Payments for Environmental Services in Latin America as a Tool for Restoration and Rural Development

Florencia Montagnini, Christopher Finney

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Abstract Payments for Environmental Services (PES) can encourage projects that enhance restoration, production, and rural development. When projects promote differentiated systems by paying farmers for the provision of services, the application of PES requires evaluation of the environmental services provided by each system. We present evaluations of carbon stocks and biodiversity in pure and mixed native tree plantations in Costa Rica. To illustrate how monetary values can be assigned, we discuss a project that awarded PES to silvopastoral systems in Costa Rica, Nicaragua, and Colombia based on carbon stocks and biodiversity. PES can promote positive environmental attitudes in farmers. Currently this project is being scaled up in Colombia based on their positive experiences with PES as a tool to promote adoption. Compared to PES systems that include only one environmental service, systems that incorporate bundling or layering of multiple services can make sustainable land uses more attractive to farmers and reduce perverse incentives.

Keywords Adoptability · Biodiversity · Bundled PES · Carbon · Degraded land · Layering

INTRODUCTION

With their relatively high yields, tropical and subtropical plantations can contribute substantially to timber production (Wadsworth 1997; Evans 1999; FAO 2001). Forest plantations are also a source of cash and a medium and long-term investment for farmers, thereby performing an important role in rural development (Chambers and Leach 1990). Furthermore, forest plantations can provide multiple environmental services, including carbon sequestration, recuperation of biodiversity in degraded systems, and the

protection of soils and watersheds (Parrotta et al. 1997; Lamb et al. 2005).

In many parts of tropical Latin America, interest has increased in restoring degraded sites by establishing plantations of native and exotic tree species. Often alternative designs such as mixed-species plantations are used in these projects. Several promising tree species have been identified for use in reforestation in many regions of Latin America. In Central America, the Organization for Tropical Studies (OTS), the Tropical Agriculture Research and Higher Education Center (CATIE), universities, non-governmental organizations (NGOs), and private projects have provided information on the productivity, biomass accumulation, and financial aspects of pure and mixed plantations. For these species, researchers estimate rotation lengths of 12–25 years and standing volumes of 250–300 m³ ha⁻¹ (González and Fisher 1994; Haggard et al. 1998; Piotto et al. 2004; Piotto et al. 2010).

Planting native tree species can be an attractive commercial opportunity for farmers and investors. Firewood and fodder from pruning and thinning provide additional early returns. However, farmers must face the bottleneck represented by the relatively high costs of plantation establishment. Payments for Environmental Services (PES) can play an important role in alleviating these costs (Goldstein et al. 2006). PES, however, are subject to several limitations that can make their application difficult, and which may represent an obstacle to the wider adoption of these programs (CIFOR 2005; Porras et al. 2008). The objective of this article is to discuss PES systems including quantified environmental services that have been used successfully to encourage restoration and rural development, and suggest means of improving PES system design in order to increase their implementation. The principal hypothesis is that PES can contribute to financing and

encouraging systems for forest restoration, such as plantations and agroforestry systems (AFS), thereby serving as instruments of rural development.

DEFINITION AND DESIGN OF PES SYSTEMS

Payments for Environmental Services are systems designed to provide economic compensation for the services ecosystems supply to society, including carbon sequestration, biodiversity, scenic beauty, and watershed protection, among others. PES systems must be both voluntary and contingent on the actual provision of environmental services (Pagiola et al. 2008). In order for PES to be implemented, environmental services must be identified and evaluated, and payment mechanisms must be established to encourage the provision of these services. Payments can be made either by private parties, as is often the case in PES focused on water or carbon, or by governments, as is often the case for biodiversity. Payments are normally given to landholders who implement or retain desired land uses, which are thought to provide the ecosystem services of interest. In practice, most PES systems are “input-based,” meaning that they compensate landholders for “inputs” such as trees planted, rather than for true “outputs” of environmental services such as, for example, increased biodiversity (Engel et al. 2008). This is because such outputs can be difficult and expensive to assess. This article contributes to the assessment of PES by examining two projects: bundled PES in forestry projects in Costa Rica, and the Regional Integrated Silvopastoral Approaches to Ecosystem Management Project in Costa Rica, Nicaragua and Colombia, which designed and implemented a PES system that evaluated and incorporated payments that were proportional to the carbon and biodiversity “outputs” achieved by farmers.

