5-7. On the other hand, ‘non-allophanic’ Andisols tend to form at lower pH likely because the formation of organo-metallic complexes which is considered to have an anti-allophanic effect, as Al preferentially forms Al-humus complexes reducing the availability of Al to form allophanic clays with Si (Shoji et al. 1993, Tonneijck et al. 2010). Accordingly, based on pH (H$_2$O) values, which are slightly above 5 in Salinas (Table 11) and slightly below 5 in MWR (Table 5), soils in Salinas are more likely dominated by allophane, while those in the MWR, Al-humus complexes. Given that soils dominated by Al-humus complexes are often associated with higher SOC storage, this could, in part, explain some of the differences in carbon storage between sites.

At the same time, the greater distance to eruptive centers likely translates into the older age of MWR soils compared with Salinas soils which could also explain greater carbon storage given a longer period to accumulate SOM (Figure 1). In addition to time of soil development, variation in precipitation could partly explain regional differences in soil carbon storage. While both sites would be classified as wet grasslands according to previous studies evaluating land-use change effects on soil carbon across a precipitation gradient (Berthrong et al. 2012; Guo and Gifford 2002; Jackson et al. 2002), MAP is higher in MWR (1590 mm/year) than Salinas (1281 mm/year) according to TRMM data. Although INAMHI station data MAP values were similar (1326 mm – MWR; 1303 mm - Salinas) between sites, the Mazar
INAMHI station data is likely an underestimate of MAP in MWR due to the lower elevation of the meteorological station. Higher precipitation in MWR would result in lower decomposition rates in MWR due to climatic factors, which, in combination with soil properties could lead to greater carbon storage in MWR compared with Salinas.

4.4. Land-use change effects on soil acidity

Afforestation in both sites caused small increases in acidification, in line with previous studies (Farley and Kelly 2004, Berthrong et al. 2009). In MWR, one pine site (MP1) was more acidic than unplanted sites at all depths, while the other pine site (MP2) was only more acidic in 0-10 cm. In contrast, in Salinas, pH was similar among afforested sites in 0-10 cm, but there was greater acidification in deeper samples. Jobbagy and Jackson (2003) propose that soil acidification with grassland afforestation can result from 3 mechanisms: increased production of organic acids, soil respiration, or sequestration and redistribution of cations. In terms of vertical distribution of changes in pH, maximum acidification should occur at the soil surface if organic acid inputs are most important driver, at depth if soil respiration is most important, and just below 10 cm where root uptake is high but organic inputs are low if cation redistribution is the major driver (Jobbagy and Jackson 2003). Accordingly, results suggest that in MWR organic acid inputs or other biological processes occurring near the soil surface are the major driver in increased acidification seen at the pine sites, particularly in MP2. Farley and Kelly (2004) similarly found lower pH
values in the top 10 cm only and attributed acidification to biological processes occurring near the soil surface including production of organic acids, chelates, and carbon dioxide. However, in MP1 (where increased acidity was found at multiple depths), the two other mechanisms may play a role. In contrast, In Salinas, the lack of change in pH in 0-10 cm suggests that either soil respiration or accumulation of cations in the biomass, or a combination of both, may be the most important drivers of acidification (Jobbagy and Jackson 2003). Given that acidification was seen in 30-60 cm samples, soil respiration appears to play a role in this. However, this finding is surprising given greater SOC storage under both Polylepis and pine than the unplanted site.

5. Conclusions and policy recommendations

PES programs are prominent on the international sustainability agenda and are rapidly growing around the world (Brockington 2011). However, their development is outpacing scientific understanding of links between promoted land uses and targeted ecosystem services pointing to the critical need for this type of research and to integrate research outcomes into policy decisions (Ruffo and Kareiva 2009). This research demonstrates the complexity of measuring the effects of land-use and land-management change on soil carbon storage in páramo grasslands and the difficulty of generalizing the effect of local scale land-use change on soil carbon from region to region (Holmes et al. 2006). This suggests that variability from one region to another may make it difficult to operationalize prescriptions for land-use change into carbon-
focused PES programs, particularly national ones that cover a variety of environmental conditions. This presents an important challenge for PES development and demonstrates that “getting the science right” in terms of linking land use and ecosystem service provision is not an easy task when programs cover broad, environmentally and socio-economically variable areas (Ruffo and Kareiva 2009: 3). However, despite the difficulty of drawing firm generalizations, this research does provide several important recommendations for PES programs targeting páramo grasslands.

Afforestation with pine can be an effective strategy to enhance aboveground carbon storage, although levels found at MWR were lower than those reported elsewhere. However, based on inconsistent outcomes in soil carbon storage, coupled with previous research suggesting declines in soil carbon storage with afforestation of páramos grasslands (Farley et al. 2004), pine plantations continue to be suboptimal as a carbon sequestration strategy. In addition to uncertain outcomes on soil carbon, there are clear negative tradeoffs with water provision following establishment of pine plantations (Buytaert et al. 2007b), suggesting that focusing exclusively on aboveground carbon storage can compromise other ecosystem functions and services (Lindenmayer et al. 2012). While Polylepis and other regionally native or native species have been advocated as potentially more sustainable than pine, further research on the effects of mature Polylepis racemosa plantations on multiple ecosystem services and biodiversity is clearly needed. The Salinas plantations may not be very representative of plantations established in páramos given very high
herbaceous cover, but this also suggests that management of understory may be an important way to improve sustainability of plantations, both pine and Polylepis.

While aboveground carbon was much lower in unplanted sites in MWR than afforested sites, results suggest that burn exclusion can be an effective aboveground carbon sequestration strategy that can be used as an alternative to afforestation. Results from MWR also show small gains in soil carbon with burn exclusion, with the possible caveat of a reversal where there is a transition to complete shrub and tree dominance. However, no direct and immediate effect of fire on SOC storage suggests that very infrequent burning is unlikely to decrease carbon storage and may be beneficial in as much as it may be necessary to maintain herbaceous cover in some regions.

The finding of relatively small changes in carbon storage with burn history, coupled with the potential for some level of burning to be beneficial for soil carbon storage in as much as it maintains tussock cover, suggests that PES programs do not necessarily need to ban burning to be effective carbon sequestration programs. Conversion of grassland to agriculture has been shown to decrease soil carbon storage to varying degrees (Guo and Gifford 2002, Buytaert et al. 2005b, Farley et al. 2012), and PES programs like SocioPáramo may be able to more effectively prevent agricultural expansion by incorporating working landscapes that allow some level of burning in conjunction with grazing. One of the most important ecosystem services of páramo grasslands is its economic value as forage, and data from MWR suggest that burn exclusion, at least under the conditions at MWR, can lead to a transition to
woody-dominated systems that would not be suitable for grazing. Given that SOC levels were similar between unplanted sites with varying burning regimes, incorporating working landscapes with some level of burning and grazing should not be ruled out of carbon-based PES projects. There is a clear need for further research on the effects of grazing on carbon stocks as well as outcomes for other ecosystem services and biodiversity, rather than basing land-use regulations on the assumption that burning and grazing necessarily lead to ecosystem degradation.

In addition to further research on land-use transitions in a greater number of sites, there are several other areas of research that would provide relevant and important information for existing and developing PES programs in Ecuador and beyond. First, future research should address how regional controls on soil carbon storage, particularly climate and volcanic ash deposits, affect the response of Andisols to land-use change. In particular, understanding how different mechanisms of soil organic matter stabilization (e.g. organo-mineral complexes, organo-metallic complexes, physical stabilization through microporosity, low pH, and Al toxicity (Tonneijck et al. 2010)) influence how soils respond to land-use change is critical. Such research would allow PES programs to more accurately estimate the extent to which land-use change influences overall ecosystem carbon storage and would help move towards modeling soil carbon and storage in a manner more appropriate for Andisols (Jansen et al. 2011). Second, joint social-ecological research, which links socio-economic, political, demographic, and biophysical conditions to land-use change and subsequently to biophysical change and ecosystem services would shed
light on páramos as coupled human and natural systems. This would allow for a more holistic understanding of links between the human and natural sub-systems in PES agreements, which is critical to predicting and improving ecological outcomes.

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Table 1: Site descriptions: Mazar Wildlife Reserve and Salinas. Note that M20Y and M1Y are the same site, but M20Y represents the area prior to the two burns in 2009, while M1Y is the same site after fire.

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
<th>Slope</th>
<th>Land cover</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWR</td>
<td>3449</td>
<td>21</td>
<td>Shrubby páramo; 60-70% tussock grass; 10-20% shrubs; 10-15% other herbaceous</td>
<td>Last burned 20 years prior to sampling; occasional alpaca grazing; cattle grazing and more frequent burning 35 years ago</td>
</tr>
<tr>
<td>M20Y</td>
<td>3449</td>
<td>21</td>
<td>Regenerating páramo; 15-25% short tussock; 10-15% shrubs (regenerating); 20-30% other herbaceous; 30-40% bare ground.</td>
<td>Burned in July 2009 as part of an experimental burn; burned again in November 2009 in an accidental burn; alpaca grazing</td>
</tr>
<tr>
<td>M1Y</td>
<td>3449</td>
<td>21</td>
<td>Grass páramo; 70-80% tussock grass; 5-10% shrubs; 10-20% other herbaceous; 10-20% bare ground.</td>
<td>Burned in January 2004; occasional alpaca grazing</td>
</tr>
<tr>
<td>M6Y</td>
<td>3428</td>
<td>20</td>
<td>Shrubby páramo; 40-50% tussock grass; 15-20% Puya; 1-5% trees; 10-15% other herbaceous</td>
<td>Last burned approximately 25 years ago; near research cabin, but minimal disturbance</td>
</tr>
<tr>
<td>M25Y</td>
<td>3453</td>
<td>13.5</td>
<td>Shrubby páramo/woodland; 5-10% tussock grass; 50-60% shrubs; 20-30% trees; 10-20% other herbaceous</td>
<td>Last burn over 45 years ago</td>
</tr>
<tr>
<td>M45Y</td>
<td>3351</td>
<td>22</td>
<td>Pine plantation; 5-10% shrubs</td>
<td>Pine plantation</td>
</tr>
<tr>
<td>MP1</td>
<td>3402</td>
<td>17.5</td>
<td>Grass páramo; b 70-80% tussock grass; 10-20% other herbaceous; 10-20% bare ground</td>
<td>Seasonal cattle grazing with frequent burning (3-5 years)</td>
</tr>
<tr>
<td>MP2</td>
<td>3249</td>
<td>20</td>
<td>30-40% P. patula (3-5 m spacing with some larger gaps); 40-50% tussock grass; 1-5% shrubs; 10-20% other herbaceous</td>
<td>8 year Pinus patula plantation; 12 years of regeneration prior to current plantation after previous 20 year rotation of Pinus patula; light cattle grazing</td>
</tr>
<tr>
<td>MG</td>
<td>3299</td>
<td>21</td>
<td>50-70% P. racemosa (3-4 m spacing with some larger gaps); 10-30% tussock grass; 10-15% pine debris from previous plantation</td>
<td>8 year Polylepis racemosa plantation; 12 years of regeneration prior to current plantation after one 20 year rotation of Pinus patula; light cattle grazing</td>
</tr>
<tr>
<td>SPr</td>
<td>3763</td>
<td>17</td>
<td>70-80% tussock grass; 20-30% bare ground with low-lying herbs</td>
<td>Páramo grassland. Little used for grazing. Last burned approximately 6 years ago.</td>
</tr>
<tr>
<td>SPp</td>
<td>3757</td>
<td>16</td>
<td>30-40% P. patula (3-5 m spacing with some larger gaps); 40-50% tussock grass; 1-5% shrubs; 10-20% other herbaceous</td>
<td>8 year Pinus patula plantation; 12 years of regeneration prior to current plantation after previous 20 year rotation of Pinus patula; light cattle grazing</td>
</tr>
<tr>
<td>SG</td>
<td>3929</td>
<td>23</td>
<td>70-80% tussock grass; 20-30% bare ground with low-lying herbs</td>
<td>Páramo grassland. Little used for grazing. Last burned approximately 6 years ago.</td>
</tr>
</tbody>
</table>
Table 2: Percent and total (tons ha\(^{-1}\)) nitrogen and carbon, C:N ratio, bulk density, pH (H\(_2\)O), and pH (NaF) for each site by depth at MWR. Note that 20-30 cm and 30-60 cm samples were not taken prior to the recent burn in M20Y. Sites with different letters are significantly different within the associated depth and variable measured (P<0.05). *MG was not included in statistical comparisons due to low sample size. ** N=9 for 0-20 cm bulk density samples for all sites with the exception of MG where N=3, N=2 for 20-30 cm and 30-60 cm BD samples for all sites. ***N=14-32 for pH (H\(_2\)O) and pH (NaF) for 0-10 and 10-20 cm, with the exception of MG where N=10-11; N=7-9 for 20-30 and 30-60 cm pH (H\(_2\)O) and pH (NaF).

