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Pine or Pasture? Estimated Costs and Benefits of Land Use Change in the Peruvian Andes

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In the Peruvian sierra near the city of Cajamarca, livelihood options of extensive grazing and plantation forestry often conflict with ecosystem services provided by the native jalca grasslands where these land uses are undertaken. This study estimates financial returns for local landowners for grazing livestock and plantation forestry and compares these values with estimated values for environmental services under each land use. Results of the estimated financial returns to landowners suggest that the profitability of each land use varies significantly because of local variation in grassland productivity, proximity to the village, and rates of time preference. In comparison to the financial returns to each land use, resulting values for environmental services were relatively high in magnitude, especially for the ecosystem service of water provision, suggesting that in most cases, overgrazing and pine plantations in the jalca will yield net economic losses at the national level. Regarding pine plantations in particular, the value for increased carbon sequestration was outweighed by the value of expected losses in water provision for irrigation, suggesting that a potential market based on carbon could yield net economic losses if water is not considered. The paper concludes that rural development can be best achieved in the study area by promoting conservation of the jalca, encouraging low-impact grazing practices, and targeting pine plantations only for areas of the jalca that are already degraded.

Keywords: Economic analysis; extensive grazing; forest plantations; land use change; jalca; valuation of ecosystem services; Peru.

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Introduction

The study area

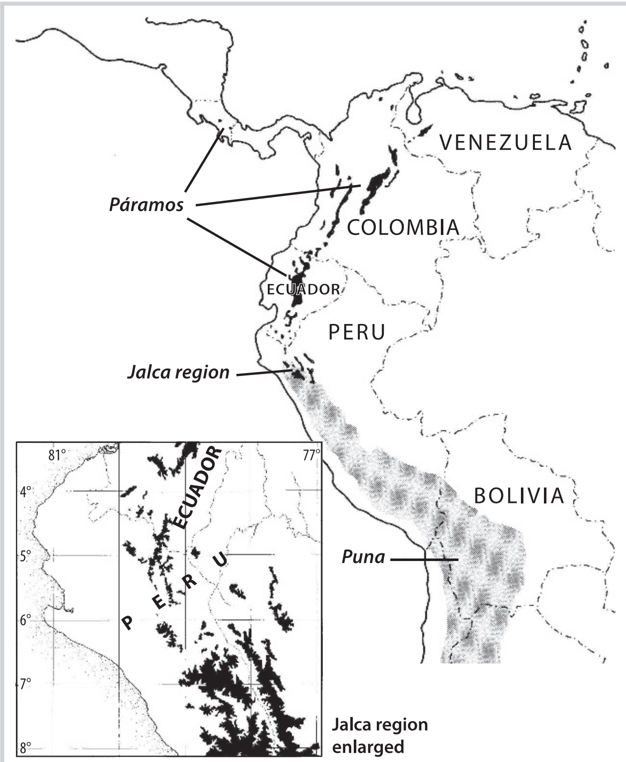
The *jalca* is an alpine grassland ecosystem renowned for its importance in regulating regional hydrology and for high levels of native plant diversity (Sanchez-Vega and Dillon 2006). This ecosystem is located primarily in northern Peru, between 4.5–8.3°S latitude and 77–80°W longitude, at altitudes between 3100 and 4200 m (Sanchez-Vega and Dillon 2006; Figure 1). The mean temperature is 8.4°C, and the average rainfall is approximately 1052 mm per year (Sanchez-Vega and Dillon 2006). The *jalca* is similar to and often classified together with the generally wetter *páramo* ecosystem to the north (Luteyn 1999), but it also shares some characteristics of the drier *puna* grasslands to the south (Sanchez-Vega and Dillon 2006). In consideration of the environmental services that these ecosystems provide, ensuring some level of conservation is increasingly being recognized as integral to local development efforts (Hofstede 2008).

Land use in the *jalca*

Around the city of Cajamarca (7°10′0″S; 78°31′0″W), where this study was conducted, much of the *jalca* has historically been utilized for the extensive grazing of sheep, and grazing in the *jalca* is an important component of local livelihoods (Garcia and Gomez 2006; Bartl et al 2009). There is concern, however, that parts of the *jalca* have been overgrazed and that new areas have become increasingly subject to overgrazing in recent years (Sanchez-Vega and Dillon 2006). Overgrazing in similar *páramo* environments in Ecuador has led to significant problems of erosion, declines in plant species diversity, and adverse effects on the ability of the ecosystem to regulate regional hydrology (Podwojewski et al 2002).