In theory, monetary values assigned to PES can range from the opportunity costs to landowners (i.e., the foregone economic benefit of using the land for another purpose, below which landowners will choose not to participate) to the true value of all environmental services provided, minus transaction costs (above which society would choose not to pay). In practice, PES generally falls between these two extremes. The true opportunity costs to landholders are often unknown and variable, and PES are generally higher than the minimum needed to make the desired land use worthwhile. Because not all PES can be monetized, and because buyers cannot be found for all environmental services, in practice PES generally do not reach the full value of all environmental services landowners provide to society.

Several authors have addressed the economic inefficiency of paying landowners more than the opportunity

cost, seeking methods that allow more environmental services to be contracted for the same total value. For example, it has been proposed that PES designers should gather further information about environmental service providers, offer different types of contracts to different buyers, or use an auction system in order to minimize the payment needed to induce land use change (Ferraro 2008). Incorporating the risk of deforestation into PES design can make PES at least twice as efficient, although a model of PES in Mexico using this methodology resulted in the PES being distributed less equally among landholders (Alix-García et al. 2008). Other authors (Wuenscher et al. 2006) have modeled PES in Costa Rica and concluded that differentiating the level of payment based on the actual amount of environmental services provided and opportunity costs would improve the program’s efficiency. The design of PES has implications for economic efficiency, environmental effectiveness, and equitability, all three of which should be examined when proposing, for example, that PES be reduced to the lowest possible level.

In the case of projects that intend to promote differentiated systems by paying land managers according to the provision of services, as is described in a case study in Colombia presented in this article, the services must also be quantified and assigned monetary value (Ibrahim et al. 2007; Pagiola et al. 2008). Several mechanisms can be used to monetize different environmental services. Scenic value can be estimated using contingent valuation estimates, such as “willingness to pay” measures, although these values have rarely been incorporated into PES systems. The value of carbon sequestration is often based on the approximate existing global market price. For watershed protection, avoided dredging, maintenance, and purification costs are generally used (Mejías Esquivel and Segura Bonilla 2002; Pagiola et al. 2002).

Very frequently, rather than evaluate, quantify, and monetize actual environmental services provided, PES systems simply compensate landowners for provision cost, i.e., the cost of producing the desired outcome, such as growing trees, including opportunity cost (Wunder et al. 2008). In this case, payments can be made based on environmental targets and the cost to farmers of providing the desired land use. This is the case of the bundled PES system in Costa Rica, described in the next section.

PES IN COSTA RICA

Costa Rica has recognized the environmental services provided by natural and plantation forests since 1996, when it established a mechanism for PES through Forest Law 7575 (Pagiola et al. 2002; Campos et al. 2005). The environmental services included in the Costa Rican

program are bundled to include: (1) watershed protection, (2) carbon sequestration, (3) biodiversity conservation, and (4) aesthetic features of the natural landscape. The main source of financing for these PES is a national tax on fossil fuel consumption, while the World Bank, grants from the Global Environmental Facility (GEF), and other sources account for about 5% of the program (Pagiola et al. 2002; Campos et al. 2005; FUNDECOR, n.d.). The National Forest Finance Fund (Fondo Nacional de Financiamiento Forestal—FONAFIFO) centralizes financial resources and issues certificates for PES. The executive branch of the federal government is responsible for determining priority areas, payments per hectare, and the maximum time period for requests.