<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
<th>%N (SE)</th>
<th>Tons N ha(^{-1}) (SE)</th>
<th>%C (SE)</th>
<th>Tons C ha(^{-1}) (SE)</th>
<th>C:N (SE)</th>
<th>BD (SE) **</th>
<th>pH (H(_2)O) (SE)**</th>
<th>pH (NaF) (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-10 cm</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1Y</td>
<td>33</td>
<td>1.2 (0.0)(^a)</td>
<td>6.3 (0.1)(^bc)</td>
<td>18.2 (0.4)(^d)</td>
<td>96.1 (2.3)(^bc)</td>
<td>15.2 (0.1)(^a)</td>
<td>0.53 (0.02)</td>
<td>4.1 (0.1)(^bc)</td>
<td>10.8 (0.2)(^ab)</td>
</tr>
<tr>
<td>M6Y</td>
<td>29</td>
<td>1.5 (0.0)(^ab)</td>
<td>5.8 (0.1)(^cd)</td>
<td>23.3 (0.4)(^bc)</td>
<td>89.4 (1.7)(^c)</td>
<td>15.4 (0.2)(^c)</td>
<td>0.38 (0.01)</td>
<td>4.4 (0.0)(^c)</td>
<td>10.8 (0.1)(^ab)</td>
</tr>
<tr>
<td>M20Y</td>
<td>25</td>
<td>1.2 (0.0)(^c)</td>
<td>6.2 (0.1)(^bc)</td>
<td>17.9 (0.5)(^b)</td>
<td>94.9 (2.4)(^bc)</td>
<td>15.2 (0.2)(^b)</td>
<td>0.53 (0.02)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>M25Y</td>
<td>33</td>
<td>1.4 (0.0)(^b)</td>
<td>6.9 (0.1)(^a)</td>
<td>22.4 (0.3)(^f)</td>
<td>106.9 (1.6)(^b)</td>
<td>15.6 (0.1)(^b)</td>
<td>0.48 (0.02)</td>
<td>4.2 (0.1)(^c)</td>
<td>11.0 (0.1)(^ab)</td>
</tr>
<tr>
<td>M45Y</td>
<td>33</td>
<td>1.5 (0.0)(^ab)</td>
<td>6.4 (0.2)(^b)</td>
<td>23.7 (0.7)(^bc)</td>
<td>102.7 (2.8)(^ab)</td>
<td>16.1 (0.2)(^b)</td>
<td>0.43 (0.02)</td>
<td>4.2 (0.1)(^b)</td>
<td>11.2 (0.1)*</td>
</tr>
<tr>
<td>MP1</td>
<td>33</td>
<td>1.6 (0.0)(^f)</td>
<td>5.5 (0.1)(^bc)</td>
<td>27.6 (0.3)(^f)</td>
<td>96.2 (1.2)(^bc)</td>
<td>17.6 (0.2)(^f)</td>
<td>0.35 (0.01)</td>
<td>3.7 (0.0)(^f)</td>
<td>10.5 (0.1)(^b)</td>
</tr>
<tr>
<td>MP2</td>
<td>27</td>
<td>1.4 (0.0)(^g)</td>
<td>5.2 (0.1)(^f)</td>
<td>24.4 (0.4)(^f)</td>
<td>89.8 (1.3)(^f)</td>
<td>17.4 (0.2)(^f)</td>
<td>0.37 (0.01)</td>
<td>4.0 (0.1)(^f)</td>
<td>10.9 (0.1)(^ab)</td>
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<tr>
<td>MG*</td>
<td>11</td>
<td>1.7 (0.0)</td>
<td>6.0 (0.1)(^c)</td>
<td>27.14 (0.2)(^d)</td>
<td>98.5 (0.7)(^e)</td>
<td>16.4 (0.1)(^d)</td>
<td>0.37 (0.01)</td>
<td>4.5 (0.1)(^f)</td>
<td>11.4 (0.1)*</td>
</tr>
<tr>
<td></td>
<td>10-20 cm</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>M1Y</td>
<td>33</td>
<td>0.9 (0.0)(^d)</td>
<td>4.8 (0.2)(^f)</td>
<td>14.5 (0.6)(^d)</td>
<td>76.73 (2.9)(^c)</td>
<td>15.9 (0.2)(^d)</td>
<td>0.53 (0.02)</td>
<td>4.2 (0.1)(^b)</td>
<td>10.7 (0.1)c</td>
</tr>
<tr>
<td>M6Y</td>
<td>31</td>
<td>1.3 (0.0)</td>
<td>4.9 (0.1)(^f)</td>
<td>20.4 (0.5)(^f)</td>
<td>78.5 (1.8)(^c)</td>
<td>16.2 (0.1)(^d)</td>
<td>0.38 (0.01)</td>
<td>4.4 (0.0)(^f)</td>
<td>11.4 (0.1)(^ab)</td>
</tr>
<tr>
<td>M20Y</td>
<td>27</td>
<td>0.9 (0.0)(^d)</td>
<td>5.0 (0.1)(^bc)</td>
<td>14.8 (0.4)(^f)</td>
<td>78.08 (2.17)(^b)</td>
<td>15.71 (0.25)(^d)</td>
<td>0.53 (0.02)</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>M25Y</td>
<td>32</td>
<td>1.2 (0.0)(^b)</td>
<td>5.7 (0.2)(^b)</td>
<td>19.9 (0.5)(^f)</td>
<td>95.0 (2.2)(^c)</td>
<td>16.2 (0.1)(^d)</td>
<td>0.48 (0.02)</td>
<td>4.3 (0.1)(^b)</td>
<td>11.4 (0.2)(^ab)</td>
</tr>
<tr>
<td>M45Y</td>
<td>31</td>
<td>1.3 (0.0)(^b)</td>
<td>5.5 (0.2)(^b)</td>
<td>21.0 (0.6)(^bc)</td>
<td>90.74(2.4)(^d)</td>
<td>16.5 (0.2)(^bc)</td>
<td>0.43 (0.02)</td>
<td>4.5 (0.1)(^c)</td>
<td>11.0 (0.2)(^ab)</td>
</tr>
<tr>
<td>MP1</td>
<td>32</td>
<td>1.5 (0.0)(^f)</td>
<td>5.4 (0.1)(^bc)</td>
<td>27.2 (0.3)(^f)</td>
<td>94.5 (1.2)(^f)</td>
<td>17.7 (0.2)(^f)</td>
<td>0.35 (0.01)</td>
<td>3.9 (0.1)(^f)</td>
<td>11.6 (0.1)(^a)</td>
</tr>
<tr>
<td>MP2</td>
<td>33</td>
<td>1.3 (0.0)(^f)</td>
<td>4.9 (0.1)(^f)</td>
<td>22.6 (0.3)(^f)</td>
<td>83.0 (1.1)(^bc)</td>
<td>17.0 (0.1)(^f)</td>
<td>0.37 (0.01)</td>
<td>4.2 (0.0)(^f)</td>
<td>11.4 (0.1)(^ab)</td>
</tr>
<tr>
<td>MG</td>
<td>10</td>
<td>1.5 (0.0)</td>
<td>5.5 (0.1)(^c)</td>
<td>26.1 (0.2)(^f)</td>
<td>94.7 (0.9)(^e)</td>
<td>17.3 (0.2)(^e)</td>
<td>0.37 (0.01)</td>
<td>4.7 (0.1)(^f)</td>
<td>12.0 (0.2)*</td>
</tr>
<tr>
<td></td>
<td>20-30 cm</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>M1Y</td>
<td>9</td>
<td>0.7 (0.0)(^i)</td>
<td>3.7 (0.2)(^f)</td>
<td>11.0 (0.6)(^f)</td>
<td>59.5 (3.4)(^c)</td>
<td>16.24 (0.3)(^b)</td>
<td>0.54 (0.01)</td>
<td>4.3 (0.0)(^f)</td>
<td>11.5 (0.2)(^c)</td>
</tr>
</tbody>
</table>

155
<table>
<thead>
<tr>
<th></th>
<th>M6Y</th>
<th>8</th>
<th>1.1 (0.1)bc</th>
<th>4.2 (0.2)bc</th>
<th>18.3 (1.0)bc</th>
<th>69.3 (4.0)bc</th>
<th>16.6 (0.2)b</th>
<th>0.38 (0.00)</th>
<th>4.7 (0.1)b</th>
<th>11.6 (0.2)bc</th>
</tr>
</thead>
<tbody>
<tr>
<td>M25Y</td>
<td>9</td>
<td>1.1 (0.1)b</td>
<td>5.1 (0.2)b</td>
<td>18.5 (0.8)b</td>
<td>87.6 (3.8)bc</td>
<td>17.1 (0.2)b</td>
<td>0.48 (0.00)</td>
<td>4.5 (0.2)b</td>
<td>11.6 (0.1)bc</td>
<td></td>
</tr>
<tr>
<td>M45Y</td>
<td>8</td>
<td>1.0 (0.1)b</td>
<td>5.1 (0.3)b</td>
<td>17.0 (1.1)f</td>
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<td>11.3 (0.3)bc</td>
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</tr>
<tr>
<td>MP1</td>
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<td>26.5 (0.6)f</td>
<td>84.4 (2.0)f</td>
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</tr>
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<td>5.5 (0.2)f</td>
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<td>94.45 (2.2)bc</td>
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<tr>
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<td>16.7 (0.3)b</td>
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<td>11.3 (0.1)bc</td>
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<tr>
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<td>15.8 (0.7)f</td>
<td>210.2 (9.8)bc</td>
<td>17.1 (0.4)f</td>
<td>0.44 (0.02)</td>
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<td>11.5 (0.1)bc</td>
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<td>12.4 (0.9)</td>
<td>14.7 (1.1)f</td>
<td>216.4 (15.6)bc</td>
<td>17.4 (0.2)f</td>
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<td>15.0 (1.2)</td>
<td>15.6 (1.4)f</td>
<td>269.8 (24.1)bc</td>
<td>17.9 (0.3)f</td>
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<td>13.4 (0.5)</td>
<td>24.8 (1.0)f</td>
<td>264.5 (10.9)bc</td>
<td>19.7 (0.4)f</td>
<td>0.36 (0.01)</td>
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<td>18.1 (0.5)f</td>
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</tr>
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<td></td>
<td>M1Y</td>
<td>9</td>
<td>1.5 (0.1)b</td>
<td>36.9 (2.2)f</td>
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<td>NA</td>
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<td>32.8 (3.4)f</td>
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<td>NA</td>
</tr>
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<td></td>
<td>M45Y</td>
<td>8</td>
<td>1.9 (0.1)b</td>
<td>38.8 (0.9)f</td>
<td>NA</td>
<td>21.1 (0.7)f</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<td>45.2 (1.8)bc</td>
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<td>31.0 (1.7)bc</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
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<td>45.6 (0.4)f</td>
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<td>NA</td>
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</table>
Table 3: Percent and total (tons ha\(^{-1}\)) nitrogen and carbon, C:N ratio, bulk density, pH (H\(_2\)O), and pH (NaF) for each site by depth at Salinas. Sites with different letters are significantly different within the associated depth and variable measured. *N=5-6 for 0-10 and 10-20 cm BD samples; n=2 for 20-30 and 30-60 cm BD samples with the exception of SPp 30-60 cm which is based off of a single sample. **N=3-9 for pH (H\(_2\)O) and pH (NaF).

<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
<th>% N (SE)</th>
<th>Tons N ha(^{-1}) (SE)</th>
<th>% C (SE)</th>
<th>Tons C ha(^{-1}) (SE)</th>
<th>C:N (SE)</th>
<th>BD (SE)*</th>
<th>pH (H(_2)O) (SE)**</th>
<th>pH (NaF) (SE)</th>
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<tr>
<td>0-10 cm</td>
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</tr>
<tr>
<td>SPr</td>
<td>31</td>
<td>0.6 (0.0)(^a)</td>
<td>4.8 (0.1)(^a)</td>
<td>9.3 (0.1)(^a)</td>
<td>72.8 (0.9)(^a)</td>
<td>15.1 (0.2)(^a)</td>
<td>0.78 (0.01)</td>
<td>5.1 (0.1)</td>
<td>10.3 (0.0)</td>
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<tr>
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<td>4.9 (0.1)(^a)</td>
<td>8.9 (0.2)(^b)</td>
<td>71.0 (1.6)(^a)</td>
<td>14.6 (0.2)(^b)</td>
<td>0.81 (0.03)</td>
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<td>10.4 (0.0)</td>
</tr>
<tr>
<td>SG</td>
<td>31</td>
<td>0.5 (0.0)(^b)</td>
<td>4.3 (0.1)(^b)</td>
<td>7.1 (0.1)(^a)</td>
<td>66.4 (1.2)(^b)</td>
<td>15.3 (0.1)(^b)</td>
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<td>5.1 (0.1)</td>
<td>10.3 (0.1)</td>
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<tr>
<td>SPr</td>
<td>32</td>
<td>0.5 (0.0)(^a)</td>
<td>4.1 (0.1)(^ab)</td>
<td>7.2 (0.1)(^a)</td>
<td>56.8 (1.1)(^a)</td>
<td>13.8 (0.1)(^b)</td>
<td>0.78 (0.01)</td>
<td>5.2 (0.1)</td>
<td>10.7 (0.1)</td>
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<tr>
<td>SPp</td>
<td>31</td>
<td>0.5 (0.0)(^a)</td>
<td>4.3 (0.1)(^b)</td>
<td>7.1 (0.1)(^a)</td>
<td>57.5 (0.9)(^a)</td>
<td>13.5 (0.2)(^b)</td>
<td>0.81 (0.03)</td>
<td>5.0 (0.1)</td>
<td>10.7 (0.1)</td>
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<tr>
<td>SG</td>
<td>30</td>
<td>0.4 (0.0)(^b)</td>
<td>3.9 (0.1)(^b)</td>
<td>6.0 (0.2)(^b)</td>
<td>55.8 (1.4)(^b)</td>
<td>14.4 (0.2)(^b)</td>
<td>0.92 (0.02)</td>
<td>5.5 (0.2)</td>
<td>10.4 (0.1)</td>
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<td>20-30 cm</td>
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<td>9</td>
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<td>3.2 (0.0)(^ab)</td>
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<td>4.8 (0.2)</td>
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<td>SPp</td>
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<td>3.2 (0.1)(^b)</td>
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<tr>
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<td>3.4 (0.1)(^a)</td>
<td>5.6 (0.2)(^b)</td>
<td>49.9 (1.6)(^b)</td>
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<tr>
<td>SPr</td>
<td>9</td>
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<td>8.5 (0.2)(^a)</td>
<td>5.5 (0.3)(^a)</td>
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<td>SPp</td>
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<td>7.8 (0.2)(^b)</td>
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<td>105.4 (1.6)(^b)</td>
<td>13.5 (0.3)(^b)</td>
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<td>5.3 (0.1)</td>
<td>10.8 (0.1)</td>
</tr>
<tr>
<td>SG</td>
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<td>8.6 (0.2)(^b)</td>
<td>5.1 (0.2)(^b)</td>
<td>122.8 (5.2)(^b)</td>
<td>14.3 (0.3)(^b)</td>
<td>0.81 (0.02)</td>
<td>6.0 (0.4)</td>
<td>10.5 (0.1)</td>
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<td></td>
</tr>
<tr>
<td>SPr</td>
<td>9</td>
<td>1.1 (0.1)(^a)</td>
<td>NA</td>
<td>28.6 (1.9)(^a)</td>
<td>NA</td>
<td>26.7 (1.9)(^a)</td>
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<td>NA</td>
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<td>54.4 (6.9)(^b)</td>
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Table 4: MWR carbon stocks (0-20 cm, 0-60 cm, aboveground carbon, and total carbon).