More recently, plantation forestry has also become a prevalent land use in high Andean ecosystems (Clapp 1995; Hofstede et al 2002), primarily using the introduced species *Pinus patula* and *Pinus radiata*. Peru has begun accelerating its plantation forestry efforts, announcing a plan to plant 1.8 million ha of land by 2024 with a focus on pine plantations in the Andean highlands (Ministerio de Agricultura, Instituto Nacional de Recursos Naturales 2005). Plantation forestry, according to its promoters, offers the promise of increasing economic returns to poor farmers while meeting local fuel wood and construction needs (Garcia Perez et al 2007). Plantation forestry can also be valuable for its role in carbon sequestration (Wright et al 2000), but a potentially costly tradeoff is that stream flows are typically reduced when converting

FIGURE 1 Map depicting the *jalca*, an alpine ecosystem bridging sites of *páramo* ecosystems to the north and the *puna* to the south. (Map based on Luteyn 1999, adapted by Dillon 2003; with kind permission from both sources)



grasslands to tree plantations (Farley et al 2005; Jackson et al 2005). In a catchment study in Ecuador, for example, afforestation of the *páramo* with *P. patula* reduced water catchment yields by 50% on average (Buytaert et al 2007). Soil nutrient status is also negatively impacted by afforestation (Berthrong et al 2009).

Purpose of this study

Both grazing and plantation forestry offer potentially valuable benefits to local landowners. However, the ecosystem services provided by a healthy *jalca* and the negative environmental externalities that can be part of overgrazing or plantation forestry call into question the economic viability of either production system. This paper estimates the profitability of grazing and plantation forestry for local landowners and compares these profits to estimated values of the ecosystem services associated with each land use.

We utilize farm budgets as they are typically constructed under cost-benefit analysis (CBA) (Gittinger 1982) to yield per-hectare financial returns of moderate grazing, overgrazing, or planting a pine forest in the *jalca*. We also estimate, on a per-hectare basis, what the changes in water provision and changes in carbon sequestration would be under each of these land uses, and we assign shadow prices to these changes. The relative importance of other changes in environmental services under these land use alternatives is also discussed.

The goal of this paper is to enhance the discourse on land use change in the *jalca* by putting private and public costs and benefits of grazing, plantation forestry, and conservation options into an economic framework. For organizations involved in promoting grazing activities, plantation forestry, and conservation in the *jalca*, *páramo*, or *puna*, this comparison of private incentives and environmental externalities offers a point of reference for designing environmentally sound interventions, suited to the needs of local landowners.

Similar analyses that compare private agricultural production incentives with environmental externalities related to water and carbon have informed land use decisions in other contexts (Croitoru and Daly-Hassen 2010; World Bank 2010). The basic economic framework used in this analysis could also serve as a starting point for analysis in other mountain regions of the world, where low-income farmers are managing environments that provide important environmental services.

Methods

Farm budget analysis framework

A private CBA calculates all costs and benefits of alternative investment options from a private perspective. A private CBA framework is used in this analysis to quantify the net present value (NPV) for private landowners of a change in land use from undisturbed *jalca* to either grazing or a pine plantation. Using a 28-year period, which is the length of time of a typical forest plantation rotation in Cajamarca (based on interviews with local foresters) the model equation utilized for the analysis is

$$\mathrm{NPV} = \sum_{t=0}^{27} \left[(B_L - C_L)/(1+r)^y - U\right] \qquad (1)$$

In the equation, NPV stands for NPV of the land use change from undisturbed *jalca* to either grazing or plantation forestry. B_L refers to the sum of all yearly benefits of a land use, including items such as wool sales from raising sheep or timber sales from planting pine, and C_L refers to all of the costs of the land use, such as labor utilized or the cost of inputs for any given year. The discount rate is signified by r, and t refers to the year. U refers to the opportunity cost of leaving the *jalca* undisturbed, and it is assumed that the net benefit of no intervention in the *jalca* would be zero for the farmer.

The discount rate adjusts future values to reflect their present utility. As a form of sensitivity analysis, 3 separate discount rates were applied. A low discount rate of 4%, based on the interest rate of the Central Reserve Bank of Peru, was utilized to represent landowners with a low rate of time preference who are subsequently willing to put money into savings. A high discount rate of 30%, based on typical microfinance interest rates in rural Peru, was

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TABLE 1 Figures utilized for estimating economic returns to sheep grazing (all prices expressed in US$ from year 2010).[a]

Livestock production estimates		Prices utilized (US$)	
Wet season dry matter production high estimate (kg ha^{-1})[b]	1935	Mutton price per kilogram (to producer)[c]	2.81
Wet season dry matter production low estimate (kg ha^{-1})[d]	968	Wool price per kilogram (to producer)[c]	1.74
Dry season dry matter production high estimate (kg ha^{-1})[b]	135	Annual purchased inputs per head[c]	4.14
Dry season dry matter production low estimate (kg ha^{-1})[d]	68	**Labor estimates**	
MJ ME kg DM^{-1} in wet season[b]	7.44	Labor cost per hour (US$)[e]	0.48
MJ ME kg DM^{-1} in dry season[b]	5.23	Labor utilized per hectare of pasture high estimate (h wk^{-1})[c]	6
Energy requirements per head herd average (MJ ME d^{-1})[f]	4.56	Labor utilized per hectare of pasture low estimate (h wk^{-1})[c]	4

[a]MJ ME: megajoules metabolizable energy; DM: dry matter.
[b]From Flores et al (2005).
[c]Based on farm interviews.
[d]Average estimates from Becker et al (1989) were approximately 50% of the estimates from Flores et al (2005).
[e]The cost of labor is considered to be 65% of the local wage rate, as found in Garcia and Gomez (2006).
[f]National Research Council (2007).

utilized to represent primarily smallholder landowners who have a high rate of time preference and are therefore willing to borrow money at high interest rates. Lastly, a discount rate of 10% was used as a standard measure (Belli et al 1998).

