2016 ERDKUNDE Vol. 70 · No. 1 · 49–67

BANNING GOATS COULD EXACERBATE DEFORESTATION OF THE ECUADORIAN DRY FOREST – HOW THE EFFECTIVENESS OF CONSERVATION PAYMENTS IS INFLUENCED BY PRODUCTIVE USE OPTIONS

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With 5 figures, 3 tables and appendix

Received 13 July 2015 · Accepted 16 December 2015

Summary: Due to ongoing conversion of the dry forests of southern Ecuador to pasture and farmland, they are among the most threatened ecosystems globally. This study explored how to control deforestation in the region while securing the livelihoods of local people through land-use diversification and compensation payments. Results are based on interview data collected from 163 households near the Laipuna Reserve in southern Ecuador. Combining modern financial theory and von Thünen's theory of land distribution, we optimized land-use shares of two types of forest management (banning and allowing goat grazing) and three crops (maize, beans and peanuts). Land-use portfolios were calculated for four different farm sizes, represented by the quartiles of the farm size distribution. We found that goat grazing was important for diversifying farm income and reducing financial risks for all farm sizes. However, forest area would still be converted to cropland under the current financial coefficients. The amount of compensation needed to maintain current forest cover was calculated for two different scenarios: 1) banning goat grazing and 2) allowing forest use where the farmer could decide how much forest area would be allocated to each land-use option. Offering financial compensation for forest preservation (Scenario 1) reduced deforestation but would still lead to a conversion of at least 23 % of current forests to croplands. Allowing forest use in a compensation scheme (Scenario 2) would help retain 96 % of the current forest cover, with 29 % of this forest being set aside for conservation. This scenario would suppose annual payments ranging from \$4 to \$89 ha^{-1}, with the largest farms requiring the lowest payments. In contrast, banning goats from the forest would even risk losing the entire forest area to cropland, if compensation fell below \$50 ha^{-1} yr^{-1}. We conclude that coupling productive options with secure compensation payments and developing policies that support land-use diversification and sustainable use of forest resources, will be most effective in conserving the Ecuadorian dry forest.

Zusammenfassung: Die Trockenwälder im Süden Ecuadors zählen zu den weltweit am stärksten bedrohten Ökosystemen. Die Hauptursache ist die zunehmende Umwandlung in Weide- und Ackerland. Ziel dieser Studie war es, einen Landnutzungsansatz zu entwickeln, der die Entwaldung reduziert, ohne die Existenzgrundlage der einheimischen Bevölkerung zu gefährden. Die Datengrundlage der Studie lieferte eine Befragung von 163 Haushalten in der Nähe des Schutzgebiets Laipuna in Südecuador. Die traditionelle Waldweide mit Ziege ist dort die flächenmäßig am weitest verbreitete Landnutzung, während Mais die profitabelste Option für Landwirte darstellt. Basierend auf einer Kombination aus moderner Finanztheorie und dem Thünenschen Modell zur Landnutzungsverteilung, wurden die optimalen Flächenanteile von Wald (mit und ohne Nutzung) und drei Ackerkulturen für das Landnutzungsportfolio eines risikoaversen Landwirtes ermittelt. Daraus wurden dann Kompensationszahlungen zur Erhaltung der bestehenden Waldflächen abgeleitet. Die Landnutzungsportfolios wurden für vier verschiedene Landbesitzgrößen (Farmtypen) berechnet. Die Beweidung mit Ziegen spielte für alle Besitzgrößen eine bedeutende Rolle für die Einkommensdiversifizierung und somit zur Reduzierung finanzieller Risiken. Die Modellergebnisse deuten, unter den gegebenen Koeffizienten, zudem einen Trend an, die Agrarflächen auszudehnen. Um die Erhaltung der derzeitigen Waldfläche sicherzustellen, wurden Kompensationszahlungen für zwei Szenarien berechnet: 1) Im Schutzszenario ist die Entschädigung an die Unterlassung der Waldnutzung gebunden und 2) der finanzielle Ausgleich wird für die Waldweide als auch für die Unterschutzstellung gezahlt, wobei der Landwirt über die flächenmäßige Allokation entscheidet. Im ersten Szenario, der Unterschutzstellung der Waldfläche, würden Kompensationszahlungen zwar die Entwaldung abmildern. Jedoch wäre eine Umwandlung von mindestens 23 % der heutigen Waldfläche in andere Landnutzungen wahrscheinlich. Wäre die Waldnutzung erlaubt (Szenario 2), könnte 96 % der Waldfläche erhalten werden. Von dieser Fläche würden sogar 30 % der als Waldweide genutzten Waldfläche freiwillig zu Gunsten des Schutzes aus der Nutzung genommen. Dieses Szenario würde Entschädigungszahlungen in Höhe von \$4 bis \$89 pro ha und Jahr erfordern, wobei die größten Farmtypen die geringste Entschädigung voraussetzen würden. Ein Verbot der Waldweide würde hingegen das Risiko der vollständigen Umwandlung von Wald in Ackerfläche mit sich bringen, falls die Kompensationszahlung unter einen geforderten Mindestsatz von \$50 ha^{-1} yr^{-1} liegen würde. Das Ergebnis zeigt, dass die Kombination aus einer sicheren Kompensationszahlungen, mit der Förderung einer diversifizierten Landnutzung und nachhaltigen Bewirtschaftung der Waldressourcen ein effektives Konzept für den Schutz der ecuadorianischen Trockenwälder darstellt.

Keywords: Land-use optimization, portfolio theory, OLUD, silvopasture, Sharpe ratio, deforestation

DOI: 10.3112/erdkunde.2016.01.04 ISSN 0014-0015 http://www.erdkunde.uni-bonn.de

1 Introduction

Humans have modified more than 50 % of the earth´s land surface with almost 13 % converted to cropland (Hooke et al. 2012). This has profound implications on the provision of ecosystem services and hence on the health and welfare of local communities (Lambin and Geist 2006; Turner et al. 2007). Much of this land-use change is a consequence of population growth – with the global population having doubled in the past 40 years – resulting in increased demand for resources (Jha and Bawa 2006; Hooke et al. 2012).

One of the most threatened ecosystems is dry forests (Miles et al. 2006; Khurana and Singh 2001; Hoekstra et al. 2005), with evidence that these types of forests have been receding at very high rates worldwide (Gasparri and Grau, 2009; Schulz et al. 2010). Approximately 49 % of all tropical dry forests have been converted to other land uses (Hoekstra et al. 2005). In South America alone, the ecosystem has lost 60 % of its original cover (Portillo-Quintero and Sánches-Azoifeifa 2010).

Dry forest degradation is driven by low biophysical and socioeconomic resilience (Sietz et al. 2011; Robinson et al. 2015). Low soil fertility, high climatic variability and population growth are responsible for the particularly fragile situation of the dry forest (Le Polain de Waroux and Lambin 2012). Frequently, dry forests are home to the poor. Due to the low resilience of agricultural systems in these regions (Sietz et al. 2011; Robinson et al. 2015) farmers are often forced to convert forest to cropland or to use the forest as an important source of food, fodder, fuelwood and materials (Schakelton et al. 2007; Le Polain de Waroux and Lambin 2012).

To counteract the effect of human activity on changing forest cover, payments for ecosystem services (PES) have been proposed as a strategy to compensate landowners for the forgone profits due to forest conservation (Engel et al. 2008). Most PES schemes have been designed for ecosystem services such as carbon sequestration or water regulation where human intervention is at a minimum (Unep, 2008; Engel et al. 2008; Pascual et al. 2010). Applying PES for forest conservation in areas where people depend on the forest for their livelihood (i.e. in agroforestry or silvopasture) is recent (Pagiola et al 2005; Huber-Stearns et al. 2013). Generally, such approaches have been implemented in mutually exclusive land uses, where the monetary value for forest conservation is often calculated as the opportunity costs of conserving forestland when considering the most profitable agricultural option (e.g., Kontoleon and Pascual 2007; Cacho et al. 2014). Following this approach, costs for PES can be very high and unfeasible, given the funds available (Pagionala et al. 2005; Knoke et al. 2011).