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<th>Site</th>
<th>0-20 cm</th>
<th>0-60 cm</th>
<th>Aboveground</th>
<th>Total</th>
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<td>M20Y</td>
<td>173.0</td>
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<td>NA</td>
<td>NA</td>
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<td>M1Y</td>
<td>172.8</td>
<td>412.0</td>
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<td>414.3</td>
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<tr>
<td>M6Y</td>
<td>167.9</td>
<td>447.4</td>
<td>5.0</td>
<td>452.4</td>
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<td>M25Y</td>
<td>201.9</td>
<td>506.0</td>
<td>13.3</td>
<td>519.2</td>
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<tr>
<td>M45Y</td>
<td>193.5</td>
<td>548.6</td>
<td>23.9</td>
<td>572.5</td>
</tr>
<tr>
<td>MP1</td>
<td>190.6</td>
<td>539.5</td>
<td>99.3</td>
<td>638.9</td>
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<td>MP2</td>
<td>172.7</td>
<td>543.4</td>
<td>122.0</td>
<td>665.4</td>
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Table 5: Aboveground carbon at MWR by vegetation type. N=9 for litter, herbaceous vegetation, and shrubs and N=3 for trees and total carbon. Sites with different letters are significantly different for the associated vegetation type (P<0.05).

<table>
<thead>
<tr>
<th>Site</th>
<th>Tons C ha⁻¹ litter (SE)</th>
<th>Tons C ha⁻¹ herbaceous (SE)</th>
<th>Tons C ha⁻¹ shrubs (SE)</th>
<th>Tons C ha⁻¹ trees (SE)</th>
<th>Tons C ha⁻¹ (SE)</th>
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<td>M1Y</td>
<td>0.4 (0.2)⁣</td>
<td>1.1 (0.3)⁣</td>
<td>0.8 (0.5)⁣</td>
<td>0 (0)</td>
<td>2.3 (0.4)</td>
</tr>
<tr>
<td>M6Y</td>
<td>0.3 (0.1)⁣</td>
<td>4.6 (0.5)⁣</td>
<td>0.2 (0.1)⁣</td>
<td>0 (0)</td>
<td>5.0 (0.9)</td>
</tr>
<tr>
<td>M25Y</td>
<td>3.1 (0.7)⁣</td>
<td>7.5 (1.9)⁣</td>
<td>1.6 (0.6)⁣</td>
<td>1.0 (0.5)</td>
<td>13.3 (2.7)</td>
</tr>
<tr>
<td>M45Y</td>
<td>5.9 (0.9)⁣</td>
<td>4.6 (1.7)⁣</td>
<td>4.8 (1.1)⁣</td>
<td>7.9 (1.9)</td>
<td>23.9 (3.0)</td>
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<tr>
<td>MP1</td>
<td>5.7 (0.8)⁣</td>
<td>0.3 (1.2)⁣</td>
<td>0.2 (0.2)⁣</td>
<td>92.0 (6.8)</td>
<td>99.3 (7.7)</td>
</tr>
<tr>
<td>MP2</td>
<td>10.3 (0.8)⁣</td>
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<td>0.4 (0.3)⁣</td>
<td>111.3 (4.4)</td>
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Table 6: Soil carbon levels (tons C ha\(^{-1}\)) in 0-20 and 0-60 cm at Salinas

<table>
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<th>0-0 cm (n= 7-9)</th>
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<td>SPr</td>
<td>129.6</td>
<td>213.3</td>
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<tr>
<td>SPP</td>
<td>128.5</td>
<td>206.1</td>
</tr>
<tr>
<td>SG</td>
<td>122.2</td>
<td>215.0</td>
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</tbody>
</table>
Figures

Figure 1 (left). Location of Mazar Wildlife Reserve and Salinas study areas. Shaded gray areas display páramo grasslands and open triangles are volcanoes. Figure 2 (right). Map of study areas and associated mean annual precipitation (MAP) (SIISE 2001).
Figure 3. Aerial photos of MWR study site from 1977 and 2000 showing increases in woody cover due to pine plantation establishment and woody expansion. (M1Y = burned 1 year prior to sampling; M6Y = burned 6 years prior to sampling; M25Y = burned 25 years prior to sampling; M45Y = burned 45+ years prior to sampling; MP1 = Pine 1; MP2 = Pine 2.)

Figure 4. Aboveground carbon (tons ha\(^{-1}\)) for each site in MWR divided into litter, herbaceous vegetation, shrubs, and trees. Note: SE values are provided in table 2.
Figure 5. Total soil carbon (tons C ha\(^{-1}\)) in 0-10 cm and 10-20 cm depths at MWR (P<0.0001). Differences in carbon contents were compared separately by depth. Sites with different letters are significantly different from each other (P<0.05). Note: M1Y and M20Y are the same site before and after burning.

Figure 6. Percent carbon by depth in MWR.
Figure 7. MWR TCR: Ratio of tons C in 0-20 cm over tons C in 30-60 cm (adjusted by depth of layer) (P<0.0001). Sites with different letters are significantly different (P<0.05).

Figure 8. MWR PCR: Ratio of percent C in 0-20 cm over percent C in 30-60 cm (P<0.0001). Sites with different letters are significantly different from each other (P<0.05).
Figure 9. Total soil carbon in 0-10 cm, 10-20 cm, 20-30 cm, and 30-60 cm depths in Salinas (P<0.0001 for 0-10 cm; P<0.05 for 20-30 cm; and P<0.01 for 30-60 cm). Differences in carbon contents were compared separately by depth; sites with different letters or different numbers are significantly different within the associated depth (P<0.05).

![Total soil carbon](image1)

Figure 10. Percent soil carbon in 0-10 cm, 10-20 cm, 20-30 cm, and 30-60 cm depths in Salinas (P<0.0001 for 0-10 and 10-20 cm). Differences in percent carbon were compared separately by depth and sites with different letters are significantly different within the associated depth (P<0.05).

![Percent soil carbon](image2)
Figure 11. Salinas TCR: Ratio of tons C in 0-20 cm over tons C in 30-60 cm (adjusted by depth of layer) in Salinas (P<0.0001). Sites with different letters have significantly different ratios (P<0.05).

Figure 12. Salinas PCR: Ratio of percent C in 0-20 cm over percent C in 30-60 cm in Salinas. (P<0.0001).
Appendices

Appendix 3.1: Site photos: MWR and Salinas

Mazar Wildlife Reserve

MWR Photo 1. Panorama of MWR showing páramo grasslands in the foreground and a pine plantation (MP1) on the ridge.

MWR Photo 3. Alpacas enjoying the new growth of tussocks after November 2009 burn.

MWR Photo 4. Alpaca grazing MWR post November 2009 fire.
MWR Photo 5. Site M1Y 6 months after the November 2009 burn. Bright green is *Calamagrostis intermedia* (tussock) regrowth.

MWR Photo 6. M20Y prior to prescribed burn in July 2009 followed by accidental burn in November 2009. Note that this site is the same location as M1Y.
MWR Photo 7. Prescribed burn carried out in July 2009 in M20Y; this site was again burned in a larger, accidental fire in November 2009 and was sampled as M1Y in July 2010.

MWR Photo 8. M6Y, grass páramo sampled 6 years after an accidental burn.
MWR Photo 9. M25Y grass and shrub páramo last burned 25 years ago.

MWR Photo 10. M45Y – shrubby páramo appears to be in transition to woodland.
MWR Photo 11. Pine plantation MWR (MP1).

MWR Photo 12. Pine plantation MWR (MP2).
MWR Photo 13. Cattle grazing outside MWR (MG).

MWR Photo 14. MWR soil profile. Note: 1 m of tape shown.
Salinas

Salinas Photo 1. SPr – *Polylepis racemosa* plantation sampled; note the abundant tussock understory.

Salinas Photo 2. SPp – site sampled with planted *Pinus patula*; note the abundant tussock understory cover.
Salinas photo 3. SG- Salinas grass páramo site, one of the few hillsides that has not been afforested in Salinas.

Salinas Photo 4. SPp (site planted with pine) soil pit. Depth shown up to 75 cm.
Salinas Photo 5. Soil pit SG (unplanted grass site). Tape is 1 m long.
Appendix 3.2: Pit information from study sites in the Mazar Wildlife Reserve.  

<table>
<thead>
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<th>Horizon</th>
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<th>Color</th>
<th>Texture</th>
<th>Structure</th>
<th>Moisture Consistency</th>
<th>% VWC</th>
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Appendix 3.3: Pit descriptions from the Salinas study area.

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Literature cited


Chapter 4

Biodiversity tradeoffs with carbon sequestration efforts in páramo grasslands

Abstract

Payment for ecosystem services programs, which compensate landowners for managing land in ways that protect or enhance one or more ecosystem service, constitute a growing approach to conservation around the world. Questions remain, however, as to whether these programs, particularly those focusing on carbon sequestration, can also protect biodiversity or whether such agreements result in biodiversity-ecosystem service tradeoffs. In this paper, I evaluate changes in plant diversity in Ecuadorian páramo grasslands following afforestation and burn exclusion, the two main land uses currently promoted by PES programs targeting these ecosystems. Research was undertaken in two study areas, and results differed between regions. In the first study area, in the Cañar province, long-term burn exclusion (25-45+ years) resulted in a transition from a herbaceous system to a woody-dominated system, while afforestation with Pinus patula caused a dramatic decline in native plant diversity, particularly of species most common to the grass páramo. In the second study area, shorter periods of burn exclusion (9-15 years) led to rapid growth and near domination of tussock grasses, while afforestation with Pinus radiata supported a large number of species, but represented a drastic shift in species composition. The second study area also included planted Polylepis racemosa trees, which, likely due to the young age of the trees, had little influence on plant diversity.
Results suggest that, at least in some regions, fire may be necessary to maintain a diverse grass páramo and that a mosaic of burn histories may provide the optimal strategy for promoting maximum levels of species diversity. While pine plantations can support native plant diversity, they dramatically change species composition and should not be promoted as a sustainable carbon sequestration strategy unless planted in degraded areas.

1. Introduction

By focusing on ecosystem services critical to well-being, Payment for Ecosystem Services (PES) programs have been advocated as a way to increase funding and public support for conservation while also widening the focus of traditional conservation efforts beyond protected areas (Armsworth et al. 2007, Wunder 2008, Goldman and Tallis 2009, Luck et al. 2009). Despite such aspirations, however, researchers have noted a lack of scientific understanding linking land use to targeted ecosystem services, leading to questions regarding whether well-intentioned initiatives are actually reaching stated ecological goals (Ellison 2009). At the same time, there is an important debate on the extent to which ecosystem services programs complement biodiversity conservation or whether they potentially promote contradictory land uses or compete for critical conservation funds (Bekessy and Wintle 2008, Goldman and Tallis 2009, Lindenmayer et al. 2012). The Millennium Ecosystem Assessment and a number of subsequent publications have suggested a positive relationship between biodiversity and ecosystem services provision (MEA
2005, Perrings et al. 2010, Bullock et al. 2011). In reality, however, the relationship between biodiversity and ecosystem services is complex and remains poorly understood (Bullock et al. 2011). Likewise, efforts to map ecosystem services and biodiversity at multiple scales have found variable outcomes, with both positive and negative correlations, often with discordant outcomes at different spatial scales (Chan et al. 2006, Naidoo et al. 2008, Anderson et al. 2009).

Yet, despite unclear relationships between biodiversity and ecosystem services, there remains strong potential for PES to contribute to both biodiversity conservation and ecosystem services protection where synergies do arise (Chan et al. 2006, Bekessy and Wintle 2008). In an assessment comparing conservation programs focusing on biodiversity or on ecosystem services, Goldman and Tallis (2009) conclude that ecosystem services programs not only are equally effective at protecting biodiversity, but also increase funding and widen support for conservation. However, particularly in the case of carbon sequestration, researchers have cautioned against potential “bio-perversities” where biodiversity protection (or other ecosystem services) are sacrificed at the expense of focusing solely on a single service (Kinzig et al. 2011, Lindenmayer et al. 2012: 28). In terms of ecosystem management, Bullock et al. (2011: 542) suggest moving away from treating biodiversity and ecosystem services as “a cause-effect relationship,” instead focusing on “how biodiversity and ecosystem services will respond to possible management actions and whether these responses will coincide or conflict.” In the same vein, a more robust and transparent evaluation of tradeoffs and synergies among different ecosystem services and
biodiversity associated with PES-promoted land-use change is essential to avoid adverse and unintended outcomes (Jackson et al. 2005, Bekessy and Wintle 2008, Lindenmayer et al. 2012).