Estimating landowner incentives for livestock production

In order to assess livestock production, a combination of primary data and literature sources was utilized. An initial set of open-ended questionnaires was conducted in 9 communities in the *jalca* to determine typical land use patterns, and 30 in-depth interviews were conducted with livestock owners who graze in the *jalca* in order to assess livestock production. Though local farming systems are largely focused on dairy production (Bernet et al 2001; Garcia and Gomez 2006), interview results suggested that only 2% of forage for dairy or beef comes from natural pasture of the *jalca*. Farmers seed rye grass (*Lolium perenne*) and clover (*Trifolium* sp) and grow other forage crops to sustain their dairy systems, and they primarily utilize the relatively distant, natural *jalca* for grazing sheep. To simplify the analysis, only sheep are considered here. Under this assumption, the relatively small amount of fodder from the *jalca* that normally goes into the dairy or beef system is instead substituted into the principal land use of sheep production.

For estimating sheep production per hectare, 2 estimates for pasture productivity were utilized: (1) a high-dry matter production estimate for the *jalca* (Flores et al 2005) and (2) a low-dry matter production estimate (Becker et al 1989). Metabolizable energy per kilogram of dry matter was then estimated based on the values derived by Flores et al (2005). The energy requirements of sheep were based on the average body weight for the flock (20 kg) as derived through farmer interviews (average selling weights were approximately 40 kg). The energy requirements of a 20-kg sheep (National Research Council 2007) and the availability of forage as previously described were then utilized to determine potential stocking rates (Table 1).

Two separate grazing scenarios were then considered. In the first, a moderate grazing scenario, it was assumed that actual stocking rates are approximately 80% of potential stocking rates, as was observed in pastoral systems in the *páramo* (Molinillo and Monasterio 1997). In the second, an overgrazing scenario, it is assumed that actual stocking rates will start at twice the potential stocking rate. Similar high stocking rates have been observed in the Peruvian Andes, and under this heavy grazing pressure, pasture productivity quickly declines (Bryant et al 1989). Overgrazed pastures in similar *páramo* environments produced approximately 50% of the amount of dry matter as pastures that were not overgrazed (Podwojewski et al 2002). For this analysis it is assumed that the initially high stocking rate for the overgrazing scenario will necessarily decline in even steps over a 3-year period and that stocking rates after the 3-year decline will be at 50% of the potential stocking rate of a pasture that is not yet degraded.

Selling prices for wool and mutton, input costs, and estimates for labor utilization for grazing were based

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TABLE 2 Figures utilized for estimating economic returns to plantation forest production (all prices expressed in US$ from year 2010).

Plantation production averages		Plantation costs	
Planting density (trees ha^{-1})	1160	Establishment cost (US$ ha^{-1})	606.14
Survival rate (%)	71	Pruning cost (US$ ha^{-1}) in years 6 and 12	58.83
Actual density (trees ha^{-1})	824	Operations etc in 1st thinning (US$ ha^{-1})	225.43
Thinning rate (% in 1st thinning)	40	Operations etc in 2nd thinning (US$ ha^{-1})	676.33
Thinning rate (% in 2nd thinning)	30	Operations etc in final harvest (US$ ha^{-1})	1052.08
Final harvest % of plantation density	30	**Mushroom production**	
Tons per tree (1st thinning)	0.09	Mushroom production (kg^{-1} ha^{-1} yr^{-1})	1.15
Tons per tree (2nd thinning)	0.36	Mushroom price (US$ kg^{-1})	2.76
Tons per tree (final harvest)	0.56	Labor costs (US$ kg^{-1})	0.91
Total tons per hectare (1st thinning)	29.66	**Firewood production**	
Total tons per hectare (2nd thinning)	88.99	Firewood price (US$ kg^{-1})	0.03
Total tons per hectare (final harvest)	138.43	Labor costs for collection (US$ kg^{-1})	0.02
Price per ton of wood	24.55	Firewood production (kg ha^{-1} yr^{-1})	1236

on averages from interviews. Labor estimates varied depending largely on the distance of the pasture from the homestead, so a high estimate and a low estimate are used here to reflect a nearby *jalca* and a distant *jalca* respectively. Because the baseline scenario considered in this analysis is a relatively undisturbed *jalca*, an initial cost for acquiring sheep is also factored into the first year of sheep production. This cost is based on the market prices for sheep and the stocking rates for each scenario as previously described.