Owners of forest properties of 2–300 ha, and owners that intend to establish or manage plantations of at least 1 ha can apply for the program through regional offices of FONAFIFO if they can demonstrate legal land tenure and hire a certified forester to attest to the land use plan. Contracts last 5–10 years, and payment levels and schedules vary by management activity. From 1997–2007, the largest area in this program was for forest conservation, with a total of approximately 500,000 ha through 2007 (FUNDECOR, n.d.). Reforestation contracts have been relatively stable since the program was begun in 1997, with an average of 4,000 ha per year, and a total of approximately 40,000 ha through 2007. In the Costa Rican system, PES for reforestation (\$840 ha⁻¹ with 46% in the first year and the rest paid 6% per year for 9 more years) are more than double those for the conservation of natural forest (\$320 ha⁻¹ equally distributed over 5 years), allowing PES to serve as a strong incentive for reforestation.

Agroforestry systems were included in the program in 2002. Farmers receive US \$1.30 per tree, with 350–3500 trees allowed in each contract, and 40–625 trees ha⁻¹, depending on the type of AFS. AFS can include: (1) timber trees and/or multi-use trees with perennial crops, (2) multi-use trees planted in blocks, (3) wind-breaks, (4) live fences, and (5) improved fallows and crop intercropping in reforestation (“taungya”) projects, both of which are allowed for PES only in indigenous territories. Over 7,000 AFS contracts, including nearly 2 million trees, have been established since 2003 (FONAFIFO 2008).

EXAMPLES OF PES USED FOR REFORESTATION IN COSTA RICA: PUBLIC AND PRIVATE INITIATIVES

In Costa Rica, the national law on PES has spurred a variety of efforts that make use of the existing PES system or adapt it for other initiatives. In addition to individual farmers, non-governmental institutions can apply for PES, increasing the

scope of the Costa Rican governmental system. For example, the REFORCAT reforestation project on the CATIE commercial farm, which uses native species on degraded pasturelands, was initiated in 2000 and was financed largely by PES. The environmental goals of the project were to improve soil quality and buffer air pollution from the municipal landfill of the neighboring city of Turrialba.

Other examples include payments to farmers, which are managed or mediated by public utility companies. For example, PES administered by the public electric company (ICE) through FONAFIFO have been used to encourage reforestation and organic farming practices in the upper Río Reventazón watershed in order to protect the Angostura hydroelectric dam. The Heredia Public Utilities Company (Empresa de Servicios Públicos de Heredia—ESPH), a private company operating through public concession, that supplies water to most of the Heredia Province, also uses a PES system to protect the water supply. An environmental fee is assessed to water users and invested in watershed protection. Landowners are paid through FONAFIFO to reforest or protect existing forest in watersheds that serve as important water storage areas. The amount paid is based on the opportunity cost of the land (for example, the payment is approximately US\$165 ha⁻¹ year⁻¹ for lands fit for cattle ranching), modified by a correction factor based on the hydrological importance of the land. The program was begun in 2000, and as of 2008 it included 1900 ha and 21 landowners (ESPH 2008).

Some Costa Rican beverage companies also have PES systems to compensate farmers for forest planting and conservation in watersheds that produce water for their commercial use. In 2002, the Florida Ice & Farm Company, which produces beer, bottled water, and fruit juices, and ESPH signed an agreement with FONAFIFO and FUNDECOR to protect and manage the Río Segundo watershed, which provides water to both companies. Combining demand allowed payments to be increased recently to values more attractive to the farmers (ESPH 2008).

VOLUNTARY CARBON OFFSETS IN COSTA RICA

Voluntary carbon offsets can be considered a special case of PES where transactions are made at the private level only. The concept of a carbon offset is complicated because offsets can involve different activities, definitions, and timeframes for measurement. Ensuring the credibility of offsets is challenging because there are many ways to determine whether a project is additional to a given baseline, and inherent uncertainty exists in measuring emissions reductions relative to such a baseline (US Government Accountability Office 2009). However, if designed and

managed properly, voluntary carbon offsets provide additional financing for reforestation.