Few calculations consider that farmers could select multiple land uses to diversify their land-use portfolio, which might include the protection and use of forests (Benitez et al. 2006). Attention should be paid to this aspect when modelling land-use decisions, because profitability is not always the exclusive driver of a farmer's decision to pursue a particular land use. The risky nature of agricultural activity, stemming from variability in prices, crop yields and climatic conditions, is a key consideration in making land-use decisions (Baumgärtner and Quaas 2010; Pannell et al. 2014). A rational response to reduce the adverse effects of such uncertainty is diversification, which is commonly observed in small-scale agriculture (Moscardi and Janvry 1977; Rosenzweig and Binswanger 1993). More recent research has tested the impact of land-use diversification on the amount of PES required by farmers, for example, through the mean-variance rule and stochastic dominance, resulting in lower payments (Castro et al. 2013; Djanibekov and Khamzina 2014). These methods compare uncertain prospects, analyzing different levels of risk and risk aversion (Benitez et al. 2006; Castro et al. 2013; Djanibekov and Khamzina 2014). But there are also approaches that reflect farmers' behavior to balance risks and returns without needing to quantify individual risk aversion (Knoke et al. 2011; 2013). Other authors have studied the effect of uncertainty in PES, when the payments are indexed to either current landowners' opportunity cost of forest conservation or to market benefits associated with forest non-use benefits (e.g. when financing PES by carbon offset markets) (Engel et al. 2015). This effect has, however, not been studied when accounting for the effect of diversification among different agricultural options as an alternative to forest use, conservation or conversion.

The general usefulness and acceptance of direct and secure PES for protecting natural ecosystems in the Ecuadorian Andes has been empirically supported by Bremer et al. (2014). In Ecuador, the "Socio Bosque" program has been developed to promote conservation of native forest and moorlands. This program transfers a direct monetary incentive per hectare of native forest to individual landowners in exchange for conservation (De Koning et al. 2011; Raes et al. 2014). The incentives paid to landowners range from \$0.50 ha^{-1} yr^{-1} for people who own more than 10,000 hectares of forest to \$30 ha^{-1} yr^{-1} to those who hold less than 50 hectares of forest (De Koning et al. 2011). These PES have, however, not yet been implemented in the dry forest of southern Ecuador. Because rural dwellers of dry forest areas depend on the forest for their livelihood, payment in exchange for non-use of forest might not be enough to avoid deforestation.

This study addresses the pressing need to investigate alternatives for incentivizing forest conservation through compensation, while allowing for diversification of the farm portfolio and careful use of forests. This study therefore quantifies the concept proposed by Knoke et al. (2008). It is the first study in the dry forests of Ecuador to investigate potential compensations through a mechanistic economic modelling approach which considers uncertainty of compensation payments and their correlation to returns of land use. The research approach goes beyond that of Knoke (2008) and Castro et al. (2013) who compared their optimal portfolios with theoretical portfolios aiming to increase the share of environmentally friendly land uses, such as secondary forest in Chile or shade coffee in Ecuador. We use a combined positive and normative approach to describe the current activities carried out by farmers, derive potential trends and finally test the effectiveness of different policies towards dry forest conservation. The objectives of this study are to:

Determine whether a difference exists between the current forest cover and the share of forest devoted to a land-use portfolio that balances returns and risks.

If there is a difference, we aim to develop PES that are adequate to prevent farmers from clearing further areas of forest, when considering the potential uncertainty of the payments. The policies of allowing and banning forest use will be contrasted.

Studies by Knoke et al. (2009b) and Wunder (2008) have demonstrated on a conceptual level that compensation payments needed to avoid deforestation should differ with farm size and possibly farm productivity. Using an extensive land-use survey we aim to account for individual farm characteristics and explore the differences in the derived compensation payments.

The paper is guided by the hypothesis that supporting land-use diversification and careful productive use of the forest will improve the effectiveness of conservation payments for forest preservation.

2 Materials and methods

2.1 Approach to modeling land-use decisions

To examine this hypothesis we apply a normative model, which assumes that the drivers of land-use decisions can be broken down to economic considerations (Lambin and Meyfroidt 2011). A traditional economic view of land use is based on the premise that land will be assigned to the use that is perceived to have the highest economic advantage. This logic was first presented as an economic theory in 1846 in von Thünen's seminal work "The Isolated State" (Samuelson 1983). The Thünen model allocates land depending on the land rent achieved. Because land rent mainly depends on transportation costs, rent decreases as distance to the market increases. Changes in land use occur where the individual curves of declining land rent for the options considered intersect. Thünen's theory on land rent and land location is still used as a basis for economic land allocation, as for example when investigating trade-offs between agricultural intensification and conservation (Phelps et al. 2013; Angelsen 2010). Combined with mathematical programming techniques it has been used to develop optimization approaches that assign land-use options in a way to reach a certain goal (objective function), such as profit maximization (see review by Janssen and van Ittersum 2007). To include risks and the effects of diversification in land-use allocation, the Modern Portfolio Theory (MPT), developed by Markowitz (1952, 2010), has been proposed (Macmillan 1992). MPT analyzes how risk-averse investors can create portfolios of assets to maximize expected returns for a given level of risk. The framework of MPT allows different land-use options and effects of diversification to be considered simultaneously. It is therefore emerging as a useful method to compare investments in different sets of land-use options or management practices (Clasen et al. 2011; Abson et al. 2013; Castro et al. 2015) and has recently been applied to study ecosystem services (Matthies et al. 2015). For selecting a specific set of land-use options, knowledge of the individual risk aversion of the investor is required (Elton et al. 2014). This risk aversion is financially represented by the additional return (or compensation) which is needed to compensate for the additional risk of a risky portfolio of assets (Castro et al. 2015). Hence, compensation payments derived from such approaches (e.g. using utility functions) can significantly differ between different degrees of risk aversion (Benitez et al. 2006). Castro et al. (2013) and Djanibekov and Khamzina

(2014) demonstrated wide potential ranges of compensation payments, including values which might not be financially feasible for most countries. Knoke et al. (2011) therefore developed the "Optimized Land-use Diversification" approach (OLUD), which reflects the behavior of farmers to balance risks and returns without the need to quantify individual risk aversion. This has great advantages for calculating compensation payments for regional or national levels (Knoke et al. 2013) as attempted in this study. For this purpose, the OLUD follows the Tobin theorem of separation (Tobin 1958) (as part of the Capital Asset Pricing Model CAPM), which expresses that the structural composition of a risky portfolio of assets will be identical for all investors (independent of their individual risk aversion), if their expectations are homogeneous and a risk free financial asset exists. For the case of land use we can translate this theory into the assumption that farmers can sell land (i.e. a risky natural investment) to invest the money in a riskless (financial) asset or, conversely, borrow money to purchase more land (Knoke et al. 2011). Hence, the degree of risk aversion is represented by buying or selling land, while individual risk aversion determines how much the farmer invests into the riskless asset and how much into the risky land-use portfolio. However, the share of different land-use options within the risky land-use portfolio is not altered by the decision of the farmer to redistribute his funds among risky or safe assets.