Estimating landowner incentives for plantation forestry

In order to estimate timber production, the average plantation density, survival rates, and establishment cost for local landowners across 12 plantation sites in the *jalca* around Cajamarca were utilized (Mendo Velásquez 2008). Timber prices, landowner costs for pruning, and rates for thinning and harvesting were derived from interviews with 10 local foresters. Tons per tree, tons per hectare, and operations costs for local landowners were taken from actual production documents provided by the Asociación Civil para la Investigación y Desarollo Forestal (ADEFOR) (ADEFOR 2009a, 2009b, 2009c). These documents included production from the first thinning, the second thinning, and the final harvest. The sites were chosen for the study based on recommendations by local foresters that they represent typical production rates. A higher and a lower productivity estimate are also included using data from trials under the Foresteria en Microcuencas Altoandinas del Programa Nacional de Manejo de Cuencas Hidrograficas y Conservacion de Suelos (FEMAP) project (Proyecto FEMAP 1998). In this study of 24 pine plantations, growth rates at high-quality sites were 23% above the mean, and growth rates at low-quality sites were 23% below the mean. The figures utilized for typical plantation production and costs are illustrated in Table 2, and for the higher and lower productivity estimates, it is assumed that harvest yields will be 23% higher and lower than the typical scenario and that operations costs will increase or decrease proportionally. Distance from the household is not considered under the pine plantation scenarios as it was with livestock production because plantation distance from the household is not likely to have a significant impact on costs and benefits.

Some forest owners collect and sell edible mushrooms that grow on the forest floor, and mushroom production, prices, and labor needs for mushroom collection were derived from interviews with these landowners. It is assumed that mushrooms are available beginning in year 7.

For firewood, rural market prices are used, and labor costs are based on interviews with local farming families, with one 40-kg load of firewood taking 3 hours to collect. Firewood production is based on the finding that 26% of tree biomass in local plantations is in branches from a total growth of 10.21 kg of biomass per year per tree (Mendo Velásquez 2008). Approximately half of the branch material can be available for firewood using local pruning methods, and it is assumed that it can be harvested beginning in year 6 after planting. This results in approximately 1.2 tons of air-dried firewood (13% moisture) that is available to be collected per hectare per year.

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Cost-benefit framework for environmental externalities

Environmental services such as water provision and carbon sequestration are also estimated on a per-hectare basis, but the costs and benefits are considered separately from the farm budgets. Water is given a shadow price through its value in downstream irrigation systems, and carbon is considered through a broader societal lens and global price forecasts. Below is the model equation utilized for estimating values for environmental externalities in this analysis:

$$\mathrm{NPV} = \sum_{t=0}^{27} [(B_E - C_E)/(1+r)^y] \qquad (2)$$

B_E and C_E refer to an environmental benefit or cost respectively, and a 28-year time period is used to be consistent with the private CBA. The discount rate utilized for environmental externalities was 10%, consistent as a standard measure with the financial analysis of the farm budgets (Belli et al 1998).

Estimating values for changes in water provision

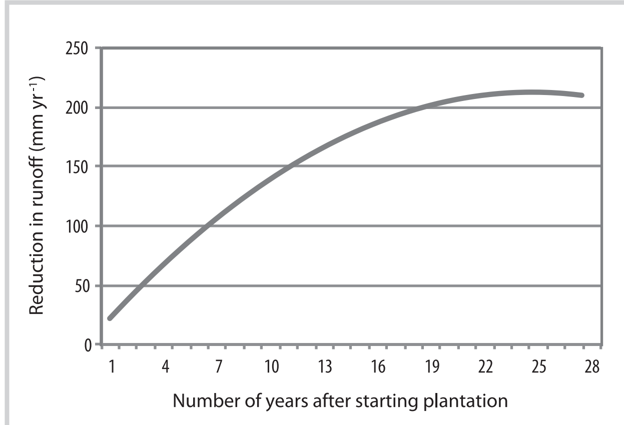
In order to quantify the likely reduction in runoff caused by pine plantations in the *jalca*, equations based on a meta-analysis of 26 catchment datasets (Farley et al 2005) were used. Based on an estimated mean annual precipitation for the Cajamarca *jalca* of 1052 mm (Sanchez-Vega and Dillon 2006), it was predicted that runoff would be reduced by an average of approximately 55% or 150 mm ha^{-1} y^{-1} over the lifespan of the plantation (Farley et al 2005). In the same study a regression equation ($y = 0 - 5.636x + 0.112x^2$, x = year) was developed to predict how the percentage of reduction in runoff was distributed over the lifespan of a plantation. Adjusting this regression of percentage change in runoff to fit the annual precipitation for the *jalca* in Cajamarca yielded the regression line in Figure 2.