1.1. PES and páramo grasslands

With elevated international interest in carbon sequestration and increasing water demand from urban, hydroelectric, and agricultural sectors, biodiverse native Andean grasslands (páramos) have become the focus of a variety of PES efforts (Albán 2011, Farley et al. 2011). The páramo is considered the richest tropical mountain flora in the world and forms part of the tropical Andean biodiversity hotspot (Myers et al. 2000, Sklenar and Ramsay 2001), supporting over 2000 species of vascular plants with a 60% endemism rate (Mena et al. 2001, León-Yanez 2011). Páramos also support a diversity of birds, small mammals, and insects, as well as the spectacled bear, mountain tapirs, and pumas (Mena et al. 2001, León-Yanez 2011). In addition to high levels of biodiversity, páramo grasslands are highly valued as the headwaters of the Andes and for the exceptionally high levels of carbon storage in their soils (Farley et al. 2004, Buytaert et al. 2006a, Buytaert et al. 2006b, Podwojewski and Poulenard 2011).

PES programs targeting páramo grasslands have primarily promoted afforestation or alteration of traditional burning and grazing practices with the goal of enhancing hydrological services or carbon sequestration, but many also claim biodiversity co-benefits (Farley et al. 2011). The first carbon sequestration projects,
run through PROFAFOR, a Dutch energy consortium’s carbon offset initiative, involved planting exotic pine (Farley 2007, Farley et al. 2011). In response to recognized adverse effects on hydrological services and soil carbon storage (Farley et al. 2004, Buytaert et al. 2007), carbon sequestration efforts have shifted towards planting native or regionally native species or on reducing burning and grazing, under the assumption of positive biodiversity and hydrological side benefits (Farley et al. 2011). Recently, the Ecuadorian government launched SocioPáramo (SP), a component of the wider SocioBosque program, which targets carbon, biodiversity, and water, as well as poverty alleviation, in páramo grasslands throughout Ecuador (de Koning et al. 2011, Farley et al. 2011). SP provides incentives to individual and community landowners to either continue with current conservation practices or to reduce grazing and eliminate burning (Farley et al. 2011). As with other PES programs around the world, however, relationships between promoted land uses and ecosystem services and biodiversity are poorly understood, despite being critical to evaluating program outcomes (Ellison 2009, Farley et al. 2011).

While biodiversity and ecosystem services in páramo grasslands are highly valued, relatively little is understood about the effects of disturbance, including fire and afforestation, on páramo plant diversity and ecosystem services (Keating 2007). Afforestation of native grasslands is expected to substantially alter habitat for native flora and fauna, with particularly strong negative effects on specialist grassland and shrubland species (Naddra and Nyberg 2001, Andres and Ojeda 2002, Buscardo et al. 2008, Bremer and Farley 2010). In a review of the outcomes of plantation
establishment on plant species richness, Bremer and Farley (2010) found an average 35% decrease in overall species richness and a 47% decrease in specialist or endemic species richness with grassland to plantation transitions. The few studies on biodiversity outcomes of páramo afforestation have focused on pine plantations with mixed results (Hofstede et al. 2002, Van Wesenbeeck et al. 2003). Hofstede (2002) found similar understory composition among pine and non-planted páramo grasslands on a regional level. However, in a more detailed study, Van Wesenbeeck et al. (2003) found that species richness and diversity declined dramatically with afforestation of a Colombian páramo, and suggested Hofstede’s (2002) failure to find significant decreases in community composition of páramo plants may have been due to the inherent heterogeneity of páramo ecosystems. There is, accordingly, critical need for further research on afforestation effects on páramo plant diversity in multiple regions. In particular, there are no known studies evaluating the biodiversity outcomes of *Polylepis racemosa*, a small statured evergreen tree native to the Peruvian Andes, despite the fact that it is currently being promoted as a sustainable species for carbon sequestration efforts (Farley et al. 2011).

In addition to afforestation, PES programs targeting páramo grasslands also promote alteration and cessation of traditional burning and grazing regimes (Farley et al. 2011). Cattle and sheep grazing, coupled with burning on 2-5 year cycles, constitutes the most common páramo land use in Ecuador (Keating 2007). Frequent burning, coupled with intensive grazing, has been associated with degradation of páramo diversity and function, leading to conservation policies focused on burn
exclusion (Hofstede 1995, Podwojewski et al. 2002). However, there has been relatively little research on the outcomes of burning on páramo species diversity and composition, particularly over long time scales (Ramsay and Oxley 1997, Keating 1998b, Suarez and Medina 2001, Keating 2007). While fire is thought to play an important role in generating or maintaining current vegetation patterns in grasslands worldwide (Bond and Parr 2010), debate continues over the extent to which fire maintains or degrades páramo plant composition and diversity (Laegaard 1992, Keating 2007). Although it is debatable whether fire is part of the “natural” disturbance regime in the Ecuadorian páramo (Ramsay and Oxley 1996, Keating 2007), there is evidence of human use of fire since the early Holocene (Keating 2007, Jantz and Behling 2012). While current conservation policies in Ecuador generally seek to exclude burning under the assumption that fire is inherently damaging, others have suggested that this ignores the historical role of fire in páramo ecology and constitutes environmental management based on the “pristine myth” (Horn 1998, Keating 2007). This second group recommends moving towards an understanding of an optimal or intermediate fire regime rather than complete burn exclusion (Horn 1998, Keating 2007).

This study evaluates plant species richness, diversity, and plant composition outcomes of the two main land uses currently promoted by PES programs targeting Ecuadorian páramo grasslands: burn exclusion and afforestation. To do so, I surveyed páramos in 15 sites within two study regions, one in Cañar province in the south of Ecuador and one in Imbabura province in the north of the country (Figure 1). Sites
included a chronosquence of burn histories ranging from burned in the last year to last burned over 45 years ago as well as sites afforested with Polylepis racemosa, Pinus radiata, and Pinus patula. I collected data at multiple spatial scales and discuss the results in terms of the extent to which current carbon-focused PES programs may have biodiversity co-benefits. While plant richness and diversity do not necessarily reflect biodiversity of other taxa, plants are the basis of the food chain, provide important ecosystem services, and are a highly valued component of páramo biodiversity (Mena et al. 2001, Goldman et al. 2008).

Specifically, this study addresses the following research questions:

1. How does burn exclusion affect plant species richness, diversity, and composition in páramo grasslands?

2. How does afforestation (with Pinus spp. or Polylepis racemosa) affect plant species richness, diversity, and composition in páramo grasslands?

2. Methods

2.1. Study area

The first study area is within Mazar Wildlife Reserve (MWR) (2°56’-2°57’ S, 78°74’ W), an 1800 ha forest and páramo reserve owned and managed by Dr. Stuart White and the NGO, Fundación Cordillera Tropical. The second study area is in the páramo owned by the community of Zuleta in the north of Ecuador (0°22’-0°23’ N,
Both sites were chosen for the availability of multiple land uses, including burn exclusion and afforestation, which are promoted by ecosystem services programs that target páramo grasslands. Study sites within each region were chosen to represent the land uses currently being promoted by PES programs targeting páramo grasslands (afforestation with *Pinus* spp. and *Polylepis racemosa* and burn exclusion). Where possible, multiple sites with the same land use were evaluated, but replication was not always possible.

Mazar Wildlife Reserve is a mixed-use reserve with 350 of 1800 ha used for alpaca grazing, with a maximum load of 160 alpacas over 350 ha (See Appendix 4.1 for site photos). Páramos in this region range from 3200-3600 m, with patches of montane forest and planted pine. Páramos outside of the reserve are used for cattle grazing and, increasingly, for agriculture, but there have been no cattle in the reserve for 25 years. Prior to 1995, the area was used for cattle grazing, and prior to 1982 was burned more frequently by the previous owner as a grazing management strategy. The closest INAMHI meterological station (Rio Mazar Rivera; M0410; 2°34’ S, 7°39’ W; 2450 m) to MWR measured MAP from 1964-2011 at 1325.9 mm; however, of note is that this station is approximately 1000 m below the MWR study area. MAP, using TRMM satellite data from 1998-2009 (Bookhagen *in review*) is 1595 mm, which is similar to 2010 precipitation (1503 mm) measured in the MWR by Fundación Cordillera Tropical (FCT), suggesting that this may be a more accurate estimate of MAP for MWR.
Native vegetation includes montane forests, grass páramo dominated by tussock grass (*Calamagrostis intermedia*) and *Puya clava-herculis*, and shrubby páramo dominated by a mix of *C. intermedia* and *Puya clava-herculis*, with shrub species including *Morella parvifolia*, *Gynoxys cuicochenis*, *Brachyotum jamesonii*, and *Valeriana hirtella*. This study area includes a range of burn histories, from páramos last burned less than a year ago to a woody páramo site last burned over 45 years ago. In the same area, there is also a total of 200 ha of 22-year old *Pinus patula* plantations, established on páramo grassland.

In order to evaluate changes in plant diversity with burn exclusion compared with sites that had been afforested with *Pinus radiata*, I identified 6 study sites in MWR, including two sites planted with *Pinus patula* and four sites in a chronosquence of time since the last burn. Sites were identified using aerial photos and the assistance of the current landowner, who has managed the area for over 30 years (S. White *pers. comm.* March 2010). All sites were similar in elevation and slope and had similar long-term land use histories, but varying recent land use histories (Table 1). Páramos in the study area have been protected from fire for 20 years, but two accidental fires occurred, one in 2004 and one in 2009. Sites included one burned less than a year ago (M1Y), a site burned in 2004 (6 years before sampling; M6Y), a site last burned 25 years ago (M25Y), and a site that has not been burned in over 45 years (M45Y). M1Y was burned twice in the year before sampling, including an experimental burn prior to the accidental burn. The two sites with the longest time since last burn (M25Y and M45Y) were both shrubby páramo, with the
M45Y site appearing to be in transition to montane forest. These sites both appear to have been grass páramo in the 1977 air photo (Figure 2), and the current landowner confirmed that the sites had been burned only once since then.

The two pine sites (MPine1 & MPine2) were planted approximately 22 years before sampling and are the first and only rotation. They were planted with the goal of understanding whether pines could help promote the expansion of native forest species. The pines are not managed for production, but several pines were harvested during the study for construction. There is little understory in either site, but there has been some colonization of native trees and shrubs in some areas. As seen in the 1977 air photo (Figure 2), these sites were grass páramo prior to planting.

The community of Zuleta, in the Imbabura province, is an indigenous community of approximately 1000 people (See Appendix 4.1 for site photos). Approximately two thirds of the community’s land is native forest and páramo. In 1995, the community, in conjunction with the neighboring Hacienda, established a community protected area (Área de Bosque y Vegetación Protectora Zuleta y Anexos) in order to protect the community and surrounding areas’ water supply (Alvaer 2011). Prior to the establishment of the protected area, there were 300-400 head of cattle in the páramo and bunch grasses were burned frequently to encourage new growth for grazing. Since the founding of the protected area, the majority of the community’s páramo has been protected from burning and all but several head of cattle removed. In place of cattle, the community launched an alpaca husbandry project, with approximately 60-70 alpacas, in collaboration with a local NGO. At the same time, in
recognition of the importance of land use in the highlands of Zuleta for their water
supply, the Municipality of Ibarra, the nearest major city, has created a compensation
for ecosystem services program which pays for a park guard to monitor the páramo
for illegal burning and grazing (Alvaer 2011, Farley et al. 2011). However, there have
been several accidental fires and one controlled burn in conjunction with the
community alpaca project.

In Zuleta, MAP is 1344 mm based on 1964-1992 measurements from the
closest INAMHI station (Zuleta; M0316; 0°12’ N, 7° 5’ W; 2901 m) located 600 m
below the study area. MAP, according to TRMM data, is lower at 855 mm
(Bookhagen in review). Native vegetation consists of grass páramo dominated
primarily by *Calamagrostis intermedia* interspersed with other herbaceous species
such as *Orthrosanthus chimboracensis*, *Halenia weddeliana*, and *Paspalum
bonplandianaum*, with intermittent shrubs, including *Hypericum laricifolium* and
*Brachyotum sp.*, as well as patches of shrubby páramo and montane forest. In addition
to protection from burning and a switch from cattle to alpaca grazing, a portion of the
community’s páramo has been afforested with *Polylepis racemosa* in a contract with
PROFAFOR (Programa FACE de Forestación), a Dutch energy consortium’s carbon
offset program in Ecuador (Farley et al. 2011). *P. racemosa* is a small statured
evergreen tree, often with a growth pattern of a large shrub. It is native to Peru, but
has been brought to Ecuador for use in reforestation/afforestation and windbreaks and
is often referred to as a native species by local communities. There are four native
Polylepis species in Ecuador, but they have not been used extensively for
afforestation or reforestation. While funds from carbon offsets paid for the *P. racemosa* trees planted in Zuleta, this species is being promoted in other PES projects based on the belief that reforestation or afforestation will also enhance hydrological services (Farley et al. 2011). The president of the community of Zuleta also indicated that planting Polylepis was a way to demonstrate land ownership (Farley 2010). Zuleta is also now a participant in the Ecuadorian government’s SocioPáramo program, which compensates community and individual landowners to eliminate burning and reduce grazing or, in some cases, to continue current conservation and sustainable management practices.