The objective of balancing risks and returns in the logic of the CAPM is described by the "Reward-to-Variability Ratio" developed by Sharpe (1966; 1994) (herein referred to as Sharpe Ratio). It represents the profitability of a given portfolio based on the relationship between the expected returns exceeding those from a risk free (financial) investment, and the associated level of risk. In the OLUD, the distribution of land-use options across a given piece of land that gives the maximum Sharpe Ratio is considered to be the optimum land-use portfolio. This means that to decrease the adverse effects of uncertainties, the decision makers must choose a land-use distribution of a set of land-use options L in which the average economic land yield (Y_L), minus the yield of a riskless benchmark investment (Y_R), is at a maximum per unit of risk. Following MPT, risk is represented by S_L, which is the standard deviation (SD) of Y_L (Knoke et al. 2013) (Equation 1):

$$\text{Max } R_L = \frac{Y_L - Y_R}{S_L} \qquad \text{Eq. (1)}$$

As per Knoke et al. (2011) and Castro et al. (2013), we used a risk-free annual return Y_R of US\$50 ha^{-1} for Y_R. This value assumes that a farmer could sell or buy one hectare of land in the Laipuna Reserve area for US\$1,000 (shortened to \$ from here on) and obtain a riskless interest rate of 5 % on this amount.

Y_L is calculated as the sum of the estimated annual financial return y of each land-use option i (i ∈ L) multiplied by its respective share in the portfolio (a_i) (Equation 2, vectors are displayed in bold):

$$Y_L = \mathbf{y}^T \mathbf{a} = \sum_{i \in L} y_i a_i \qquad \text{Eq. (2)}$$

subject to

$$1^T\mathbf{a} = \sum_{i \in L} a_i = 1$$

$$a_i \geq 0$$

The financial return y_i is a function of productivity, production costs and prices of each land-use option. To account for the time value of money, financial returns of individual land-use options are represented by the sum of the discounted net cash flows, i.e. the net present value (NPV) over 20 years, which were then converted into annuities. We used this practical approach for our model to appropriately include the revenues from an initial conversion of forest to cropland, and to adequately compare land-use options, considering the differences in the distributions of net cash flows that are caused by different management schemes for crops and livestock (described in section 2.3.2). A discount rate of 5 % following Knoke et al. (2013) and Castro et al. (2015) was applied. Following MPT, portfolio risk S_L, is calculated by

$$S_L = \sqrt{\mathbf{a}^T \Sigma \mathbf{a}} = \sqrt{\sum_{i \in L} \sum_{j \in L} a_i a_j \mathrm{cov}_{i,j}} \qquad \text{Eq. (3)}$$

with

$$\mathrm{cov}_{i,i} := \mathrm{var}_i$$
$$\mathrm{cov}_{i,j} = k_{i,j} s_i s_j$$

subject to

$$1^T\mathbf{a} = 1$$
$$a_{ij} \geq 0$$

where $\sum$ is the covariance matrix in which variances var_i and covariances $\mathrm{cov}_{i,j}$ of financial returns for every possible land-use combination are considered

(Knoke et al. 2013). Covariances between two land-use options i and j are calculated by multiplying the respective standard deviation (s_i, s_j) of the respective annuities ($y_{i,j}$) with the correlation coefficient $k_{i,j}$. The values for s_i, s_j and $k_{i,j}$ were calculated based on a frequency distribution of expected annuities of each land-use option, which were derived from a Monte Carlo simulation (MCS) using 1,000 simulation runs. Yield and price fluctuations based on historical time series were included in the MCS by applying bootstrapping (sampling with replacement), as recommended by Barreto and Howland (2006) and applied by Roessiger et al. (2011). In this method a random year is drawn for each of the considered 20 years and each MCS run. Prices and yields of the respective random year are selected out of the historic time series and used to calculate the net cash flow of each year simulated.

Based on the normative qualities of the OLUD approach (Knoke et al. 2013), we attempt to show trends in agricultural production and their effects on forest conservation and offer recommendations for improving actual land use, rather than making accurate predictions for the future.

2.2 Deriving compensation payments

Given the OLUD approach, if the optimal forest share was smaller than the current forest share, compensation for forest preservation would become necessary. For calculating compensation payments we used two different scenarios: in the first scenario, the farmer was offered a compensation payment for each hectare of forest, independent of whether it was further used (in this study for silvopasture, see below) or set aside for preservation ("forest use+compensation"). The second scenario ("preservation") assumes that no forest use was allowed and therefore that the forest would not generate any revenues apart from compensation payments (CPs).

Using Sharpe's approach (1966) (Equation 1), we calculated the amount of annual compensation per hectare of forest that, when added to the annuities achieved from forest use, would result in a maximum objective function and maintain the current forest proportion. If the current forest area could not be achieved through financial compensation, the amount of compensation which would maximize the forest area was calculated.

However, depending on the perspective, PES and related CPs may also be uncertain. For example, Engel et al. (2015) considered two sources of uncertainty in PES. First, the opportunity costs for landowners that are imposed by forest preservation vary greatly over time. Second, market values associated with non-use benefits, such as those potentially resulting from carbon-offset markets, are also highly volatile. The authors therefore indexed PES either to current land opportunity costs, assuming a positive correlation between PES and land returns, or to the European carbon market, assuming no correlation between PES and land returns. To account for the fact that CPs are not completely risk-free and could vary over the 20-year time period, we assumed a coefficient of variation of 20 %. This value is rather high, but may be more realistic compared to a variability of 5 % used by Knoke et al. (2011). The correlation coefficient of CPs with other land-use options was assumed to be zero in our basic scenario, following Knoke et al. (2011). To test the effect of different assumptions concerning the variation of CP and the correlation coefficient of CPs, a sensitivity analysis was carried out and is included in the appendix. Uncertainty of CPs was added to price and yield uncertainties according to Equation 3.

2.3 Study area and selected land uses

The study site is located in southwest Ecuador in the Province of Loja (see Fig. 1) and belongs to the Tumbesian region - a biome characterized by tropical dry forests and recognized for its high level of endemism (Best and Kessler 1995; Espinosa et al. 2011). Our research addresses a core zone represented by the private reserve Laipuna (2,102 hectares) and its buffer zone (7,400 ha). This study site was selected because such buffer zones of protected areas are particularly threatened (Arturo Sánchez-Azofeifa et al. 2003), and thus, effective compensation schemes are urgently needed.

Sixteen small villages surround the reserve. We found 755 inhabitants, living in 163 households, mainly producing maize on farms and grazing goats in the forest (herein referred to as silvopasture). According to NCI (2005) the practice of raising goats is not regulated. Goats are mostly raised in an extensive wood pasture management system. To date, most inhabitants are subsistence farmers living in extreme poverty. Seventy-eight percent of the surveyed families live on less than US$3,000 per year. Because they often hold very limited amounts of land, they depend on the forest as grazing ground for their livestock (Paladines 2003).

Fig. 1: Location of the research area

Due to the diversity of farm structures and the various livestock and crops cultivated, we only selected the most common land uses for inclusion in the model. For crop cultivation these are maize, beans and peanuts. Including three different crops as alternatives to forest use in our model accounts for the commonly observed practice of crop diversification as a measure to reduce agricultural risks. Based on our interviews (described below) we found that these three crops currently account for nearly 75 % of the cultivated land within the study area, and generate approximately 70 % of the total income. Crop cultivation in the area requires fertilization every five years, thus demanding an additional investment. Maize is cultivated once a year, while beans and peanuts are usually sown and harvested twice a year.

An alternative to converting forest to cropland is to use it for goat grazing. Because the area of natural forest actually used by farmers cannot be clearly identified, and boundaries within the forest are often not clear, we used the number of goats per farmer as a proxy for actual forest use. According to our survey, a goat that is allowed to graze freely in the forest would use an area of between three to four hectares. This value is similar to that of Fao (2010), which states 3.6 hectares per animal for goat silvopastoral systems. Assuming a value of three hectares per goat, we calculated that 1,650 hectares of forest surrounding Laipuna Reserve are currently used for the silvopastoral system.