One example of private carbon offsets in Costa Rica is Reforest The Tropics (RTT), which aims to offset USA-generated carbon dioxide emissions by planting trees in Costa Rica (www.reforestthetropics.org). With donations from USA sponsors, they work with participating Costa Rican farmers to reforest tropical pastures and sequester carbon, in land managed by CATIE, or on private farmland, using native and exotic species. The native species used have been shown to grow well in the region by recent research, and include high-value timber species such as mahoganies and cedars. Exotic species include klinki pine (*Araucaria hunstenii*) and *Eucalyptus deglupta* hybrids. RTT uses mixed-species designs in its plantations so that fast-growing species can be harvested early for farmer income while slower growing, longer-lived trees can be used for long-term production and carbon storage (Cuenca Capa 2009).

RTT has a goal of sequestering about 30 ton $\text{ha}^{-1} \text{year}^{-1}$ of carbon for the first 25 years of tree growth. These values are higher than those measured for some of the same species in this region, demonstrating the challenge of quantifying environmental services. However, better site quality, timely plantation management, and judicious species selection can significantly increase rates of tree growth and C sequestration. In addition, calculations from field measurements are currently being used to update RTT goals. Of the total growth, approximately 20% is thinned at 8–10 years to provide income to the property-owner, leaving the rest for the carbon account of the sponsor. RTT thins plantations every 3–5 years, creating a cash flow for the farmer. The landowner benefits from the sale of timber products from thinnings and the final harvest. Donors pay US\$8–15 ton^{-1} , or US\$5000–10,000 ha^{-1} , a value comparable to current carbon prices worldwide (Point Carbon 2009). Landowners are also paid US\$1500 ha^{-1} of the offset price, which is comparable to the total cost of establishment and higher than payments through FONAFIFO. Since RTT was established in 1998, carbon offset plantations have been established for approximately 75 sponsors, for a total of 120 ha (<1–50 ha per plot). RTT is now seeking to include more economically valuable wood to ensure more stable income to farmers (personal communication, H. Barres, RTT, 2010).

HOW TO PAY FOR REFORESTATION: OUR EXPERIENCES IN THE CARIBBEAN REGION OF COSTA RICA

The establishment costs of plantations can be high, especially during the first 1–4 years, due to site preparation,

planting, weed control, pruning, thinning, and other management activities (Montagnini et al. 1995). As an example, here we present results based on our long-term experiments with native species reforestation in the Caribbean region of Costa Rica (Montagnini and Mendelsohn 1997; Piotta et al. 2010). The studies were performed at La Selva Biological Station (10°26'N, 86°59'W, 50 m mean altitude, flat terrain, 24°C mean annual temperature, 4000 mm mean annual rainfall). The objective of the research was to examine the plantations' ability to recover soils, productivity, and ecosystem services on formerly degraded pasturelands. Native tree species were planted in an experimental design using pure and mixed-species plots, with species chosen based on their potential growth, form, potential recuperation of soil fertility, and economic value. Plantations were measured annually to estimate productivity and biomass. Biomass and carbon accumulation were initially estimated when thinning the plantations and using allometric equations thereafter. In order to monitor biodiversity, natural regeneration of tree species in the plantation understory (Butler et al. 2008) and Lepidoptera abundance and species richness (Magellan et al. 2010) were evaluated and compared to control plots of unplanted degraded pasture. Records were kept of costs involved in plantation establishment and management, including the cost of seedlings, and labor for planting, weeding and thinning (Piotta et al. 2010).

In our case, plantation costs were relatively low because intensive management practices were not conducted since plantations were intended primarily to recover degraded pasture. With more intensive management geared to increasing productivity, costs may be twice those shown in Figs. 1a and b (Piotta et al. 2010). On the other hand, timber sales can provide substantial income. Based on measurements taken at 16 years of age, near the commercial rotation of most of the species studied, the estimated income from timber sales makes this plantation economically attractive (Fig. 1b; Fig. 2).