Nine sites were chosen in Zuleta that included the maximum range of burn histories found in the study area, some of which were planted with *Polylepis racemosa*, as well as one site that had been planted with pine and one that was formerly used for agriculture (Table 2). This included 5 sites that had not been burned in 9-15 years and two sites burned in the last 1-3 years. One of the recently burned sites was accidentally burned 2.5 years prior to sampling while the other was an 8 ha controlled burn for alpaca grazing conducted 6 months prior to sampling. Three of the “burn exclusion” sites and one of the recently burned sites had been planted with *Polylepis racemosa* 5-6 years prior to sampling, with trees ranging from 70-325 cm tall at the time of sampling. I also included one site with 40 year-old *Pinus radiata*, established on páramo grassland, as this was the only area that had been planted with pine in the vicinity. This area was highly disturbed with evidence of past grazing and selective harvesting. Finally, I included one site that was formerly used
for agriculture that was planted with *Polylepis racemosa* five years ago. The *P. racemosa* was larger in this site than the others, ranging from 200-400 cm tall. As with sites at MWR, these sites were chosen to shed light on biodiversity outcomes of land uses promoted by PES programs targeting páramo grasslands.

### 2.2. Vegetation sampling

Vegetation sampling was conducted between March 2010 and July 2010. I established three evenly spaced 20 m transects per site and surveyed 1 m x 1 m quadrats every 2 m along each transect, alternating above and below the transects for a total of 33 quadrats per site. I recorded all species within the 1 m² plots along with percent cover of each species. The height of tussock grasses and any woody species present in each quadrat were noted. I also established three 10 m x 20 m plots per site and recorded all species present. Frequencies and heights of woody species taller than 50 cm were recorded within the 200 m² plots. Plot sizes were chosen for their appropriateness for measuring diversity of herbaceous and woody species respectively (Mueller-Dombois and Ellenberg 1974). For additional percent cover estimates, I established three randomly placed 2 m x 2 m plots in each 10 x 20 m plot and recorded the five most abundant species in addition to percent cover.

### 2.3. Analysis

Analysis is based on species richness (SR), diversity (Shannon Diversity Index), and community composition at several scales, including 1 m² (n=33 per site),
200 m$^2$ (n=3 per site), and 600 m$^2$ (total SR; n=1 per site). Percent cover of herbaceous species was estimated by averaging the percent cover of species in the 1 m$^2$ plots and percent woody species estimated by the average of woody percent cover in 4 m$^2$ plots. I compared SR at the 1 m$^2$ scale using ANOVA followed by Tukey HSD post hoc tests (JMP version 8). I did not conduct statistical analyses on the 200 m$^2$ and 600 m$^2$ plots due to the small sample size.

I also calculated sample-based rarefaction curves (species accumulation curves) using Estimate S version 8.2.0. Rarefaction analysis generates 99 curves, which are averaged to create accumulation curves for each land cover type along with associated 95% confidence intervals. Such curves graphically display how species richness increases with area sampled, shedding light on how area (or number of samples) relates to the potential to capture all species under a particular land use/cover (Colwell 2006). Sites are considered statistically different where 95% confidence intervals do not overlap.

To estimate diversity within each site, I calculated the Shannon diversity index (H') (Shannon and Weaver 1949) with increasing sample size using the 1 m$^2$ data. The Shannon index calculates the uncertainty associated with predicting the species of an individual selected at random from a community. It ranges from 0 where there is no diversity to ~5 in the most diverse systems. Estimate S, which is also used to compute the Shannon diversity index and other diversity and similarity indices, runs 50 randomizations, adding samples at random to the pool, without
replacement, to calculate H’ with increasing samples size. The Shannon diversity
index is calculated with the following formula:

\[ H' = -\sum(P_i \log[P_i]) \], where \( P_i \) = the percent cover of each species/divided by the total plant cover.

Finally, to compare plant community composition, I used Estimate S to
calculate the number of shared species between sites, the Sorenson similarity index
(Cs), and Bray-Curtis index (Bray and Curtis 1957, Colwell 2006). Similarity indices
were computed using the total number of species encountered at the 600 m² scale.

The Sorenson similarity index uses only presence/absence data and is calculated with
the formula:

\[ Cs = \frac{2a}{b+c} \], where \( a \) is the number of shared species and \( b \) and \( c \) are the number of
species in sites \( b \) and \( c \) respectively.

The Bray-Curtis Index (also referred to as the Sorenson quantitative index)
incorporates species abundance data with the formula:
CN = 2\(jN\) / \((N_a + N_b)\), where \(N_a\) is the total number of individuals/cover in site A; \(N_b\) is the total number of individuals/cover in site B; and \(2jN\) = sum of the lower of the two abundances/cover for species found in both sites.

Sorenson and Bray-Curtis indices closer to 1 indicate a higher degree of similarity between sites while indices closer to 0 indicate greater dissimilarity.

3. Results

I found a total of 100 species in MWR and 96 species in Zuleta (Appendices 4.2 & 4.3). With the exception of the planted *Pinus* spp. and *Polylepis racemosa*, no non-native species were encountered. There were differences among sites within each region at the 1 m² \((P<.0001)\), 200 m², and 600 m² scales (Tables 3 & 4).

3.1. Mazar Wildlife Reserve

In MWR, the scale of analysis altered the order of SR among M6Y, M25Y, and M45Y, but the pine sites always had the lowest number of species. The highest total SR (600 m²) was found in M25Y (59 species) and the lowest SR in the two pine sites (30 and 22 species). In turn, mean SR at the 1 m² scale was significantly higher in M6Y (13.4 species) followed by M25Y (9.9 species), with the lowest mean SR levels found in the two pine sites (0.8 and 1.2 species) (Figure 3; Table 3). At the 200 m² scale, M25Y also had the highest mean SR (45 species), with the pine sites again having the lowest number of species (30 and 22 species). Patterns at the 200 m² scale
and total SR (600 m$^2$) are similar with the exception that M45Y slightly surpassed M6Y in number of species at the larger scale. The sample-based rarefaction curve displaying SR with increasing number of 1 m$^2$ samples (for a total of 33 m$^2$) is similar to patterns seen at the 200 m$^2$ scale, with the highest SR levels found in M25Y followed by M6Y, and lowest values in the two pine sites (Figure 4).

H’ was computed as a function of increasing sample size (Figure 5). H’ values at 33 m$^2$ were similar among sites, but highest in M45Y and lowest in M1Y. The relatively low H’ in M25Y, in contrast to high SR at this site, is likely due to the high tussock ground cover (Appendix 4.2). The near linear increase in H’ in the first pine site is indicative of the patchy distribution of isolated understory species.

Species composition changed from herbaceous- to woody-dominated from M6Y to M45Y, with M25Y supporting a large diversity of both herbaceous and woody species. M6Y was dominated by Poaceae species including tussock grass (C. intermedia; 63% cover) and Paspalum bonplandianum (13% cover), with intermittent herbaceous species as well as small shrubs, including Brachyotum jamesonii and Morella parvifolia. M25Y also supported high cover of Poaceae, including 21% C. intermedia and 13% Cortaderia nitida, but with a greater diversity and abundance of woody species including Morella parvifolia, Brachyotum jamesonii, Miconia bracteolata, Gynoxys cuicochensis and Hedyosmum cumbalense. In M45Y, woody species, including the ones found in M6Y and M25Y and others such as Myrsine andina, Olea sp., and Hesperomeles obtusifolia, dominated along with mats of Disterigma empetrifolium and only 2% C. intermedia cover. M1Y contained a
mixture of shrubs (primarily *Morella parvifolia*, *Gynoxys cuicochensis*, and *Brachyotum jamesonii*) that survived or were resprouting after fire, as well as regenerating *C. intermedia* and other grasses (Appendix 4.2).

The lowest Bray-Curtis and Sorenson indices of similarity were found between the pine sites and the páramo sites of any burn history, particularly between the pines and the two most recently burned sites (M1Y and M6Y) (Table 4). M6Y and M45Y are also very dissimilar, reflecting the fact that many of the herbaceous species found in M6Y are not found in M45Y while many of the woody species in M45Y are not in M6Y. The greater similarity of the two woody sites (M25Y and M45Y) to M1Y than to M6Y is likely due to the shrubby cover that persisted post fire in M1Y.

### 3.2. Zuleta

Different patterns of plant richness and diversity with land management were found in Zuleta. In contrast to MWR, the greatest number of species overall (600 m$^2$ scale) was found in the pine site (ZPine), with 43 species (Table 4). Relatively high levels of total SR were also found in the former agricultural site that had been planted with *P. racemosa* (ZAG-P; 34 species). The highest SR among páramo sites was found in the site burned 2.5 years ago and planted with Polylepis (ZB-P) (39 species) and lowest in two unburned sites planted with *P. racemosa* (ZUB-P-2 & ZUB-P-3; 24 species) (Table 4).
Patterns of SR were similar at finer scales with the exception that ZB-P (burned 2.5 years prior to sampling) surpassed all sites, including the pine site, in mean SR at both the 1 m² and 200 m² scales (Table 4; Figure 6). At the 1 m² scale, ZB-P had significantly more mean species per 1 m² (10.5) than all other sites, while the lowest SR values were found in three of the burn exclusion sites, including one planted with *P. racemosa* (2.6-3.3 species) (Table 4; Figure 6). At the 200 m² scale, SR was also highest in ZB-P (39 species) and lowest in two unburned sites (ZUB-3 and ZUB-P-2) (Table 4; Figure). As with MWR, I found similar trends in the sample-based rarefaction curve as those observed at the 200 m² scale (Figure 7). At all scales, ZB (the site burned 6 months ago) had similar SR values as the unburned sites, although species composition differed (Table 4 & 6; Figure 6).

Unburned sites (including sites with and without planted Polylepis) in Zuleta were highly dominated by tall tussock (*C. intermedia*) with heights ranging from 70-100 cm and complete canopy cover. At the 1 m² scale, species richness was higher in sites planted with *P. racemosa* (ZUB-1: ZUB-P-1 & ZUB-2: ZUB-P-2). This was also true at broader scales for ZUB-1 and ZUB-P-1 (Table 3; Figure 7). However, the third unburned site planted with Polylepis (ZUB-P-3), which did not have a paired unplanted site, had the lowest SR at all scales. This is possibly due to the exceptionally tall *C. intermedia* in that site (110-120 cm, compared to 80-100 cm in ZUP-P-1 and 70-100 cm in ZUB-P-2).

The domination of *Calamagrostis intermedia* (tussock grass) in the unburned páramo sites (both unplanted and planted with *P. racemosa*) resulted in low H’ for
these sites. Intermediate values were found in the recently burned sites (ZB-P and ZB) and the highest values in the pine site and former agricultural site (Figure 8).

With the exception of ZPine and ZAG-P, H’ values were substantially lower in Zuleta than MWR, again reflecting domination by *C. intermedia* (Figures 6 & 9).

While the pine and former agricultural sites supported relatively high levels of species richness, it is important to note that species composition in these sites were dominated by isolated woody forest species (including *Monnina crassifolia*, *Brachyotum ledifolium*, and *Vallea stipularis*), in the case of the pine site, and disturbance-tolerant ruderal species (such as *Taraxum serpylifolia*, *Anothoxanthum adortum*, and *Rumex acetosella*), in the case of the former agricultural site (Appendix 4.3). The pine site supported a large diversity of disparately distributed native woody species, with native species composition resembling native forest rather than grass páramo. This is evident in the dissimilarity in species composition between ZPine and páramo sites, as reflected in the Sorenson and Bray Curtis Indices (Table 6). The former agricultural site (ZAG-P) was also dissimilar to the páramo sites as well as to the pine site.

The two most similar sites were the two unburned and unplanted sites (ZUB-1 and ZUB-2), sharing 72% of species and having a Bray Curtis Index of 0.926, but all sites that were unburned for 9-12 years were also very similar to each other. Intermediate levels of similarity were found between unburned and recently burned páramo sites (Table 6).
4. Discussion

Understanding the effect that afforestation and burn exclusion have on páramo plant diversity and richness is critical to evaluating the potential risks and benefits to biodiversity associated with emerging carbon-based PES programs. Results point to the difficulty of generalizing the effects of land management across environmentally variable regions with different long-term land use histories. Yet, findings provide important insight into the biodiversity outcomes of afforestation and challenge the assumption that burn exclusion is the optimal way to protect páramo plant diversity.

4.1 Afforestation and plant diversity

Results from MWR concur with previous studies finding reduced species richness with grassland afforestation in general (Buscardo et al. 2008, Bremer and Farley 2010), and of páramos in particular (Van Wesenbeeck et al. 2003). As found elsewhere, the richness and abundance of species most typical of páramo grasslands, including *Calamagrostis intermedia*, declined the most (Van Wesenbeeck et al. 2003, Bremer and Farley 2010). The two pine sites were least similar to the grass páramo site (M6Y; sharing 24-29% of species) and most similar to the native woody site (M45Y; sharing 36-46% of species), indicative of a greater number of forest species in the patchy pine understory than of shade intolerant grassland species.