Due to the wide range of farm sizes and respective differences in farm characteristics, we also differentiated between four farm types that represent the four quartiles from the data set sorted according to farm size. They will be referred to as "small" (< 2.5 ha of farm area, excluding forest area), "small-medium" (2.5–4 ha), "medium-large" (4–5.5 ha) and "large" (5.5– 4 ha). The compensations calculated for the farm quartiles were compared to an "average farm type" represented by the mean values of coefficients. The mean value was chosen because it is the most frequently used measure for aggregating values on the landscape level and is most likely to be used for calculating PES (Knoke et al. 2009b). By comparing the results for the average farm type with the quartiles we demonstrate potential effects of not accounting for different farm sizes. Farm size distribution is presented in figure A of the appendix.

2.4 Data sources

In 2013 we surveyed each of the 163 households engaged in crop cultivation or livestock grazing in the 16 villages around Laipuna; these households managed a total cultivated area of 852 hectares. The number of households excludes 20 families living in the area, who do not currently perform any agricultural activities. We used a semi-structured questionnaire based on the "Farm Census" carried out by the Ecuadorian National Institute of Statistics and Censuses (INEC) in 2010. Survey questions of the face-to-face interviews included social information (number of family members, gender, education *etc.*), land-use activities and the associated costs and revenues. This information was then used for deriving economic coefficients for each farm type (Tab. 1). Most farmers interviewed grow crops for family consumption only, so the prices of goods were estimated based on prices in local markets.

To assess the economic return obtained from converting one hectare of forest to agriculture in the first year, we assumed that an average merchantable timber volume of 30 m^3 ha^{-1} could be obtained. This value aligns with data given by Fao (2001) and Gema (2005) for dry forests in Costa Rica and Peru. A stumpage value of US$30 m^{-3} (shortened to $ from here on) was assumed, which is the price currently paid for firewood (Mae 2011). Given the low wood volume and the lack of valuable timber species, we assume eco-

Tab. 1: Coefficients of the most common current land-use options for the average farm type and each of the four farm types. Means and standard deviations (SD) were obtained from interviews with 163 farmers at the study site. Yields are given in [t ha^{-1}] for crops and in liters of milk per goat per year for forest use. Prices are given in [\$ t^{-1}] for crops and \$ per thousand liters of goat milk for forest use. Production costs are given in [\$ ha^{-1}], referring to one crop rotation or one year of forest use, respectively.

FARM TYPE	Coefficients	Maize		Beans		Peanuts		Forest use	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Average	Yield	2.0	0.2	1.2	0.1	1.0	0.1	700	179
	Price	350	45	690	62	800	90	700	100
	Production costs	420	45	550	51	540	125	25	9
Small	Yield	2.3	0.1	1.3	0.1	1.1	14	600	91
	Price	323	34	616	11	707	32	530	49
	Production costs	407	64	508	58	524	108	17	3
Small-medium	Yield	2.2	0.1	1.2	0.1	1.1	0.1	650	164
	Price	330	33	642	23	740	83	600	144
	Production costs	420	36	530	53	520	86	20	4
Medium-large	Yield	2.0	0.1	1.2	0.1	1.0	0.1	700	160
	Price	380	40	730	67	842	48	650	90
	Production costs	424	28	530	43	579	107	25	6
Large	Yield	2.0	0.1	1.1	0.1	0.9	0.1	800	62
	Price	384	38	760	38	870	63	800	82
	Production costs	436	46	560	46	560	29	30	7

nomic returns from timber and firewood harvesting in the remaining forests to be negligible. The value of forest is therefore based on information available on the silvopastoral system. We used price and yield of milk as the obtained value for the silvopastoral system and calculated that approximately 30 % of goats produce milk (i.e. are fully grown and female). For simulating the effects of price and yield fluctuations on economic returns, we used historical data on price and yields over 30 years (1980 – 2010) (Fao 2010) (Data is given in the appendix in figure B and C).

3 Results

3.1 Economic returns and risk of the land-use alternatives

Maize was found to be the most profitable land-use option with a mean annuity of \$391 ha^{-1} yr^{-1}, followed by peanuts (\$325 ha^{-1} yr^{-1}). However, both of these land-use options involve considerable risk, reflected by the SD of annuities of \$144 ha^{-1} yr^{-1} and \$141 ha^{-1} yr^{-1} for maize and peanuts, respectively. For both land-use options the distribution of simulated annuities included negative values. The silvopastoral option provided the lowest mean annuity of \$104 ha^{-1} yr^{-1} but also showed the lowest risk with a SD of only \$26 ha^{-1} yr^{-1}. Annuities of both crop cultivation and forest use generally increased with farm size (Fig. 2). Because our research focused on the share of forest in current and optimal land-use portfolios, from here on we will only display the shares of all crops pooled together.

3.2 Economic returns and risk of optimal land-use portfolios

For the average farm the optimal portfolio of land-use options would have 45 % of the area covered by dry forest under silvopasture, 37 % beans, 9 %

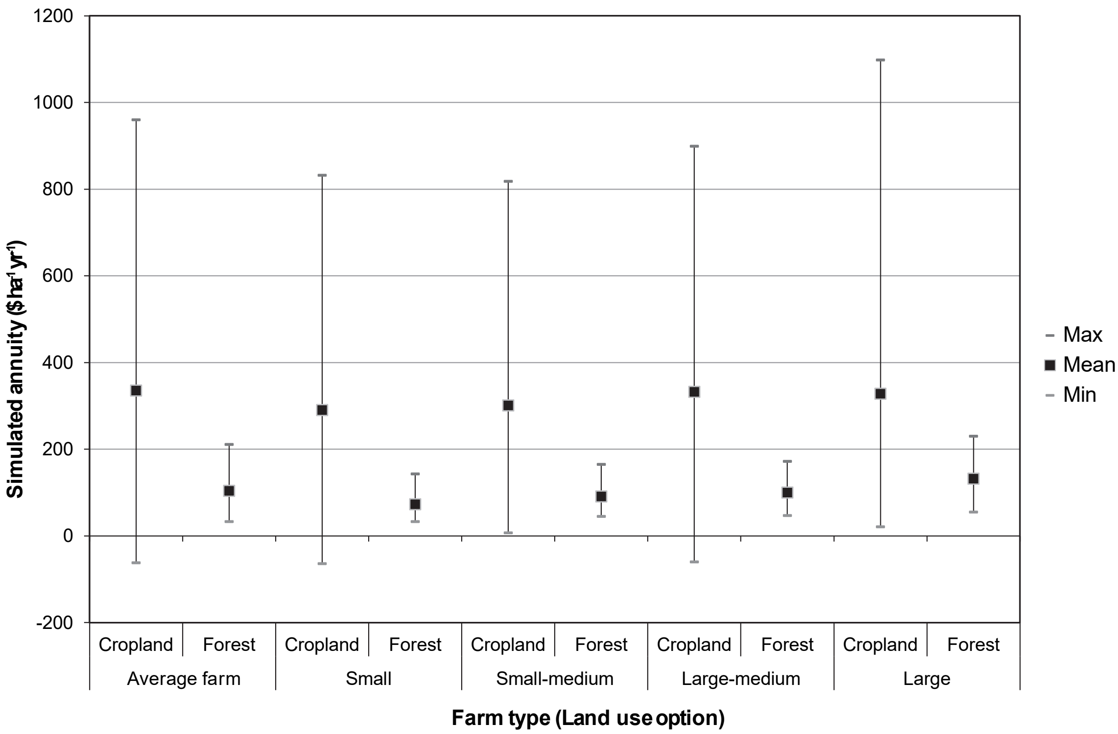

Fig. 2: Distribution of annuities of cropland cultivation (maize, beans and peanut cultivation were pooled together) and forest use for the various farm types. Distribution was derived based on historical price and productivity fluctuations adopted from FAO (2010) using MCS

maize and 9 % peanuts. Hence, silvopasture is an important component of efficient land-use portfolios, which maximize the Sharpe ratio (Equation 1). The optimum share of silvopasture within the farm portfolio was, however, smaller than the current share of forest use (Tab. 2), which would imply a conversion of 21 percentage points of forest area to cropland.