In the Costa Rican system, PES are not enough to cover the full cost of plantation management or maintenance (Fig. 1a). PES do, however, contribute substantially to early return on investment, a very important factor to many rural farmers who cannot afford to wait until final harvest. Prior to year 4, however, PES help offset establishment costs.

How can a farmer with limited economic resources pay the cost of reforestation? Income from the sale of plantation products can take several years, depending on site and species. The use of agroforestry systems (combinations of trees with crops) and/or agrosilvopastoral systems (combinations of trees with beef or dairy cattle) can provide earlier returns from the sale of crops or animal products. Some financial schemes, such as the advanced payment for

Fig. 1 **a** Cumulative PES and cumulative costs related to plantation establishment and maintenance, both expressed as US\$ ha⁻¹. Data on costs from Montagnini and Mendelsohn (1997) and Piotto et al. (2010). PES data are for plantation establishment in Costa Rica, from FONAFIFO (2008). **b** Cumulative costs of plantation establishment and maintenance and cumulative income (net present value) from PES, thinnings and prunings (years 4 and 6) and final harvest; both expressed as US\$ ha⁻¹. Data on plantation income from Piotto et al. (2010)

timber administered in Costa Rica by FUNDECOR, are useful in encouraging reforestation (FUNDECOR, n.d.). Subsidies, such as reduced taxes, also work well in some cases. PES are presented here as an alternative means of offsetting initial costs and thereby encouraging reforestation.

EVALUATION AND QUANTIFICATION OF ENVIRONMENTAL SERVICES: CARBON SEQUESTRATION AND BIODIVERSITY

Quantifying carbon sequestration requires field measurements, biomass collection, the use of mathematical models such as allometric equations, and other techniques. Carbon stocks in forests and plantations are generally calculated from measurements of aboveground biomass accumulation. If calculated over a time period, C stocks are assumed to equal C sequestration rates. Since C sequestration is a process that removes C from the atmosphere, it is a flow usually accounted for on a yearly basis, and the stock of C existing at a given point in time after reforestation is to some extent indicative of the C sequestration that happened since the plantation was established. However, the fate of

the sequestered carbon needs to be taken into consideration; for example, if the forest is subsequently used to produce bio-energy, a part or even most of this C sequestered is released to the atmosphere again. On the other hand, carbon accounting based only on aboveground biomass can fail to account for future carbon storage on-site (as belowground biomass, increased soil carbon content, or long-term change in land cover from pasture to forest) and off-site (when timber is used for durable goods such as construction or furniture, as is typically the case with the native hardwood species studied here).

Estimations of carbon stocks in our experimental plantations with pure and mixed native species at 16 years of age indicated that the species *Vochysia guatemalensis*, *Dipteryx oleifera*, *Terminalia amazonia*, and *Hieronyma alchorneoides* have good growth and high carbon stocks (Table 1). These species are used in reforestation projects in this region, where PES are used to partially finance such projects through the existing Costa Rican PES system (Redondo-Brenes 2007). Mixed plantations had carbon stocks similar to or greater than those of pure plantations because well-planned mixed plantations allow the complementary use of resources such as light, nutrients, and space by different species. Figure 3 shows summarized results of biodiversity monitoring including natural regeneration of tree species in the plantation understory (Butler et al. 2008) and Lepidoptera abundance and species richness (Magellan et al. 2010) comparing both to control plots of unplanted degraded pasture. Carbon stocks are also shown in Fig. 3 to contrast the role of different plantation systems on the provision of different environmental services: biodiversity, and carbon.