High species richness found in the Zuleta plantation contrasts with results from MWR and from past studies on afforestation of grasslands (Van Wesenbeeck et al. 2003, Buscardo et al. 2008, Bremer and Farley 2010). This site may be anomalous
for several reasons, including evidence of disturbance, with several large gaps where trees had been harvested, coupled with the plantation’s location adjacent to a native forest patch, which likely facilitated dispersal and establishment of native woody species (Bremer and Farley 2010). This interpretation is supported by previous studies of afforestation effects on biodiversity, which have found proximity to native vegetation to be a key determinant of plant species richness under plantations (Hartley 2002, Brockerhoff et al. 2008, Bremer and Farley 2010). However, MWR plantations were also established near native forest patches, so greater SR in Zuleta is likely also related to the greater number of gaps in the plantation (Hartley 2002). While there was a large number of native woody species found only in the Zuleta pine plantation, it should be noted that these were primarily single individuals or population patches, with 74% of ground cover consisting of pine litter (Appendix 4.3). These results highlight the perils of using species richness as a measure of biodiversity, as it does not take into account the distribution and overall plant community composition.

In contrast, afforestation with Polylepis in Zuleta did not have a pronounced influence on species richness. However, the Polylepis planted were not yet large enough to change light availability or ecosystem structure and so would have less influence on plant diversity and composition. While ZB-P had the highest species richness at all scales (other than pine), this appears to have little to do with the planted Polylepis, as they were less than 120 cm in height and no larger than a small shrub. Rather, in this case, the recent fire (2.5 years ago) opened up the tussock
canopy, providing opportunities for colonization by small herbaceous species (Ramsay and Oxley 1996).

However, some disturbance of the tall tussock canopy, associated with planting *P. racemosa*, may increase the richness and abundance of some herbaceous species by providing some bare ground and light availability. There was greater diversity in two of the three burn exclusion sites planted with Polylepis, likely related to gaps created in the tall tussock canopy with planting. This observation provides support for the intermediate disturbance hypothesis and concurs with previous studies in páramo grasslands finding greatest SR under páramos with intermediate levels of disturbance (Collins et al. 1995, Sklenar and Ramsay 2001, Keating 2007).

While the Polylepis planted in ZAG-P (former agricultural site) does not appear to have helped restoration of a grass páramo, it does appear to have facilitated establishment of some native species. The relatively high number of species in the former agricultural site afforested with Polylepis, dominated by native, disturbance-tolerant, ruderal species and some native woody species, is likely related to the former agricultural land use rather than to *P. racemosa* establishment. However, in this site, the *P. racemosa* were relatively large (up to 400 cm) and did appear to facilitate the establishment of native woody shrubs. This supports the idea that, when plantations are established on degraded lands, they may have positive biodiversity outcomes (Goldman et al. 2008, Bremer and Farley 2010).
4.2. **Burn exclusion and plant diversity**

The intermediate disturbance hypothesis has been found to apply in some cases in regards to fire frequency and grassland species richness, but not in others (Connell 1978, Uys et al. 2004). For example, plant diversity was shown to increase with fire frequency in Scottish highlands (Hobbs et al. 1984), but decrease with increasing fire frequency in North American Prairies (Collins et al. 1995). While the majority of research on the effects of fire in páramos suggests that burning tends to favor dominance by tussocks and other fire-tolerant growth forms at the expense of shrubby species (Laegaard 1992, Keating 1998a, Sklenar and Ramsay 2001, Suarez and Medina 2001), the ability of shrubs to survive and recover from fire is variable (Ramsay and Oxley 1996, Horn 1998, Keating 2007). While it is not clear whether some páramo species require fire to complete their life cycles, many páramo species are tolerant of burning, and some species are enhanced by some level of burning, taking advantage of openings in the tussock canopy following fire (Ramsay and Oxley 1996, Keating 2007).

While outcomes varied by region, results suggest that some level of burning increases species richness and diversity in páramo grasslands, supporting several previous studies on fire and plant diversity in páramos (Sklenar and Ramsay 2001, Keating 2007). Results from both MWR and Zuleta support the intermediate disturbance hypothesis (Connell 1978), although what is classified as “intermediate” disturbance in terms of burn history varies between sites. In MWR, M6Y and M25Y can be classified as “intermediate” burn histories in relation to other study sites that
were burned more or less frequently, while in Zuleta ZB-P, with 2.5 years since the last burn is the “intermediate” burn site. In MWR, the highest number of species was found in M6Y at the 1 m$^2$ scale and in M25Y at larger scales. Likewise, in Zuleta, the highest number of species (in páramo sites) was found in ZB-P, particularly at the 1 m$^2$ scale.

Other studies have also found that plant diversity response to fire is scale dependant, including in South African fynbos where the intermediate disturbance hypothesis held true at a 1 m$^2$ scale, but at 100-1000 m$^2$ scales the lowest species richness was found with intermediate burning (Schwilk et al. 1997). However, in the present study, if M6Y and M25Y are classified as “intermediate” disturbance levels, the intermediate disturbance hypothesis seems to hold true at multiple scales at MWR. M25Y supported a mix of páramo species and woody species more typical of native woodlands and forests, leading to high SR levels at broader scales, while M6Y, dominated by small herbaceous species, supported a larger number of species at the 1 m$^2$ scale. While less pronounced at coarser scales, ZB-P was similarly the most species rich site in Zuleta (with the exception of pine at 600 m$^2$). In contrast to MWR, where burn exclusion led to a transition to native woodlands, burn exclusion (over 9-15 years) in Zuleta led to an almost complete domination of tussock grass (C. intermedia) with heights of 70-120 cm. In another study conducted in the Zuleta region, however, páramos with over 7 years of burn exclusion, were characterized by high shrub cover and a domination of C. intermedia (PPA 2008), suggesting that this succession pattern may change over time and in space.
The dominance of a single species in Zuleta is reflected in the very low $H'$ values. These sites also contained large amounts of litter with much of the biomass consisting of dead tussock. Competitive dominance by tussock grass with burn exclusion and the necessity of fire both for native plant diversity and the health of the tussocks themselves has been noted in Australian grasslands (Morgan and Lunt 1999). Among the páramo sites, the biggest difference between the recently burned sites that had the highest species richness at all scales and the unburned sites was at the 1 m$^2$ scale. This is likely due, in part, to a decrease in some herbaceous species, rather than a complete disappearance of species in unburned areas. The relatively high species richness in the most recently burned sites in Zuleta is likely due to greater opportunity for establishment of small herbaceous species with openings in the tussock canopy after fire (Ramsay and Oxley 1996).

Results suggest a mosaic of burn histories/frequencies likely maximizes beta diversity (landscape diversity), as species composition varies between burned and unburned areas (Sklenar and Ramsay 2001). This was particularly the case in MWR, as species composition dramatically switched from one dominated by *C. intermedia* and herbaceous species (M6Y) to a mix of herbaceous and woody species (M25Y), to a system almost entirely dominated by woody species (M45Y) (Appendix 4.2). While less apparent, there were also species found only in burned or only in unburned areas in Zuleta (Appendix 4.2). Accordingly, conserving the maximum amount of species at a landscape scale will likely require that some areas be protected from burning while others be burned at least once every 10-20 years.
Different outcomes of burn exclusion in the two study regions could be due to a number of factors. First, the period of burn exclusion was much shorter in Zuleta (9-15 years vs. 25-45 years in MWR). Thus, it is possible that, with continued burn exclusion, the Zuleta sites may transition to woodier vegetation as has been documented in the MWR region (Jokisch and Lair 2002). Second, the two study regions have different long-term land use histories. Land-use history in Zuleta included an intense grazing and burning regime prior to establishing the community protected area in 1995. Although MWR also was managed for cattle during the second half of the 20th century, burning and grazing regimes were not as intense. Likewise, while Zuleta’s páramos were used for grazing as part of a large hacienda during the colonial period, MWR was largely uninhabited during this period (White and Maldonado 1991, PPA 2008). Third, the Zuleta sites are at a slightly higher elevation (3600 m vs. 3400 m) and have lower MAP, which may be less conducive to rapid woody growth. This is not supported, however, by the woody species found under the pine plantation and by the large pine trees themselves. It seems more likely that the rapid growth of the tussock grass in Zuleta simply outcompetes woody species and that the presence of more forest remnants in MWR for seed sources facilitates more rapid and prolific woody growth (Hartley 2002, Brockerhoff et al. 2008, Bremer and Farley 2010). Finally, MWR páramos are used for extensive alpaca grazing which provide intermediate levels of disturbance that may provide woody and smaller herbaceous species a chance to compete with the tussock grass (Collins et al. 1995, Marion et al. 2010)
5. Conclusions and policy recommendations

Given the tendency for carbon offset projects to focus on aboveground carbon, afforestation and burn exclusion will likely continue to be promoted where carbon is the prioritized ecosystem service. While the pine plantations in the two study areas, particularly in Zuleta, did support native woody species and some herbaceous species, these plantations drastically changed the plant composition and structure of the páramo grasslands they replaced. At the same time, pine plantations have been shown to decrease runoff globally (Farley et al. 2005) and to lower soil carbon storage in the páramo (Farley et al. 2004, Farley et al. 2012). Where PES programs aim to maintain the páramo land cover and associated ecosystem function and services, planting pine is not recommended. While pine plantations were not found to be “green deserts” in this study (Bremer and Farley 2010: 3893), the MWR pine plantations were characterized by lower plant diversity, suggesting that focusing almost exclusively on carbon sequestration through monoculture plantations may have important tradeoffs in some contexts, which need to be explicitly considered to avoid “bio-perversity” in PES programs (Lindenmayer et al. 2012: 28).

The limited effect of planting *Polylepis racemosa* on native plant diversity was likely due to the fact that the plantations are still young, so biodiversity outcomes should continue to be monitored over time. In assessing changes in carbon storage in the Zuleta sites, Farley et al. (2012) conclude that, while *P. racemosa* did not have any detectable impact on soil carbon storage, the trees also contributed very little to
aboveground carbon storage compared with the native herbaceous vegetation. Thus, while *P. racemosa* plantations in Zuleta, at this time, has no detectable influence on native plant diversity, there seems to be little ecological benefit, even in terms of carbon sequestration. However, according to the community of Zuleta, planting *P. racemosa* is a way to demonstrate land ownership and constitutes a more sustainable land use option than intensive grazing or pine plantations (Farley 2010).

However, this study does provide an example of how carbon credits can be used to benefit a degraded site. Although not a native species, *P. racemosa* is more similar to native species than pine. While debatable whether such plantations are preferable to natural regeneration, in particular due to the potential for hybridization with native Polylepis species, the *P. racemosa* planted in the former agricultural site in Zuleta seemed to facilitate native shrubby regrowth in a system otherwise dominated by low-lying, disturbance tolerant, ruderal species. The *P. racemosa* were also largest at this site, with the highest aboveground carbon stocks after the pine plantation. Soil carbon stores were lower in this site than the unplanted sites, but this is likely attributed to the former agricultural land use rather than the trees (Farley et al. 2012). Accordingly, this research suggests that afforestation of degraded areas may have some ecosystem benefits and display fewer negative ecosystem services and biodiversity tradeoffs seen in some cases of afforestation of native grasslands.

With respect to burning, Keating (2007:44) cautions against using the “pristine myth,” or the idea that páramos should be managed without human use, and characterizes it as a “false scientific basis for conservation efforts.” Results do not
support the assumption that burn exclusion is necessary or even desirable to conserve páramo plant diversity, which is a critical finding given that PES programs often operate under the assumption that burning has detrimental ecosystem services and biodiversity outcomes. In Mazar Wildlife Reserve, long-term burn exclusion has led to forest expansion in some areas. This phenomenon will likely accelerate in a context of rising treelines with global climate change (Buytaert et al. 2010). If a goal of PES programs is to conserve grass páramo in these areas, a landscape highly valued for its cultural and aesthetic value, forage, and other ecosystem services, then some level of burning is necessary to maintain a diverse grass páramo. In the case of Zuleta, removing burning after a long period of frequent burning and grazing has not led to a transition away from a grass páramo, but has reduced diversity of the grasslands, leading to an almost complete dominance of tussock grass. While the effect of longer-term burn exclusion in this area is unknown, some level of relatively infrequent burning, conducted in a mosaic fashion, will likely provide more positive outcomes for plant diversity than complete fire exclusion. Results support the idea infrequent burning of some páramo areas (e.g. once every 10-20 years) will likely have beneficial effects on landscape-level plant diversity, concurring with estimates of fire recovery times for páramos (Ramsay and Oxley 1996, Horn 1998, Keating 2007). Given that SocioPáramo is currently paying landowners to continue burn exclusion or to eliminate burning, a more accurate understanding of the long-term ecological response to burn exclusion at a wider variety of sites is imperative to
moving towards a better understanding of páramo ecology and to ensuring that PES policies are based on ecological realities rather than myths.

While páramos are burned for a number of reasons, the most common reason is the use of fire as a management tool to encourage new tussock growth for grazing animals. While this study did not examine the effects of cattle grazing on páramo plant diversity, many of the sites evaluated did include alpaca grazing. Given that one of the most important ecosystem services provided by the páramo is its value as forage for cattle, sheep, and camels, further research is needed on the interaction of burning and grazing prior to banning burning as a grazing enhancement strategy outright. While regulation of burn frequency and intensity and grazing management can be effective to protect plant diversity and other ecosystem services, this research suggests that infrequent fires (coupled with alpaca grazing) can provide a source of sustainable livelihoods that could be incorporated into PES programs.

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### Tables

Table 1. Site descriptions for MWR.