The returns of the optimal farm portfolios generally increased with farm size (Tab. 2). Given the current and optimal forest shares in these portfolios (Tab. 2), the highest relative reduction of forest area under silvopasture was found for the smallest farm type with 43 %. For the largest farm type, the current forest share is already similar to the optimal forest share. Hence, the reduction would only amount to 3 percentage points. In absolute terms, the estimated (potential) conversion of the silvopastoral system to cropland would be largest in the small-medium and medium-large farm types, because those quartiles currently cover the largest estimated forest area (under use), and the relative difference between current and optimal forest area is particularly high (Fig. 3).

Tab. 2: Comparison of current and optimal farm portfolios in terms of forest share, returns and risks

	Share of area under silvopasture (%)		Portfolio Return ($ ha^{-1} yr^{-1})		Portfolio Risk (SD) ($ ha^{-1} yr^{-1})	
Farm type	Current	Optimal	Current[1]	Optimal	Current	Optimal
Average	66	45	190	219	36	31
Small	69	39	149	188	29	29
Small-medium	80	47	142	195	24	25
Medium-large	76	54	162	209	27	28
Large	44	43	261	227	54	32

[1] Current portfolio return is based on the simplified shares of the selected crops and forest use according to our interviews

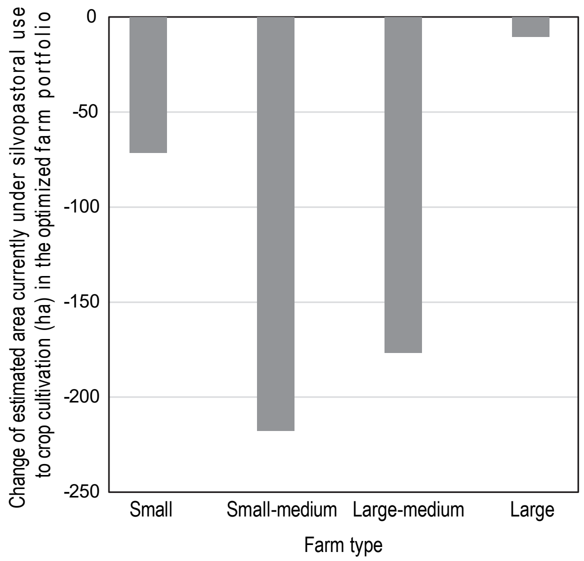

Fig. 3: Estimated difference between current and optimal area under silvopasture for the four farm types. For calculating the absolute change in forest area at the study site, the relative change in forest area estimated from the farm portfolio (Tab. 2) was applied to total land area under forest use in each type. The latter information was derived from the interviews

3.3 Compensation to avoid deforestation

In the preservation scenario, in which forest use was not allowed, we found that for the average farm type the entire forest area under silvopasture would be converted to cropland if the annual payment was less than $50 per hectare of forest (Fig. 4a). Below this value, CPs cannot compensate for the foregone revenues from not using the forest. Beyond this value, forest area quickly increases. This is due to the attractiveness of a high and relatively secure annual payment compared to the volatile returns from crop cultivation. The maximum achievable forest cover would be obtained for a compensation of \$100 ha^{-1} yr^{-1} (Tab. 3). For higher compensations, the share of forest in the land-use portfolio would even decrease again. As CPs increase, the level of uncertainty of the CP contributes significantly to the portfolio uncertainty. This means that even high, but uncertain, financial payments cannot compensate for the reduced degree of diversification under high forest shares. The maximum achievable forest share is still lower than the current forest share, implying a deforestation of 10 percentage points (for the average farm type) (Tab. 2 and 3). Hence, for this scenario, CPs alone would not succeed in retaining the current forest share in the farm portfolio.

If goat grazing was allowed under a PES scheme, then even under compensations lower than \$50 ha^{-1} yr^{-1}, 45-58 % of the current forest area would be retained in the portfolio (Fig. 4b). To maintain the complete current forest share, a compensation payment of \$57.20 ha^{-1} yr^{-1} would be required for the average farm type (Tab. 2). Under such a CP, which does not preclude forest use, a farmer who strives to balance risks and returns would decide to set aside 29 % of the forest area for conservation, in order to lower the financial risk expected from forest use.

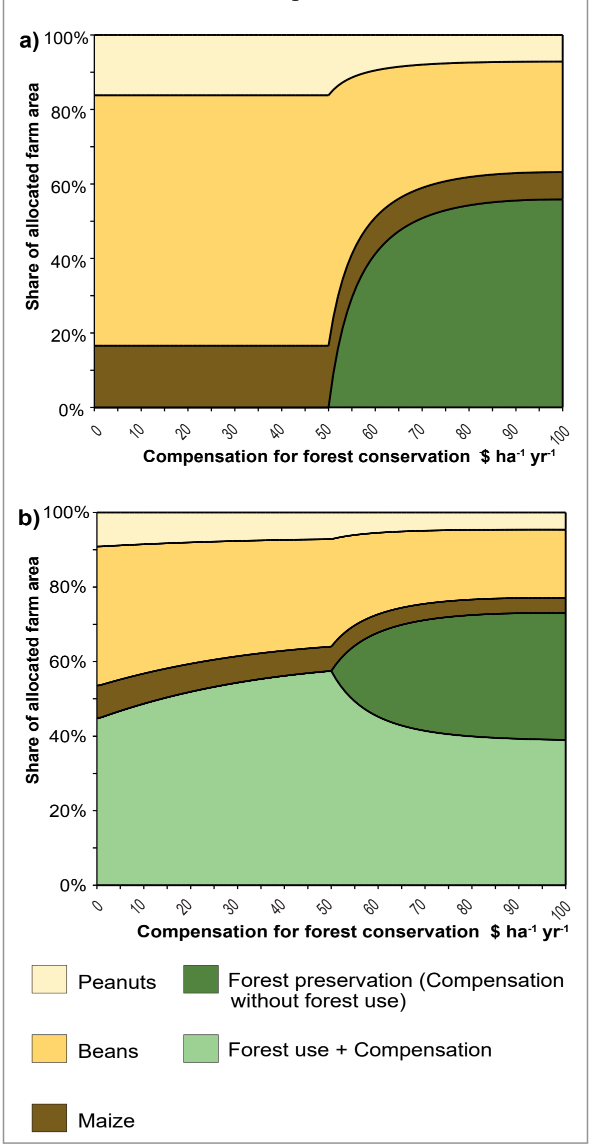

Fig. 4: Land-use portfolios for the compensation scenario in which payments are conditional to not using the forest (a) and (b) in which payments are given for both forest preservation and use. Data refers to average farm type, but a similar pattern was found for all farm types (see text and figure 5 for details). Note that for the average farm, the current forest cover is 66 %

Tab. 3: Derived compensation payments for the two scenarios. "Forest area achieved" refers to the sum of the shares of land allocated to both forest conservation and silvopasture in the land-use portfolio (see also table 2 and figure 5). Forest cover in bold corresponds to the current forest cover.

Farm type	Scenario "forest use+compensation" Forest cover achieved[1]	Scenario "forest use+compensation" Compensation ($ ha^{-1} yr^{-1})	Scenario "preservation" Forest cover achieved	Scenario "preservation" Compensation ($ ha^{-1} yr^{-1})[1]
Average	**66 %**	57.20	56 %	100.00
Small	**69 %**	57.50	55 %	100.00
Small-medium	72 %	89.10	52 %	99.90
Medium-large	74 %	88.80	56 %	99.50
Large	**44 %**	4.00	**44 %**	62.30

[1] Compensation was estimated using the value of the maximum forest cover achievable by additional payments

The only financial measure to achieve the current forest share in the preservation scenario would be to reduce the volatility of compensation payments. Our sensitivity analysis showed that the coefficient of variation of CPs had a significant effect on the amount of CP and the forest cover obtained (Appendix, Tab. A). For instance, assuming a SD of 10 % of the annual CP, the current forest share could be maintained with a CP of $56 ha^{-1} yr^{-1} for disallowing forest use.