This water is valued in this analysis through its potential for use by downstream water users. It is assumed that 89% of this water would be put to human use further down in the watershed based on average annual flows and average water use in the Jequetepeque watershed (Girón Echeverry 2003). Approximately 98% of this water use is for agricultural purposes (Girón Echeverry 2003). In similar irrigated agriculture systems in Ecuador, water was valued to be worth US$ 0.26 per cubic meter (Rodriguez 2003). For this analysis, this same value for water, adjusted for inflation, was applied to the reduction in runoff for each year, yielding a shadow price for changes in water quantity after planting a pine forest. Sensitivity analysis was conducted using a 50% higher and 50% lower water price, because the actual value is uncertain.

Estimating values for carbon sequestration

Figure 3 shows the basic factors considered in modeling the net impact on carbon when planting a pine forest.

FIGURE 2 Estimate for reduction in runoff for the Cajamarca *jalca* (mean annual precipitation 1052 mm) based on Farley et al (2005). (Figure by Matthew L. Raboin)



When branches are not included, as they are likely to be burned as firewood, an average of 3.54 tons of aboveground carbon accumulation per hectare per year was found in a study of pine plantations in the Cajamarca *jalca* (Mendo Velásquez 2008). Taking an average root to shoot ratio of 0.24 for tropical upland forests (Cairns et al 1997), the belowground forest carbon was then estimated at 1.15 tons per hectare per year.

For grassland carbon, the approximate averages of aboveground and belowground biomass for tropical alpine grasslands from studies presented by Hofstede and Rossenaar (1995) were utilized. The total aboveground and belowground biomass estimations used were 23.6 and 10.2 tons per ha, respectively, and it is assumed that 50% of this biomass is carbon. When converted to a forest, it is assumed that all of this biomass would decompose, yielding a loss of 16.9 tons of carbon (tC) ha^{-1}. Through overgrazing, it is assumed that half of this biomass would be lost (Podwojewski et al 2002).

Estimates for long-term changes in soil carbon are based on an average loss of 15% of soil carbon after conversion of pasture to pine plantations (Berthrong et al 2009) and the loss of 50% of soil carbon caused by overgrazing (Podwojewski et al 2002). Average soil carbon stocks in the Peruvian sierra are 11.83 kg m^{-2} (Zimmerman et al 2010), indicating there would be a decrease of 17.7 tons of soil carbon per hectare with plantation forestry and 59.2 tons per hectare with overgrazing. It was assumed that total changes in carbon stocks were evenly distributed throughout the 28-year plantation rotation.

These assumptions yielded an estimated net annual carbon accumulation of 3.46 tons per hectare per year with a pine plantation and a net loss of 2.4 tons per hectare per year with overgrazing. It should be noted that only the land use change itself is considered in the assumptions for carbon accumulation, and no consideration is given to emissions related to end uses, processing, transportation of final products, etc.

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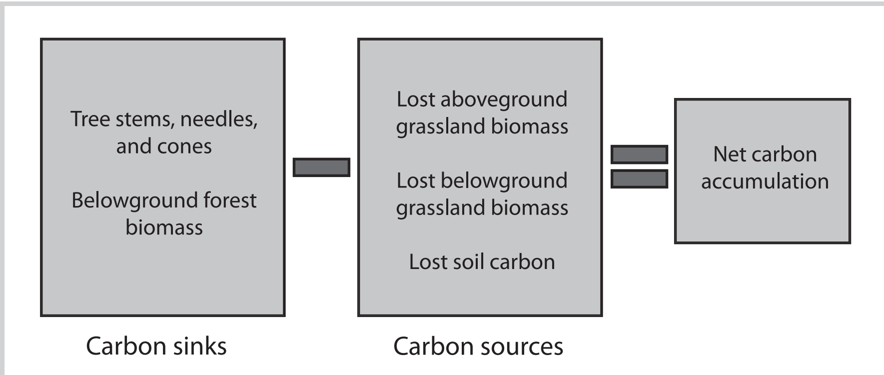
FIGURE 3 Modeling net carbon accumulation of planting a pine forest in the *jalca*. (Figure by Matthew L. Raboin)



Carbon sequestration or emissions are global impacts, and an appropriate shadow price for carbon sequestration is highly uncertain. Here, the average price of 21 models for mid- to long-range carbon price forecasts (US$ 28 tC^{-1}) as estimated by Weyant et al (2006) was utilized. To represent a range of potential values for carbon, sensitivity analysis was conducted at a 50% higher and a 50% lower price.

Additional notes on methods

All values expressed in this analysis were adjusted from their year of collection or publication to US$ from year 2010 according to the consumer price index (Bureau of Labor Statistics 2011) in order to adjust for inflation. Longer-term scenarios beyond the 28-year plantation rotation are not considered, but it should be noted that there could be residual impacts of alternative land uses, especially in the case of soil erosion as well as changes in soil structure and nutrient status. Multiplier effects have also not been taken into account in this analysis. That is, the potential for additional costs and benefits related to value-added products or jobs created through timber, wool, meat, or other industries have not been evaluated.