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
<th>Slope (°)</th>
<th>Land cover</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1Y</td>
<td>3449</td>
<td>21</td>
<td>Regenerating páramo; 15-25% short tussock; 10-15% shrubs (regenerating); 20-30% other herbaceous; 30-40% bare ground</td>
<td>Burned twice in year prior to sampling (one experimental and one accidental burn); alpaca grazing</td>
</tr>
<tr>
<td>M6Y</td>
<td>3428</td>
<td>20</td>
<td>Grass páramo; 70-80% tussock grass; 5-10% shrubs; 10-20% other herbaceous; 10-20% bare ground</td>
<td>Burned 6.5 years prior to sampling; occasional alpaca grazing</td>
</tr>
<tr>
<td>M25Y</td>
<td>3453</td>
<td>13.5</td>
<td>Shrubby páramo; 40-50% tussock grass; 15-20% Puya; 15-20% shrubs; 1-5% trees; 10-15% other herbaceous</td>
<td>Last burned approximately 25 years ago prior to sampling; near research cabin, but minimal disturbance</td>
</tr>
<tr>
<td>M45Y</td>
<td>3351</td>
<td>22</td>
<td>Shrubby páramo/woodland; 5-10% tussock grass; 50-60% shrubs; 20-30% trees; 10-20% other herbaceous</td>
<td>Had not been burned in at least 45 years prior to sampling</td>
</tr>
<tr>
<td>MPine1</td>
<td>3402</td>
<td>17.5</td>
<td>Pine plantation; 5-10% shrubs</td>
<td>Pine plantation</td>
</tr>
<tr>
<td>MPine2</td>
<td>3249</td>
<td>20</td>
<td>Pine plantation; 1-5% shrubs</td>
<td>Pine plantation</td>
</tr>
</tbody>
</table>
Table 2. Site descriptions for Zuleta.

<table>
<thead>
<tr>
<th>Site</th>
<th>Elevation (m)</th>
<th>Slope (°)</th>
<th>Land cover</th>
<th>Land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZB-P</td>
<td>3626</td>
<td>20</td>
<td>Grass páramo planted with <em>P. racemosa</em>; 50-60% tussock grass; 25-35% other herbaceous; 1% <em>P. racemosa</em>; 1-5% bare ground</td>
<td>Recent burn (2.5 yrs); planted <em>P. racemosa</em> (40-120 cm tall, only in transects 2 and 3)</td>
</tr>
<tr>
<td>ZB</td>
<td>3654</td>
<td>15</td>
<td>Regenerating páramo; 35-45% tussock grass; 1% shrubs; 5-10% other herbaceous; 40-50% bareground</td>
<td>Recent burn (&lt;1 yr); alpaca grazing</td>
</tr>
<tr>
<td>ZUB-1</td>
<td>3655</td>
<td>13</td>
<td>Grass páramo; 95-100% tussock grass; 1-5% other herbaceous</td>
<td>Intermediate burn (9 yrs); alpaca grazing</td>
</tr>
<tr>
<td>ZUB-P-1</td>
<td>3610</td>
<td>12</td>
<td>Grass páramo planted with <em>P. racemosa</em>; 90-95% tussock grass; 5-10% other herbaceous; 1% <em>P. racemosa</em></td>
<td>Intermediate burn (12 yrs); planted <em>P. racemosa</em> (100-250 cm tall)</td>
</tr>
<tr>
<td>ZUB-P-2</td>
<td>3643</td>
<td>11.5</td>
<td>Grass páramo planted with <em>P. racemosa</em>; 90-95% tussock grass; 5-10% other herbaceous; 1% <em>P. racemosa</em></td>
<td>Burn exclusion (15 yrs); planted <em>P. racemosa</em> (70-120 cm tall)</td>
</tr>
<tr>
<td>ZUB-2</td>
<td>3645</td>
<td>12.5</td>
<td>Grass páramo; 90-95% tussock grass; 1-5% shrub; 5-10% other herbaceous</td>
<td>Burn exclusion (15 yrs)</td>
</tr>
<tr>
<td>ZUB-P-3</td>
<td>3635</td>
<td>11</td>
<td>Grass páramo planted with <em>P. racemosa</em>; 80-90% tussock grass; 5-10% <em>P. racemosa</em>; 5-10% other herbaceous</td>
<td>Burn exclusion (15 years); planted <em>P. racemosa</em> (150-325 cm tall)</td>
</tr>
<tr>
<td>ZPine</td>
<td>3601</td>
<td>16</td>
<td>60-80 % <em>P. radiata</em>; 15-25% shrub; 5-10% other herbaceous</td>
<td>Planted pine (40 yrs old); previously used for grazing</td>
</tr>
<tr>
<td>ZAg-P</td>
<td>3518</td>
<td>12</td>
<td>Former agricultural site planted with <em>P. racemosa</em>; 5-10% tussock grass; 40-60% other herbaceous; 20-30% bareground; 5-10% <em>P. racemosa</em></td>
<td>Former agriculture site (potato cultivation 10 yrs prior); planted <em>P. racemosa</em> (200-400 cm tall); alpaca grazing</td>
</tr>
</tbody>
</table>

Table 3. Species richness at 1 m², 200 m², and 600 m² scales in Mazar Wildlife Reserve.

<table>
<thead>
<tr>
<th>Site</th>
<th>SR 1m² (n=33)</th>
<th>SR 200 m²(n=3)</th>
<th>SR 600 m²(n=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1Y</td>
<td>6.6 (.4)</td>
<td>31 (2.3)</td>
<td>34</td>
</tr>
<tr>
<td>M6Y</td>
<td>13.4 (0.5)</td>
<td>35.7 (1.2)</td>
<td>45</td>
</tr>
<tr>
<td>M25Y</td>
<td>9.9 (.6)</td>
<td>45 (1.2)</td>
<td>59</td>
</tr>
<tr>
<td>M45Y</td>
<td>6.8 (.3)</td>
<td>32.7 (2.8)</td>
<td>48</td>
</tr>
<tr>
<td>MPine1</td>
<td>0.8 (.2)</td>
<td>13.7 (1.2)</td>
<td>30</td>
</tr>
<tr>
<td>MPine2</td>
<td>1.2 (.2)</td>
<td>12.7 (3.0)</td>
<td>22</td>
</tr>
</tbody>
</table>
### Table 4. Species richness at 1 m², 200 m², and 600 m² scales in Zuleta.

<table>
<thead>
<tr>
<th>Site</th>
<th>SR 1m² (n=33)</th>
<th>SR 200 m² (n=3)</th>
<th>SR 600 m² (n=1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZB</td>
<td>5.2 (.2)</td>
<td>19.7 (1.7)</td>
<td>29</td>
</tr>
<tr>
<td>ZB-P</td>
<td>10.5 (.3)</td>
<td>29.0 (1.7)</td>
<td>39</td>
</tr>
<tr>
<td>ZUB-1</td>
<td>3.3 (.2)</td>
<td>19.7 (1.9)</td>
<td>28</td>
</tr>
<tr>
<td>ZUB-P-1</td>
<td>4.9 (.3)</td>
<td>25.7 (2.3)</td>
<td>37</td>
</tr>
<tr>
<td>ZUB-P-2</td>
<td>3.2 (.2)</td>
<td>16 (0.0)</td>
<td>25</td>
</tr>
<tr>
<td>ZUB-P-3</td>
<td>6.1 (.3)</td>
<td>18.0 (1.5)</td>
<td>24</td>
</tr>
<tr>
<td>ZUB-P-3</td>
<td>2.6 (.2)</td>
<td>15.3 (1.9)</td>
<td>24</td>
</tr>
<tr>
<td>ZPine</td>
<td>4.5 (.4)</td>
<td>26.7 (4.3)</td>
<td>43</td>
</tr>
<tr>
<td>ZAG-P</td>
<td>6.7 (.2)</td>
<td>24.3 (2.4)</td>
<td>34</td>
</tr>
</tbody>
</table>

### Table 5. Number of shared species between sites and Sorenson and Bray Curtis similarity indices for Mazar Wildlife Reserve.

<table>
<thead>
<tr>
<th>Sample A</th>
<th>Sample B</th>
<th># of Species Sample A</th>
<th># of Species Sample B</th>
<th>Shared Species</th>
<th>Sorenson</th>
<th>Bray-Curtis</th>
</tr>
</thead>
<tbody>
<tr>
<td>M6Y</td>
<td>MPine2</td>
<td>45</td>
<td>22</td>
<td>8</td>
<td>0.239</td>
<td>0.106</td>
</tr>
<tr>
<td>M6Y</td>
<td>MPine1</td>
<td>45</td>
<td>30</td>
<td>11</td>
<td>0.293</td>
<td>0.133</td>
</tr>
<tr>
<td>M1Y</td>
<td>MPine2</td>
<td>34</td>
<td>22</td>
<td>10</td>
<td>0.357</td>
<td>0.175</td>
</tr>
<tr>
<td>M1Y</td>
<td>MPine1</td>
<td>34</td>
<td>30</td>
<td>13</td>
<td>0.406</td>
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<td>M45Y</td>
<td>45</td>
<td>48</td>
<td>20</td>
<td>0.43</td>
<td>0.204</td>
</tr>
<tr>
<td>M45Y</td>
<td>MPine1</td>
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<td>30</td>
<td>14</td>
<td>0.359</td>
<td>0.211</td>
</tr>
<tr>
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<td>MPine1</td>
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<td>30</td>
<td>15</td>
<td>0.337</td>
<td>0.217</td>
</tr>
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<td>M25Y</td>
<td>MPine2</td>
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<td>15</td>
<td>0.37</td>
<td>0.242</td>
</tr>
<tr>
<td>M45Y</td>
<td>MPine2</td>
<td>48</td>
<td>22</td>
<td>16</td>
<td>0.457</td>
<td>0.269</td>
</tr>
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<td>M1Y</td>
<td>M45Y</td>
<td>34</td>
<td>48</td>
<td>20</td>
<td>0.488</td>
<td>0.355</td>
</tr>
<tr>
<td>M25Y</td>
<td>M45Y</td>
<td>59</td>
<td>48</td>
<td>33</td>
<td>0.617</td>
<td>0.514</td>
</tr>
<tr>
<td>M6Y</td>
<td>M25Y</td>
<td>45</td>
<td>59</td>
<td>35</td>
<td>0.673</td>
<td>0.521</td>
</tr>
<tr>
<td>M1Y</td>
<td>M6Y</td>
<td>34</td>
<td>45</td>
<td>28</td>
<td>0.709</td>
<td>0.557</td>
</tr>
<tr>
<td>MPine1</td>
<td>MPine2</td>
<td>30</td>
<td>22</td>
<td>12</td>
<td>0.462</td>
<td>0.564</td>
</tr>
<tr>
<td>M1Y</td>
<td>M25Y</td>
<td>34</td>
<td>59</td>
<td>30</td>
<td>0.645</td>
<td>0.632</td>
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</tbody>
</table>
Table 6. Number of shared species between sites and Sorensen and Bray Curtis similarity indices for Zuleta.

<table>
<thead>
<tr>
<th>Site A</th>
<th>Site B</th>
<th># Species Site A</th>
<th># Species Site B</th>
<th>Shared Species</th>
<th>Sorensen</th>
<th>Bray-Curtis</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZPine</td>
<td>ZUB-P-2</td>
<td>43</td>
<td>24</td>
<td>6</td>
<td>0.179</td>
<td>0.075</td>
</tr>
<tr>
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<td>ZPine</td>
<td>28</td>
<td>43</td>
<td>7</td>
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<td>0.081</td>
</tr>
<tr>
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<td>ZPine</td>
<td>37</td>
<td>43</td>
<td>10</td>
<td>0.25</td>
<td>0.109</td>
</tr>
<tr>
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<td>ZUB-2</td>
<td>43</td>
<td>25</td>
<td>10</td>
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<td>0.118</td>
</tr>
<tr>
<td>ZPine</td>
<td>ZUB-P-3</td>
<td>43</td>
<td>24</td>
<td>10</td>
<td>0.299</td>
<td>0.125</td>
</tr>
<tr>
<td>AGP</td>
<td>ZUB-1</td>
<td>34</td>
<td>28</td>
<td>11</td>
<td>0.355</td>
<td>0.147</td>
</tr>
<tr>
<td>AGP</td>
<td>ZUB-2</td>
<td>34</td>
<td>25</td>
<td>12</td>
<td>0.407</td>
<td>0.158</td>
</tr>
<tr>
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<td>43</td>
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<td>0.166</td>
</tr>
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<td>ZUB-P-1</td>
<td>34</td>
<td>37</td>
<td>14</td>
<td>0.394</td>
<td>0.167</td>
</tr>
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<td>ZB-P</td>
<td>43</td>
<td>39</td>
<td>14</td>
<td>0.341</td>
<td>0.168</td>
</tr>
<tr>
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<td>34</td>
<td>24</td>
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<td>0.175</td>
</tr>
<tr>
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<td>ZPine</td>
<td>29</td>
<td>43</td>
<td>12</td>
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</tr>
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</tr>
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<td>25</td>
<td>14</td>
<td>0.519</td>
<td>0.54</td>
</tr>
<tr>
<td>ZB</td>
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<td>29</td>
<td>28</td>
<td>16</td>
<td>0.561</td>
<td>0.554</td>
</tr>
<tr>
<td>ZB</td>
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<td>29</td>
<td>37</td>
<td>19</td>
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<td>0.554</td>
</tr>
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</tr>
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<td>ZB-P</td>
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<td>0.616</td>
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<tr>
<td>ZUB-1</td>
<td>ZB-P</td>
<td>28</td>
<td>39</td>
<td>21</td>
<td>0.627</td>
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</tr>
<tr>
<td>ZUB-P-3</td>
<td>ZB-P</td>
<td>24</td>
<td>39</td>
<td>21</td>
<td>0.667</td>
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</tr>
<tr>
<td>ZB</td>
<td>ZB-P</td>
<td>29</td>
<td>39</td>
<td>22</td>
<td>0.647</td>
<td>0.66</td>
</tr>
<tr>
<td>ZUB-P-2</td>
<td>ZB-P</td>
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<td>21</td>
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<td>ZUB-P-2</td>
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<td>ZUB-P-3</td>
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<td>24</td>
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<td>0.525</td>
<td>0.823</td>
</tr>
<tr>
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<td>ZUB-P-2</td>
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<td>0.577</td>
<td>0.824</td>
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<td>ZUB-P-2</td>
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<td>0.84</td>
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<td>24</td>
<td>13</td>
<td>0.542</td>
<td>0.851</td>
</tr>
<tr>
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<td>ZUB-P-2</td>
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<td>25</td>
<td>14</td>
<td>0.571</td>
<td>0.852</td>
</tr>
<tr>
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<td>ZUB-P-3</td>
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<td>24</td>
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<td>0.862</td>
</tr>
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<td>18</td>
<td>0.581</td>
<td>0.885</td>
</tr>
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<td>0.902</td>
</tr>
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<td>ZUB-2</td>
<td>28</td>
<td>25</td>
<td>19</td>
<td>0.717</td>
<td>0.926</td>
</tr>
</tbody>
</table>
Figures

Figure 1. Study area locations. The shaded gray areas represent the range of páramo grasslands.