In PES systems based on the amount of services provided, rather than values such as opportunity costs, the level of payments depends on the quantification of services. The process of quantifying environmental services involves several potential distortions, including the choice of which environmental services to be considered, and the choice of indicators to be used for each service. Figure 3 provides a good example of the importance of these decisions. If only carbon stocks were considered in this system, landowners would have a strong incentive to plant *V. guatemalensis*, *D. oleifera*, *T. amazonia*, or a combination of these species, which can store more than twice as much carbon in aboveground biomass as *Balizia elegans*, *H. alchorneoides*, *Vochysia ferruginea*, or *J. copaia*. However, if the abundance of understory tree regeneration is included as an indicator of future forest structure capable of supporting higher levels of biodiversity, a different set of incentives emerges: *B. elegans*, *H. alchorneoides*, and *V. ferruginea* outperform *T. amazonia* and *Virola koschnyi*, and are similar to *D. oleifera* in fostering natural regeneration of tree species in the understory.

Fig. 2 A 16-year-old *Vochysia guatemalensis* tree at la Selva Biological Station, Costa Rica. This species was among the fastest growing trees in our experiments to restore degraded pastures (Table 1), and it is among the most frequently planted species by farmers in the region. The estimated Net Present Value of *Vochysia guatemalensis* was US\$6,000 ha⁻¹ (Piotto et al. 2010). Photo: Daniel Piotto

Including Lepidoptera as a bioindicator further complicates this issue because the number of individual butterflies and moths is only slightly higher in these plantations than in degraded pasture, and varies among plantations by tree species. Further, a PES system designed based on the data in Fig. 3 would also be contingent on the relative weights assigned to each service and indicator. This type of analysis can make implementation of PES systems expensive; however it is worth noting that these payment systems depend heavily on the decisions of their designers, who can set priorities on the services that are more crucial to protect or promote for any given landscape of concern.

PAYMENTS FOR ENVIRONMENTAL SERVICES AS A TOOL FOR RESTORATION OF DEGRADED PASTURE IN TROPICAL LATIN AMERICA

In tropical Latin America, over 60% of cattle pastures are degraded, representing a threat to the sustainability of agriculture in the region (Montagnini 2008). In Central America, pastures now cover more than eleven million ha (about 30% of the total land area), half of which are estimated to be degraded (Wassenaar et al. 2007). Such degradation is associated with decreased farm productivity, soil erosion, contamination of water supplies, greenhouse

Table 1 Density, volume, and carbon stocks of native trees in pure and mixed plantations at 16 years of age, La Selva Biological Station, Caribbean region of Costa Rica

Species	Tree density (# ha ⁻¹)	Volume (m ³ ha ⁻¹)	C in biomass (ton ha ⁻¹)
Plantation 1			
<i>Jacaranda copaia</i>	315 ^a	210 ^b	15.3
<i>Vochysia guatemalensis</i>	381 ^a	406 ^{a,b}	43.1
Mix of two species	454 ^a	519 ^a	49.7
Plantation 2			
<i>Dipteryx oleifera</i>	403 ^a	92 ^b	49.5
<i>Terminalia amazonia</i>	261 ^b	203 ^a	58.5
<i>Virola koschnyi</i>	381 ^a	263 ^a	28.3
Mix of three species	344 ^{a,b}	247 ^a	67.5
Plantation 3			
<i>Balizia elegans</i>	295 ^{a,b}	102 ^b	18.1
<i>Hieronyma alchorneoides</i>	347 ^a	143 ^{a,b}	23.5
<i>Vochysia ferruginea</i>	215 ^b	153 ^{a,b}	16.3
Mix of three species	373 ^a	206 ^a	28.1

Note: Mean values within each plantation differ significantly (Tukey test, $P < 0.05$) when followed by different letters. Source: Piotto et al. (2010)