This study also reveals that the effectiveness of financial compensation for avoiding deforestation could be overestimated if differences among farm types are disregarded. The high current forest shares of the small-medium and medium-large farm types with more than 76 % forest share would not be retained, even when CPs were offered for forest use (Fig. 5). Silvopasture dominates the land-use portfolio of these farms, and under the forest preservation scenario a less volatile CP with a coefficient of variation of less than 10 % during a 20-year period would be needed to compensate for the strong reduction in diversification through high shares of preserved forest. Through allowing forest use, 90 % and 98 % of the current forest area could be maintained in our model for the small-medium and medium-large farm type, compared to a share of only 64 % and 74 %, respectively in the preservation scenario.

For the "forest use+compensation" scenario the amount of compensation needed also differed between farm types, particularly for the largest farms (Tab. 3). Due to the small difference between the current and optimal forest share in this farm size quartile, a compensation payment of only $4 ha^{-1} yr^{-1} would be required, while up to $89 ha^{-1} yr^{-1} would be required for smaller farms (if forest use was allowed). The allocation of land to forest use and preservation under this compensation scheme differed between farm types (Fig. 5). The higher the share of the silvopastoral system in the current land-use portfolio, the greater the share of forest that would be allocated to preservation. For the very high forest shares of more than 76 % in the current land-use portfolios of small-medium and medium-large farms, it would be more favorable to set aside some of the forest area to avoid financial risks related to a high share of forest use.

Applying the optimal portfolios to the whole area of Laipuna (and considering different farm types), revealed a likely reduction of the current forest cover by 29 %. Offering compensation payments would succeed in reducing deforestation to 23 % in the preservation scenario, and 4 % when forest use was allowed. In the latter scenario, 29 % of this for-

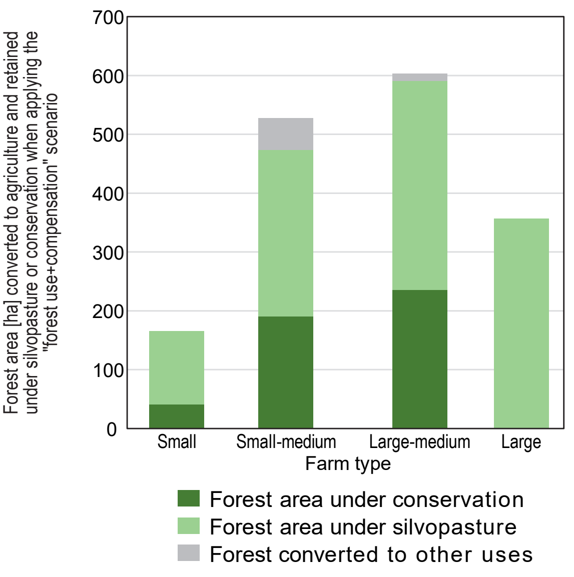

Fig. 5: Forest area that would be maintained in the area of Laipuna under the "forest use+compensation" scenario by farm type and type of forest use

est area would be set aside for conservation. Despite the higher forest area maintained in the "forest use+conservation scenario", this payment scheme would still require less financial resources with $105,584 yr^{-1} as compared to the "preservation" scenario ($113,738 yr^{-1}).

3.4 Sensitivity analysis

The CPs derived from this modelling approach depend on a range of assumptions. As outlined by Knoke et al. (2011), the value of the riskless investment strongly impacts the required CPs. Increasing land prices, and hence the increased opportunity to invest in a safe asset using the money received from selling the land, could lead to increasing CPs to maintain the forest area at a similar magnitude. For instance, assuming a riskless investment of $75 ha^{-1} yr^{-1} (corresponding to a land price of $1,500 ha^{-1}) would require a compensation of $84 and $150 ha^{-1} yr^{-1} for the average farm type in the "forest use+compensation" and "preservation" scenarios, respectively. However, in the region of Laipuna a riskless investment of more than $50 ha^{-1} yr^{-1} is unrealistic and our results might instead be rather overestimated.

The interest rate is also an important factor influencing the amount of compensation necessary to retain forest cover. With increasing interest rates the optimal share of forest area decreases. In our study, this is not so much driven by delayed returns of forest use, as this is only one year for goat grazing, but by the impact of the interest rate on the riskless investment. Hence, CPs of at least $20 ha^{-1} yr^{-1} would be required for an interest rate of 10 % to retain at least some silvopasture in the portfolio. However, when banning forest use, the value of CPs at a 10 % interest rate would have to exceed $100 ha^{-1} yr^{-1} to have forest in the portfolio (Appendix, Fig. B).

Being based on MPT, this approach requires correlations between all land-use options considered. We set the correlation between CP and other land-use options at 0. Given that the correlations between annuities of all land-use options were very low (ranging from -0.07 to -0.08) this value appears a realistic assumption. Assuming a positive correlation would lead to higher amounts of compensation, while a negative correlation would reduce the payment amount. However, even for a comparably high correlation of -0.5 and +0.5 CPs would still lie between $25 and $87 ha^{-1} yr^{-1} for the "compensation+forest use" scenario. In the compensation scenario, the current forest share would only be maintained for a correlation of -0.5 and a compensation of $28 ha^{-1} yr^{-1}. Across all other assumptions, the results are consistent with our findings, that compensation payments would not succeed in maintaining Laipuna's forests when goats are banned from the forest (Appendix, Tab. C).

4 Discussion

4.1 The importance of land-use diversification and forest use for avoiding deforestation

Diversification of land-use is particularly important in dryland ecosystems, due to highly variable rainfall and regional and global commodity price spikes (Tadesse et al. 2014), which can threaten the food security of poor farmers (Sietz et al. 2011). According to Robinson et al. (2015), intensifying agricultural production (i.e. increasing yields per unit of area) to spare natural ecosystems from further clearing is widely impeded in drylands and might even increase socio-economic vulnerability. Our study underlines this finding by showing that forest use is an important component for land-use diversification to increase stability of farm income. This is in line with the findings of Knoke et al. (2009a, 2011), who used a more conceptual approach.

However, in our model, risk-averse farmers would still strive to expand their current agricultural area, with the cost of shrinking forest cover. If livestock grazing was banned from the forest without compensating for the foregone revenues, pressure on these forests would strongly increase. Farmers who refrain from forest clearing and instead practice diversified land-use systems, including restoration options (Knoke et al. 2014) and/or careful forest use, provide positive externalities for society, for which they should be compensated (Baumgärtner and Quaas 2010; Kremen and Miles 2012; Paul and Knoke 2015).

Our study shows that for both options of allowing and banning forest use, additional payments are needed to reduce deforestation. Such additional payments might not, however, succeed in stopping the expansion of agricultural land into natural ecosystems if they involve high financial risks. This finding highlights the importance of reducing uncertainties in such payment schemes for deforestation, for example through long-term funds and contracts (Appendix, Tab. A). Allowing forest use would, however, ensure a 25 % higher forest cover as compared to the preservation scenario, while considerably reducing the amount of payments needed.

In the preservation scenario, 51 % of the whole land area of Laipuna would theoretically be fully protected (when accounting for differences in farms). This option would, however, ignore the social and cultural importance of forest use (Pohle et al. 2010; Pohle et al. 2013). At our study site it could even put food security at risk, as goat grazing in the forest is an important and secure source of milk and meat. In contrast, in the forest use scenario a considerable area would still voluntarily be set aside for preservation. This voluntary conservation is driven by economic interests and does not consider individual household conditions that might undermine purely economic behavior. However, on a landscape scale this tendency is very likely to be observed. The preservation option furthermore involves a high risk of complete forest cover loss if the CPs lie below the minimum required threshold for maintaining forest in the portfolio. If forest use was allowed and all farmers would follow an optimal land-use portfolio, even without any CPs, forest cover at the study site would still amount to 47 %. As financial means for forest protection are usually scarce and are subject to mid-term political decisions (Cacho et al. 2014), the risk that the CP actually received by local farmers lies below the minimum required amount or decreases in the future is high. For instance, the estimated payments in our model are considerably higher for most farm types than those realized by the "Socio Bosque" program. However, a direct comparison should account for the assumptions underlying the model (discussed in section 4.2). In summary, our findings support our hypothesis that diversification and forest use are important means for designing effective compensation schemes.