Figure 2. Aerial photos of study site from 1977 and 2000 showing increases in woody cover due to pine plantation establishment and woody expansion. (M1Y = burned 1 year prior to sampling; M6Y = burned 6 years prior to sampling; M25Y = burned 25 years prior to sampling; M45Y = burned 45+ years prior to sampling; MP1 = Pine 1; MP2 = Pine 2.).
Figure 3. Species richness in 1m² (n=33 per site) and 200 m² (n=3 per site) plots. Sites with different letters are significantly different (P<0.05).

Figure 4. Sample-based species rarefaction curve for the Mazar Wildlife Reserve with increasing area. Curves with different letters have non-overlapping 95% confidence intervals.
Figure 5. Shannon Diversity Index ($H'$) for Mazar Wildlife Reserve with increasing sample size.

Figure 6. Species richness in $1\text{m}^2$ (n=33 per site) and $200\text{ m}^2$ (n=3 per site) plots. Sites with different letters are significantly different ($P<0.05$).
Figure 7. Sample-based species rarefaction curve for Zuleta with increasing area. Curves with different letters have non-overlapping 95% confidence intervals.

Figure 8. Shannon Diversity Index (H’) with increasing area for Zuleta sites.
Appendices

Appendix 4.1: Site photos (Zuleta)

Zuleta

Zuleta photo 1. Site ZB – burned 6 months prior to sampling as part of a prescribed burn for alpaca grazing

Zuleta photo 2. ZB-P – burned 2.5 years prior to sampling and planted with P. racemosa. This site is more diverse given greater openings in the tussock canopy.
Zuleta photo 3. ZUB-1 – site last burned approximately 9 years ago a thick and dominant tussock canopy.

Zuleta photo 4. ZUB-P-1 – site last burned 12 years ago planted with *P. racemosa*.
Zuleta photo 5. ZUB-2 – site last burned approximately 15 years ago with some shrub cover.

Zuleta photo 6. ZUB-P-2 – last burned approximately 15 years ago with planted *P. racemosa*. 
Zuleta photo 7. ZUB-P-3 – last burned approximately 15 years ago with planted *P. racemosa*. Polylepis were larger at this site than other sites (with the exception of AG-P) for unknown reasons.

Zuleta photo 9. ZAG – site formerly used for agriculture and planted with *P. racemosa*.

## Appendix 4.2: MWR species list.

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
<th>M1Y</th>
<th>M6Y</th>
<th>M25Y</th>
<th>M45Y</th>
<th>MPine1</th>
<th>MPine2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acanthaceae</td>
<td>Blechnum sp.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>&lt;1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Apiaceae</td>
<td>Eryngium humile</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aquifoliaceae</td>
<td>Ilex myricoides</td>
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<td>0</td>
<td>0</td>
<td>&lt;1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Araceae</td>
<td>Anthurium sp.</td>
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<td>0</td>
<td>0</td>
<td>&lt;1</td>
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</tr>
<tr>
<td>Araliaceae</td>
<td>Azorella penduliculata</td>
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<td>0</td>
<td>0</td>
<td>&lt;1</td>
<td>0</td>
<td>1</td>
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<td>Araliaceae</td>
<td>Oreopanax aveccennifolius</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>&lt;1</td>
<td>0</td>
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<td>Asteraceae</td>
<td>Baccharis buxifolia</td>
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<td>0</td>
<td>0</td>
<td>&lt;1</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Asteraceae</td>
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Literature cited


Podwojewski, P., J. Poulenard, T. Zambrana, and R. Hofstede. 2002. Overgrazing effects on vegetation cover and properties of volcanic ash soil in the paramo
of Llangahua and La Esperanza (Tungurahua, Ecuador). Soil use and management 18:45-55.


CONCLUSION

1. Findings

This dissertation jointly analyzed the socio-economic and ecological dimensions of emerging payment for ecosystem services (PES) programs targeting páramo grasslands. Findings contribute to a growing body of literature on PES and have implications for PES program development in Ecuador and elsewhere.

Chapter 2 focused on Ecuador’s SocioPáramo PES program in terms of how enrollment influences local livelihoods. This research responds to a noted lack of empirical research on the social outcomes of PES, despite heated debate regarding the extent to which PES can be a tool for poverty alleviation and rural development (Corbera et al. 2007, Wunder 2008, Brockington 2011). Whether PES can contribute to these social goals depends, in part, on whether these programs are accessible and desirable to the poor and how participation influences livelihoods (Miranda et al. 2003, Rosa et al. 2004, Grieg-Gran et al. 2005, Zbinden and Lee 2005). To evaluate SP from this perspective, I employed a conceptual framework which combined the Sustainable Livelihoods Approach (Chambers and Conway 1992) with Brown and Corbera’s (2003:S45) equity framework, focusing on “equity in outcome.”

I found important and widespread moderate but positive outcomes of PES participation on financial, natural, social, and human capital (“equity in outcome”). However, the context in which PES participation occurs is a critical determinant of outcomes. In particular, I found that positive outcomes often required pre-existing capital, suggesting that it takes capital to make capital in the context of PES programs.
such as SocioPáramo. In most cases, SocioPáramo has led to strengthened adaptive capacity through providing a more diversified income base and by enhancing non-financial capital. However, in some cases, particularly among smallholders and medium-sized landowners, participation may increase vulnerability to biophysical and economic stressors through restricting use of permanent and seasonal grazing lands.

Chapters 3 and 4 focused on improving understanding of the land-use changes most commonly promoted by PES programs in Ecuador, namely burn exclusion and afforestation (Farley et al. 2011). This was done through analysis of carbon storage and plant diversity in three field sites in Ecuador that offered the unique opportunity to evaluate burn exclusion as well as afforestation with *Pinus* spp. and *Polylepis racemosa*. While afforestation with pine is widespread in Ecuadorian páramos, long-term burn exclusion and afforestation with *Polylepis racemosa* are still relatively rare. These land uses are being promoted by PES programs with limited evidence of ecological outcomes, making this research timely and relevant.

Findings point to significant changes in carbon storage and plant diversity with afforestation and burn exclusion in the three study regions. In terms of above-ground carbon storage (evaluated in Mazar Wildlife Reserve), results were unsurprising in that pine plantations stored the most carbon in above-ground biomass and that above-ground carbon increased with time since the last burn. Differences in soil carbon storage between study regions (Salinas and Mazar Wildlife Reserve) were much greater than variations due to land-use change within regions.
There were, however, moderate, but important land-use change effects within study regions. The effects of afforestation on soil carbon storage varied by site, with small, positive increases in Salinas and small, variable outcomes in MWR. Lower total carbon surface to greater depth sample ratios (TCRs) in the grass site compared with the plantations in Salinas suggest that these differences are not due to underlying environmental variation, but generalizations are difficult given that the grass site was at a higher elevation and had a steeper slope than the plantations. Salinas plantations had a thick native understory dominated by tussock grasses (in stark contrast to MWR plantations), suggesting that maintaining a grass understory may be key for soil carbon storage.

In MWR, carbon storage in the top 0-20 cm differed between the two pine plantations, with carbon storage varying from intermediate levels to low levels compared to unplanted sites. Of note was the finding of significantly less carbon in the top 0-20 cm of a pine plantation compared with the adjacent shrubby páramo site burned over 45 years ago, suggesting greater carbon storage under native woody vegetation than under pine. MWR TCRs, in turn, suggested decreased soil carbon storage under pines compared to all páramo sites except the site unburned for 45 years, which was dominated by shrubs and trees, pointing to greater carbon storage under tussock-dominated cover. However, it is unclear whether TCRs effectively normalize for environmental variation or whether greater carbon storage in greater depth samples is a result land-use change impacts at greater depths. Results of this study, and particularly from Salinas, contrast with previous research indicating lower

Findings from analysis of plant diversity at MWR and Zuleta provide support for the intermediate disturbance hypothesis (Collins et al. 1995) in that intermediate levels of burning increased plant species richness at both sites. Response to burn exclusion varied by study region, however, with a transition to a woody dominated system in MWR and a domination of tussock grasses in Zuleta. Such differences are likely attributed to the much longer period of burn exclusion in MWR (45+ years) compared with Zuleta (9-15 years), and to a more intensive long-term land-use history in Zuleta, along with the higher elevation of the Zuleta sites.

Afforestation with pine caused a decrease in species richness at MWR, which contrasted with high levels of species richness in the pine plantation in Zuleta. This difference is attributed to greater abundance of gaps from harvested trees in the Zuleta plantation, allowing for the colonization of forest species from a nearby forest patch. Despite high levels of species richness, however, the Zuleta plantation, like the plantations at MWR, resulted in a drastic change in plant composition, with pine plantations sharing few species in common with the grass páramo. The small statured *Polylepis racemosa* trees planted in the native grass páramo in Zuleta had little effect on plant richness and diversity, likely due to the young age of the plantations. However, *Polylepis racemosa* planted on a former agricultural site appears to have
facilitated woody regrowth, suggesting that these plantations may have potential to help restore degraded land (Bremer and Farley 2010).

2. Policy implications

The socio-economic and ecological outcomes of land-use changes associated with PES programs targeting páramo grasslands are relevant to PES program development, broadly, and in páramo grasslands in particular. In-depth research on the first year and half of Ecuador’s SocioPáramo program suggests that PES is neither a “silver bullet” nor “fools gold” for poverty alleviation and rural development (Landell-Mills and Porras 2002: 5). While not a panacea for poverty alleviation and rural development, this research supports that idea that, when used as part of a wider toolbox of approaches, PES can play an important role in contributing to sustainable páramo management (Rosa et al. 2004, Muradian et al. 2010, Farley et al. 2011). For SocioPáramo, and PES in general, to attract and benefit a wider range of landowners, particularly rural smallholders and communities, the wider context of land tenure insecurity, land distribution, environmental attitudes, and the development of alternative livelihood strategies will need to be further addressed.

While results point to generally positive outcomes for financial, social, natural, and human capital with PES participation, in some cases, reduced access to permanent and seasonal grazing lands as a result of PES land-use regulations could increase vulnerability to economic and biophysical stressors. Given this livelihood tradeoff, which particularly affects smallholders and medium-sized farmers and likely
limits wider participation, it is critical that land-use regulations be based on established rather than assumed relationships between land use and ecosystem services and biodiversity (Keating 2007, Ellison 2009, Ruffo and Kareiva 2009, Kinzig et al. 2011). SocioPáramo would likely have greater success at limiting agricultural expansion if landowners were able to continue with some level of grazing and burning, as this would lead to PES incentives complementing rather than replacing current livelihoods. Camelid grazing and low levels of cattle and sheep grazing are permitted in some SocioPáramo contracts, but a prohibition on burning may limit production potential. This points to a clear need to evaluate whether burn exclusion is necessary or beneficial for páramo carbon storage, hydrology, and biodiversity.

Results from MWR and a parallel study in Zuleta (Farley et al. 2012) suggest small, but positive increases in carbon storage with burn exclusion, particularly for above-ground carbon. However, fire, at least at infrequent intervals, is unlikely to have a major effect on soil carbon storage, which constitutes a much larger carbon pool than above-ground biomass. At the same time, results of this study suggest that some level of burning, particularly when conducted in a mosaic fashion, enhances species richness and may be necessary to maintain a grass-dominated páramo, at least in some regions. Given the importance of the páramo for biodiversity, carbon, water regulation, and local livelihoods, it is critical to ensure that land management regulations are not focused on a single service or based on the “pristine myth,” which
assumes that páramo biodiversity and ecosystem services are maximized by removing all anthropogenic disturbance, including fire (Denevan 1992, Keating 2007).

With its focus on protecting native vegetation and bundling multiple ecosystem services and biodiversity, SocioPáramo represents a positive step away from PES programs that focus exclusively on carbon and promote “bioperverse” landscapes such as monoculture tree plantations (de Koning et al. 2011, Farley et al. 2011, Lindenmayer et al. 2012). While afforestation can enhance carbon stocks and support a native understory, PES programs that strive to protect native páramos are preferable, given a greater capacity for biodiversity and multiple ecosystem services co-benefits. This research shed light on outcomes of burn exclusion compared with afforestation in páramo grasslands, but there is a clear need for further research on the effects of land use and management on biodiversity and multiple ecosystem services in a greater number of sites. Future studies should also focus on comparing páramos converted to agriculture, páramos used for grazing and burning, and protected páramos to further illuminate how the type and intensity of land use influences biodiversity and ecosystem services outcomes.
Literature cited


carbon stocks and response to land-cover change. Global Biogeochemical Cycles 20.