Fig. 3 Understory tree regeneration abundance, Lepidoptera abundance, and carbon stocks in aboveground biomass in mixed and pure plantations of native species, La Selva, Costa Rica. Notes: Data on understory tree seedlings regeneration are taken from Butler et al. (2008) and reported as numbers of individual tree seedlings 16 m⁻². Data on Lepidoptera are taken from Magellan et al., 2010 and reported as number of individuals 4096 m⁻². Data on aboveground carbon are taken from Piotto et al. (2010) and reported as tons C ha⁻¹ accumulated over 16 years of growth. Carbon data were not collected for control (unplanted degraded pasture) plots, and should not be assumed to equal zero. All three studies were conducted on the same experimental plots

gas emissions, further loss of biodiversity, and degradation of landscapes (Harvey et al. 2005, Pagiola et al. 2007). Silvopastoral systems (SPS) that involve the combination of trees with pastures and livestock in settings such as dispersed trees in pastures, tree alley pasture systems, fodder banks, and pastures with live fences and windbreaks, can provide benefits to farmers by enhancing nutrient cycling, fodder production for animals, and

diversification of income thus contributing to the ecological and economic sustainability of cattle farms (Montagnini 2008, Yamamoto et al. 2007) (Figs. 4, 5).

In addition to on-site benefits, the higher complexity of silvopastoral systems relative to grass monoculture systems has important benefits for biodiversity. Recent assessments of biodiversity within SPS indicate that many of these systems (e.g., high density trees in pastures and live multi-strata fences) have levels of species richness comparable to those of early secondary forest, and that networks of live fences in pastures are important for landscape connectivity (Harvey et al. 2005). SPS can also fix significant amounts of carbon in the soil and in above- and below-ground biomass, providing an important contribution to climate change mitigation (Ibrahim et al. 2010). These positive externalities of SPS are generally not included in farmers' land use planning, in part because farmers are not compensated for off-site benefits.

Although SPS provide significant benefits, lack of capital and high labor cost of establishment and management represent the two most important barriers to the adoption of these systems (Dagang and Nair 2003; Calle et al. 2009). Recently, PES have been used to encourage restoration and rural development in Matiguás, Nicaragua; Esparza, Costa Rica, and Quindío, Colombia, regions with similarly degraded pastures, in a project financed by the World Bank and GEF (Ibrahim et al. 2010). Bioindicators were used to monitor biodiversity in 8–13 different land use types, including pasture with high and low tree density, degraded pasture, tall and short live fences, forest fallows, primary forest, gallery forest, and secondary forest. The data showed that some species prefer a specific habitat, including open areas, leading to the conclusion that a combination of diverse silvopastoral systems and forests improves biodiversity conservation. Using field data, the

Fig. 4 Finca Pinzacuá, Quindío, Colombia, participating in the silvopastoral project mentioned in text and in Table 2. To establish useful trees in active pastures, the owner designed this system in which he plants rows of native trees at 2 m distance between trees and 10 m between rows. Each row is protected by electric wire (the single line shown in picture at *front*) so that trees can grow while cattle graze

in the surrounding areas. Trees planted included nitrogen-fixing species for restoration and fodder such as *Inga edulis* (darker foliage, at *front*), and *Gliricidia sepium* (lighter, round crowns, in the back), as well as valuable timber species such as mahoganies (*Swietenia macrophylla*) (smaller trees at *front* and on the *right*, closer to cattle) (Calle 2008). Photo: Alicia Calle

expected diversity can be calculated for each land use type based on percentage tree cover.

The objective of this PES system was to encourage a level of tree cover that maximizes biodiversity while maintaining pasture productivity at levels acceptable to farmers. The researchers compared the percentages of tree cover in pastures to the increase in live weight of cattle ($\text{kg ha}^{-1} \text{ year}^{-1}$), and the number of bird species. Bird species diversity was highest at 50–60% tree cover, but the threshold for good cattle productivity was 28–35% tree cover. Thus, a tree cover of about 30% may be an appropriate balance between productivity and biodiversity in these systems (Ibrahim et al. 2010).