For additional environmental impacts of land use change (water quality impacts, changes in regulation of stream flow, noncarbon soil impacts, and biodiversity impacts) no quantitative valuation was attempted. The magnitude of these impacts is considered in the results and discussion section.

Results and discussion

Summary results

The results presented in Figure 4 suggest some general trends when all of the scenarios are considered at a standard 10% discount rate. First, on potentially productive sites, moderate grazing appears to be the most profitable endeavor for landowners. However, the profitability of moderate grazing becomes minimal on low productivity sites, and even negative if the low-productivity site is far from the homestead. Second, in the case of overgrazing, the NPV is negative in all but one scenario. Even then, the magnitude of the global value for carbon emissions caused by overgrazing was greater than the potential profits for landowners. Lastly, the profitability of plantation forestry appears modest for local landowners, and the resulting values for environmental externalities caused by plantation forestry are substantial in comparison. Reduced stream flow caused by a pine plantation was the most significant value at approximately −US$ 3000. This was considerably higher than the value of carbon sequestered by a pine plantation (approximately US$ 1000).

Financial incentives for moderate grazing, overgrazing, and plantation forestry

The expanded results presented in Table 3 illustrate the importance of the landowner rate of time preference in determining the profitability of each land use scenario. With the most substantial profits of plantation forestry coming years after the initial investment, a pine plantation is particularly sensitive to the landowner rate of time preference. For landowners with a low 4% rate of time preference, waiting a long period of time for a payoff becomes more viable, and plantation forestry therefore becomes a much more attractive option, with reasonable profits even on less productive sites. On the other extreme, landowners with a 30% rate of time preference are unlikely to invest in a pine plantation. The relative profitability of grazing was less substantially altered by the landowner rate of time preference.

The low NPVs for overgrazing across all scenarios do not explain why overgrazing is common in the study area. However, a time profile of cumulative cash flows illustrates that the net benefits for the first 3 years are highest under overgrazing (see Figure 5). This holds true across all scenarios, suggesting that farmers who overgraze likely have immediate cash needs for a

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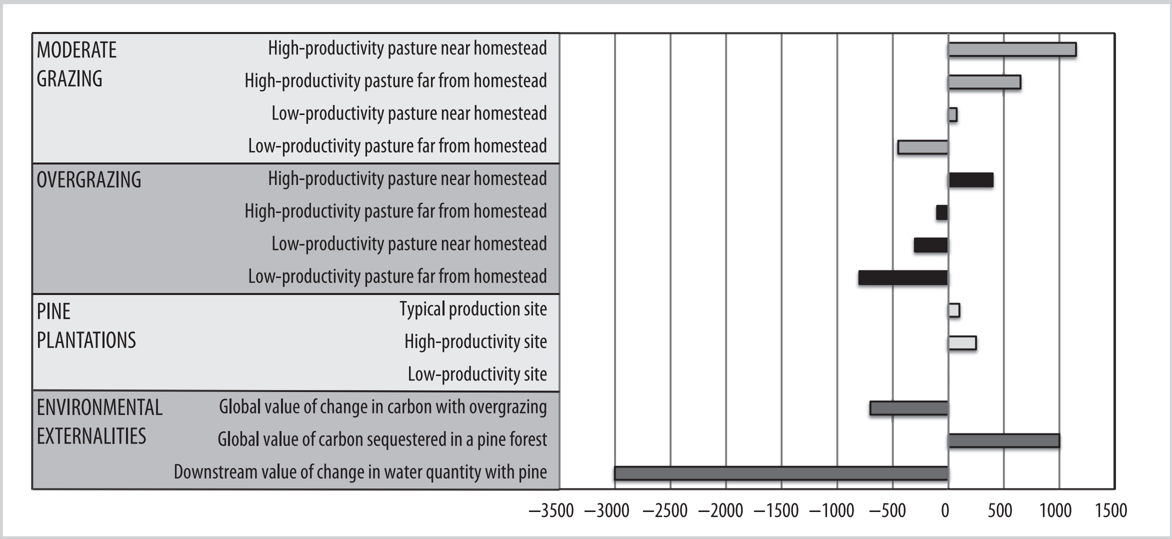
FIGURE 4 Comparison of private land use scenarios and environmental externalities (NPV in US$ for 28 year time period). (Figure by Matthew L. Raboin)



relatively short-term time horizon. Farmers could conceivably abandon their grazing activities after the first 3 years, leaving with small profits. Depending on the availability of land, they could even move on to overgraze a new area. With increasing scarcity of undisturbed areas of the *jalca*, however, moving from one area to another is becoming a less available, unsustainable option.

TABLE 3 Landowner incentives for moderate grazing, overgrazing, and plantation forestry at 3 discount rates (expressed as NPV of 28-year land use cycle in US$ per hectare).