We also found that required compensations can differ considerably between sizes of land-holdings. This finer resolution in the analysis demonstrates that, particularly for the intermediate farms, preservation becomes an important component of land-use portfolios. This implies that preservation incentives might be most effective in farms of these quartiles, which also have the largest forest area. For smaller and larger farms, not being allowed to use the forest would require CPs twice to 15 times as high as those calculated for the "forest-use+compensation" scenario.

Although grazing is less damaging than a complete clearance of a forest, overgrazing might also degrade dry forests by impeding natural regeneration, thus impoverishing species composition (Podwojewski et al. 2002; Espinosa et al. 2014) and potentially leading to desertification. Yet, excluding livestock from landscapes with grazing history may also risk reduced biodiversity and increased occurance of devastating wildfires as demonstrated, for example, for Mediterranean regions (Papanastasis 2009). Up to now, the rather low stocking rates in Laipuna are unlikely to cause irreversible detrimental effects on the ecosystem (Nci 2005). Nevertheless, our interviews reveal that the number of animals has increased considerably during the last decade. Hence, there is an urgent need to estimate and regulate the appropriate stocking rates for livestock grazing in tropical dry forests (Cueva et al. 2015).

4.2 Using OLUD for calculating compensation payments

This study is a first application of the OLUD model for a real landscape using an extensive data set from a household survey, which makes it possible to consider different farm conditions. Being based on portfolio-theoretic assumptions on financial decision-making, OLUD remains a normative model. This implies that the results cannot be empirically "tested", because it does not give exact predictions of the future (Roll 1977; Fama and French 2004). However, this approach offers important insights into how best to capitalize on synergies and reduce trade-offs between forest use and preservation.

Nevertheless, the derived land-use portfolios and compensation payments show realistic values. Particularly for the largest farms, optimal and current land-use portfolios were very similar. We argue that farmers with larger land-holdings, who also had the higher household income, make the most informed decisions, due to better access to markets and information resources compared to small subsistence farmers. Hence, our objective function can adequately model the decision-making of farmers, implying that small farmers are also very likely to approach the estimated "optimal portfolios".

If compensations were calculated based on the opportunity cost approach, comparing forest use to the most profitable land-use option (i.e. maize production), the required compensation would range between \$273 and \$281 ha^{-1} yr^{-1} if forest use was allowed and up to \$402 ha^{-1} yr^{-1} if forest use was banned. Consistent with the findings of Knoke et al. (2009b, 2011) including the perspective of a farmer who strives to balance risks and returns leads to more realistic CPs.

As with any mechanistic model, the results depend on a range of important assumptions. Our sensitivity analysis showed that CP amounts particularly depend on the return from the riskless investment as a basic parameter, and on the underlying uncertainty of CPs. Determining these values, particularly the adequate return for a riskless investment, can be challenging (Elton et al. 2014). Our study shows, however, that applying realistic ranges for uncertainties, correlations and land prices leads to realistic results, without altering the general finding that allowing forest use is important for maintaining current forest shares.

In summary, this study supports the general usefulness of this approach for deriving CPs for real landscapes.

5 Conclusions

Given the severe land-use conflicts in the region and the importance of forest use for local livelihoods, we recommend to avoid banning goat grazing and instead to invest in implementing diversified land-use portfolios and sustainable management of the silvopastoral system. Exploring alternative non-timber forest products is another important aspect to be addressed in future research (see Cueva et al. 2015). Both systems, forest preservation and careful forest use, will equally require an effective compliance mechanism and policies for securing land tenure.

In conclusion, combining agricultural subsidies and payments for forest use and preservation on a voluntary basis can promote and control the sustainable use of both cropland and forest resources, to reduce deforestation, increase financial stability and still facilitate land being set aside for nature conservation.

Acknowledgements

This project is part of the Platform for Biodiversity and Ecosystem Monitoring and Research in South Ecuador supported by the German Research Foundation (DFG PAK 824/1, subproject KN 586/9-1). The lead author holds a scholarship of the National Secretary of Higher Education (SENECYT). The authors also thank Universidad Tecnica Particular de Loja for its financial support and Nature and Culture International for logistic help in the research area. We are grateful to Elizabeth Gosling for language editing and Esther Reith for assistance with figures.

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Appendix

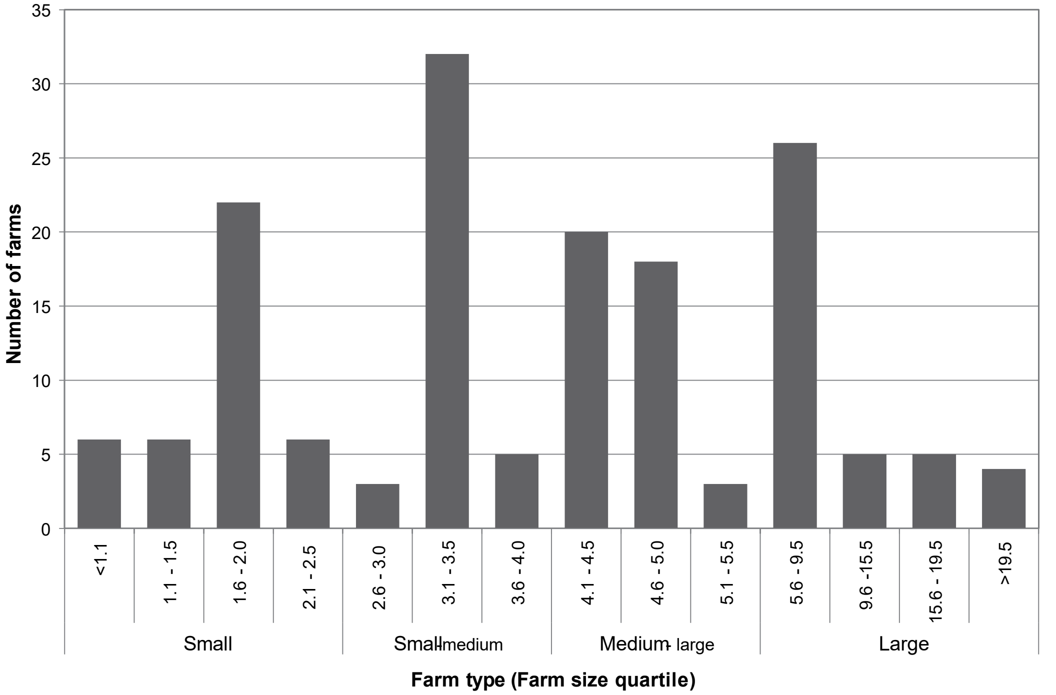

Fig. A: Distribution of farm sizes according to our interviews and the four quartiles of farm size