	Landowner rate of time preference		
Moderate grazing	**4%**	**10%**	**30%**
High-productivity pasture near homestead	2100	1150	375
High-productivity pasture far from homestead	1125	650	150
Low-productivity pasture near homestead	175	75	−25
Low-productivity pasture far from homestead	−700	−450	−250
	Landowner rate of time preference		
Overgrazing	**4%**	**10%**	**30%**
High-productivity pasture near homestead	550	400	250
High-productivity pasture far from homestead	−325	−100	50
Low-productivity pasture near homestead	−575	−300	−75
Low-productivity pasture far from homestead	−1450	−800	−300
	Landowner rate of time preference		
Pine plantation	**4%**	**10%**	**30%**
Typical production site	1325	100	−500
High-productivity site	1700	250	−475
Low-productivity site	1050	0	−500

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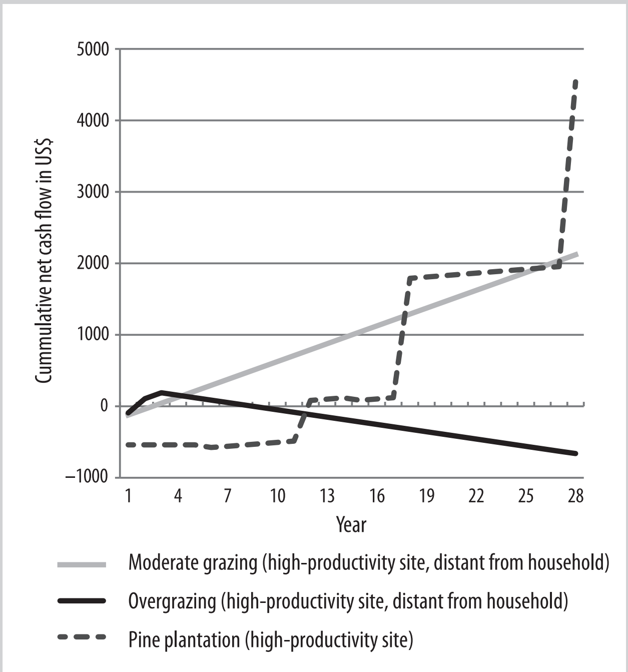
FIGURE 5 Time profile of net cash flows. (Figure by Matthew L. Raboin)



Environmental externalities associated with moderate grazing, overgrazing, and plantation forestry in the *jalca*

Sensitivity analysis, wherein alternate prices were included for carbon and water, suggests that even at lower estimated prices, the values for environmental externalities are still of a significant magnitude relative to production values. In the case of a pine plantation, water and carbon values will offset one another only if one assumes the high value for carbon and the low value for water (see Table 4).

Table 5 expands upon the expected environmental externalities by showing additional impacts of utilizing the *jalca* for moderate grazing, overgrazing, or a pine plantation. Overall, the externalities associated with moderate grazing were marginal compared with other land uses. On relatively productive pastures, net profits of moderate grazing for landowners may justify any negative environmental externalities associated with moderate grazing.

For plantation forestry, not only is the value for carbon sequestration outweighed by the high value for the reduction in stream flow, but also there are additional negative environmental externalities to be considered. Negative impacts on soil nutrients and plant diversity further suggest that pine plantations yield net environmental losses when planted in the *jalca* and that these losses are of greater value than potential profits for landowners. It should also be noted that pine plantations, when replacing grassland ecosystems, tend to reduce not only base stream flow but also low stream flow, meaning less water is available for downstream use during critical dry periods (Farley et al 2005; Keenan and van Dijk 2007). An important caveat, however, is that pine plantations can better regulate stream flow and reduce sedimentation when planted on already degraded grasslands (Keenan and van Dijk 2007).

The environmental impacts of overgrazing are clearly negative. Though changes in water quality and stream flow regulation were not given quantitative values, the high value for changes in water quantity caused by a pine plantation suggest that these additional water-related impacts caused by overgrazing would also be of a high value. The additional loss in carbon, the negative soil impacts, and the negative biodiversity impacts suggest that the small profits that landowners may make in the first years of overgrazing are heavily outweighed in value by negative regional and global environmental externalities.

Conclusions

This study suggests that there is no single answer for the best land use in the *jalca*. The profitability of each land use varies for local landowners depending on small differences in labor requirements or likely ranges in rates of time preference or pasture productivity. Heterogeneous mountain topography likely heightens this variability. At the same time, the costs of environmental externalities have a high degree of uncertainty. Land use decisions in the *jalca* therefore need to consider both the specific needs of the landowner and the environmental contexts of the plot of land in question.

TABLE 4 Price sensitivity for carbon and water (expressed as NPV of 28-year land use cycle in US$ per hectare).

Price (per ton of carbon)	US$ 14.00	US$ 28.00	US$ 42.00
Value of change in carbon with overgrazing	−350	−700	−1025
Value of carbon sequestered in a pine forest	500	1000	1500
Price (per m^3 of water)	US$ 0.16	US$ 0.31	US$ 0.47
Value of change in water quantity with a pine plantation	−1550	−3000	−4550

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TABLE 5 Summary of environmental externalities associated with moderate grazing, overgrazing, and pine plantations in the *jalca.*

Environmental externalities	Land use		
	Moderate grazing	Overgrazing	Pine plantation
Change in water quantity	Potential reduction in base flow (Buytaert et al 2006) but less severe than with overgrazing	Potential reduction in base flow (Buytaert et al 2006)	Estimated value of reduced stream flow per hectare of pine = −**US$ 3000**[a)]
Change in water quality	Potential for negative impacts (Buytaert et al 2006) but less severe than with overgrazing	Increased sedimentation (Podwojewski et al 2002)	Minimal (Keenan and van Dijk 2007)
Change in regulation of stream flow	Potential for negative impacts (Buytaert et al 2006) but less severe than with overgrazing	Decreased water infiltration in soils, reduced stream flow in dry season, increased runoff and higher risk of flooding in rainy season (Podwojewski et al 2002)	Minimal (Keenan and van Dijk 2007)
Carbon sequestration	Likely reduction in plant and soil carbon to a lesser magnitude than overgrazing	Estimated value per hectare for change in carbon in plant biomass and soil = −**US$ 700**[a)]	Estimated value per hectare of carbon sequestered in pine plantation = **US$ 1000**[a)]
Soil impacts	Potential for negative impacts (Buytaert et al 2006) but less severe than with overgrazing	Increased erosion and loss of soil carbon results in loss of soil structure and water holding capacity (Podwojewski et al 2002)	Decreased soil nitrogen, decreased pH, and decrease in cations Ca, K, and Mg (Berthrong et al 2009)
Biodiversity impact	Alteration of grassland species composition due to varied palatability of species and responses to grazing pressure (Molinillo and Monasterio 1997)	Significant decline in number of plant species, replacement of tussock grass by carpet grass vegetation (Podwojewski et al 2002)	Grassland species significantly reduced due to increased shade and pine needle litter later[b)]

[a)]Values for carbon sequestration and changes in water quantity are estimated per hectare over a 28-year time period at a 10% discount rate (expressed as NPV in US$ ha^{-1}).

[b)]Studies of biodiversity impacts of pine plantations in the Andean sierra are limited. One exception (Hofstede et al 2002) yielded variable results. However, unpublished data and general observations from the authors of this study suggest that the shade and needle litter layer produced by pine plantations greatly reduces species diversity in the plantation understory as compared with an undisturbed jalca.

At the same time, some general principals can be defined. First, in many cases, moderate grazing appears to yield the best tradeoff between private benefits and environmental impacts. Moderate grazing generally causes the least negative environmental externalities in the *jalca*, and where pastures are relatively productive, moderate grazing would also be the most profitable activity for landowners.

Second, overgrazing appears to be the worst option. Although the returns are marginally higher than moderate grazing for the farmers with immediate cash needs, a number of studies have shown that the environmental effects of overgrazing are very negative. Where overgrazing is increasingly prevalent, the incentives necessary to alter farmer behavior towards promoting more sustainable grazing would be small compared with the steep environmental costs of overgrazing. In this regard, there are significant opportunities for alignment of benefits between the alternative interests of stakeholders such as downstream water users, foreign carbon buyers, the national government, and organizations or donors with interests in conservation or general welfare.

Third, though pine plantations can be seen as advantageous from some perspectives, their promotion in relatively undisturbed areas of the *jalca* likely leads to net social losses. From the perspective of developing global carbon markets, pine plantations in the *jalca* offer carbon sequestration benefits, but from the perspective of downstream water users, pine plantations represent a steep cost in available water for irrigation. With the prices for carbon (US$ 28 tC^{-1}) and water (US$ 0.31 m^3 $water^{-1}$) used in this study, the value for stream flow benefits without the plantation is approximately 3 times greater than the value for carbon sequestration with the plantation, suggesting that for greater economic

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efficiency, pine plantations should be actively discouraged in relatively undisturbed parts of the *jalca*.

On the other hand, if pine plantations are targeted for areas that have already been overgrazed, compacted, or degraded, hydrological flows could be better regulated because of improved water infiltration into the soil under the plantation, and erosion and sedimentation could also be reduced (Keenan and van Dijk 2007). Carbon benefits could also be reaped, and some landowners would have the highest returns from plantation forestry on these lands. Targeting plantation forestry for parts of the *jalca* that are already degraded could therefore yield net benefits.

In summary, this study highlights the utility of considering productive activities and multiple environmental externalities within an economic framework. Similar approaches could be utilized in diverse mountain regions where smallholders manage valuable ecosystems. With this economic perspective as a starting point, donors, governments, nongovernmental organization partners, and other stakeholders can better design interventions that lead to mutual benefits for conservation and livelihoods.

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