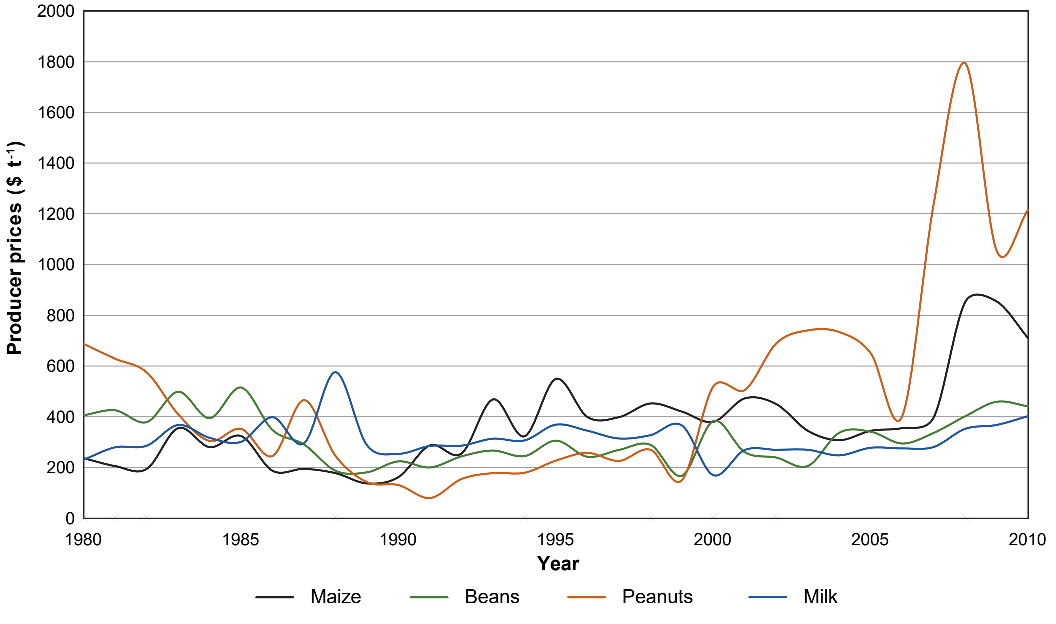

Fig. B: Historical prices for the products most commonly produced in the surroundings of Laipuna Reserve. Data adopted from FAO (2010). Please note that values for forest use (milk) refer to $ per thousand liters. Due to the change in the Ecuadorian currency in 2000 prices before this year were converted from the former currency "Sucre" to US dollars using annual exchange rates of the Central Bank of Ecuador. http://www.bce.fin.ec/

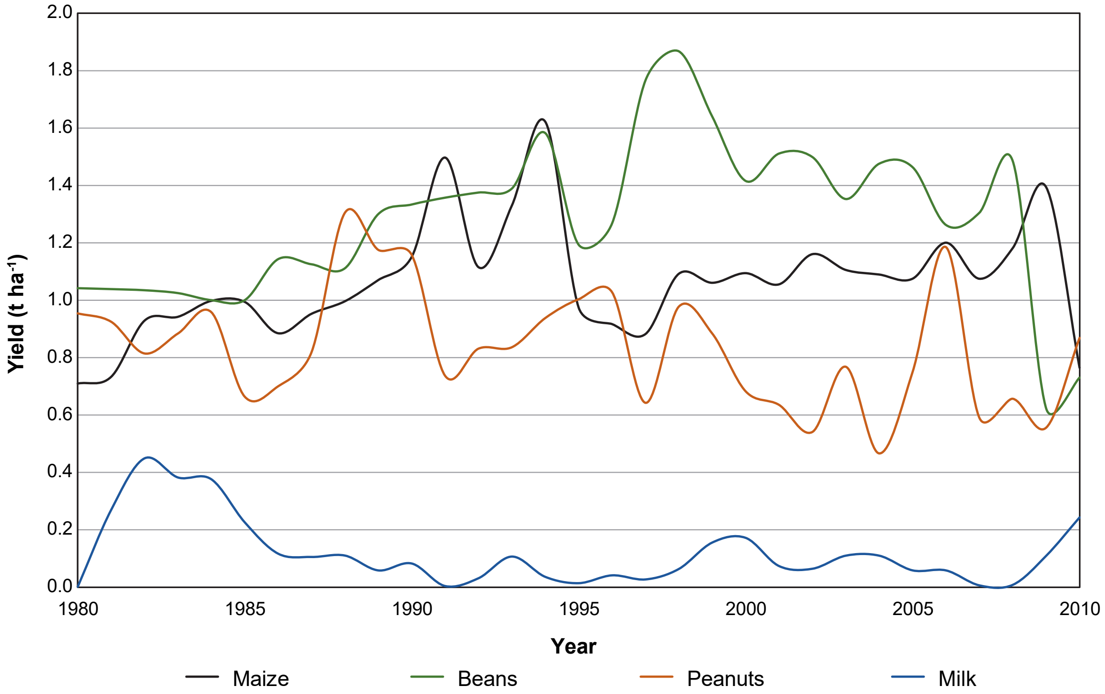

Fig. C: Historical yields for the products most commonly produced in the surroundings of Laipuna Reserve. Data adopted from FAO (2010). Yield of milk is given in thousand liters per ha

Tab. A: Examples for the results of the sensitivity analysis. The table shows the compensation payments (in \$ ha^{-1} yr^{-1}) for the two scenarios, resulting from changing the coefficient of variation (CV) of the assumed compensation payment (CP) (given as annuity) (ceteri paribus). Basic assumptions used for results presented in the paper are given in bold. Only results for the "average farm type" are given, as effects were similar across all farm types

	Scenario "preservation+forest use"	Scenario "preservation"
Coefficient of variation of CP		
2 %	50.05	50.20
5 %	50.30	51.30
10 %	51.20	56.00
20 %	**57.20**	**100.00**[1]
25 %	69.90	100.00[2]

[1] For this variation the current share of silvopasture of 66 % was not achieved. A forest share of only 56 % would be achieved
[2] For this variation the current share of silvopasture of 66 % was not achieved. A forest share of only 45 % would be achieved

Tab. B: Effect of interest rate on optimal share of silvopasture in the land-use portfolio and effects on resulting compensation payments. Results are displayed for two assumption on coefficient of variation of compensation payments (please note: in the manuscript 20 % is used as assumption). For those cases, in which current forest share of 66 % could not be maintained through compensation payments, maximum forest share is given in brackets

Interest rate	Optimal share of area under silvopasture	CP Scenario "forest use+compensation"	CP Scenario "preservation"
Coefficient of variation of CP: 5 %			
1 %	62.5 %	10.00	10.10
5 %	44.8 %	50.30	51.30
10 %	0 %[1]	91.00	102.90
Coefficient of variation of CP: 20 %			
1 %	62.5 %	10.10	11.20
5 %	44.8 %	57.30	100.00 (56 %)
10 %	0 %[2]	113.50	200.60 (53 %)

[1] A minimum CP of 25$ ha^{-1} yr^{-1} is needed to have silvopasture in the portfolio
[2] A minimum CP of 26$ ha^{-1} yr^{-1} is needed to have silvopasture in the portfolio

Tab. C: Compensation payments derived for varying assumptions on the coefficient of correlation between the CP and the annuity of other land-use options for a CV of CP of 20 %. Forest shares of less than 66 % imply a trend towards deforestation

	Scenario "preservation+forest use"		Scenario "preservation"	
Coefficient of correlation[1]	Forest share (%)	Compensation (in \$ ha^{-1} yr^{-1})	Forest share (%)	Compensation (in \$ ha^{-1} yr^{-1})
0	66	57	56	100
0.01	66	58	55	102
-0.01	66	56	57	98
0.1	66	77	49	127
-0.1	66	46	62	82
0.5	59	87	13	>1000
-0.5	66	25	66	28

[1] The coefficients of correlation found for the different land-use options (within different farm types) ranged from -0.07 to +0.08

Tab. D: Compensation payments derived for varying assumptions on the coefficient of correlation between the CP and the annuity of other land-use options for a CV of CP of 5 %

Coefficient of correlation[1]	Scenario "preservation+forest use" Compensation (in \$ ha^{-1} yr^{-1})	Scenario "preservation" Compensation (in \$ ha^{-1} yr^{-1})
0	**50.30**	**51.30**
0.01	50.50	51.50
-0.01	50.00	51.00
0.1	53.10	53.60
-0.1	47.70	49.00
0.5	69.00	64.30
-0.5	39.80	41.20

[1] The coefficients of correlation found for the different land-use options (within different farm types) ranged from -0.07 to +0.08