To calculate the payment for each land use type, environmental service indices were developed based on the assumption that native forest with >80% tree cover provides the highest level of environmental services. Native forest was assigned 1 point for carbon and 1 point for biodiversity, or a total of 2 environmental services points.

Mature secondary forest in this region is estimated to sequester $10 \text{ tC ha}^{-1} \text{ year}^{-1}$; $10 \text{ ton C} = 1 \text{ environmental service point}$. At the other end of the spectrum, it was assumed that degraded pasture with <50% tree cover provided the least environmental services, and was assigned 0 points for carbon and 0 points for biodiversity. The “Environmental Services Index” was based on the estimated potential of each land use type to provide each of the two environmental services based on its tree cover (Madrigal Ballesteros and Alpizar Rodríguez 2008). In order to provide an incentive to farmers with farms that were already in good condition, and prevent the creation of a perverse incentive, the initial payment in 2003 was based on the baseline condition of the farm. In Colombia, farmers were paid US\$10 per baseline point and US\$75 per additional point each year. Table 2 presents the environmental service points assigned to each land use type of a farm in Quindío, Colombia, where the farmer received both technical assistance and PES through the project (Fig. 4).

Fig. 5 Finca El Guayabo, Quindío, Colombia, also participating in the silvopastoral project mentioned in text. The owner, Alba Lucía, shows the progress of her new live fences of *Gliricidia sepium*, a nitrogen-fixing tree native to Central America. This multiple-use tree

helps restore soils, provides nutritious fodder for cattle, and works great as fencing material since it can be reproduced by stem cuttings and stands periodic prunings to maintain the fence low and harvest fodder for cattle (Calle 2008). Photo: Alicia Calle

With PES and technical assistance, the farmer adopted more sustainable land uses such as live fences, improved pastures with trees, and other silvopastoral systems, increasing the environmental service points of his farm from 25.9 to 60.2 in 4 years. In the example above, the PES paid to the farmer increased from US\$259 in 2003 to more than US\$1000 year⁻¹, for a total of US\$6600 from 2003–2007 (Calle 2008).

PES, FARMERS' ATTITUDES, AND THE ADOPTION OF SUSTAINABLE LAND USE SYSTEMS

PES can serve as an incentive to increase the adoption of more sustainable land uses, as shown by the experiments summarized above. In many cases, PES are insufficient to compensate farmers for the cost of changing land uses. In the Colombian project presented, PES covered approximately 60% of the cost of implementing new systems; this value is comparable to our estimates in Costa Rica.

Nevertheless, one important outcome of PES is a change in farmers' attitudes.

The permanent adoption of sustainable land use systems depends on the farmer's perception of costs and benefits of the new system compared to conventional systems. Technical assistance and PES contribute to helping the farmer analyze and understand the productive and environmental advantages of new systems. PES can help farmers understand and implement the social value of land use choices. PES provide a tangible connection between sustainable practices, environmental services, and economic benefits (Calle et al. 2009).

LAYERING AND BUNDLING PES

In systems that layer or bundle PES, landowners are paid for providing multiple services from a single plot of land. With PES layering a landowner might be paid by different buyers for each of several services such as sequestering carbon, protecting watershed function, preserving natural

Table 2 Points assigned to land uses for carbon sequestration and biodiversity conservation in Finca Pinzacuá, Quindío, Colombia, at the beginning of project in 2003, and changes resulting from PES and technical assistance in 2007

Land use	Area 2003	Points 2003	Area 2007	Points 2007
Improved pasture, without trees	38.5	19.2	0	0
Improved pasture, low tree density	1.4	1.3	10.4	9.4
Improved pasture, high tree density	0	0	21.5	28.0
New live fences	0	0	5.9	3.6
Tall live fences/windbreaks	0	0	0.8	1.0
Fruit plantations	0.8	0.6	0	0
Timber plantations	0	0	0.7	1.0
Natural succession	0	0	0.9	1.3
Gallery forest	3.2	4.8	4.1	6.3
Silvopastoral system	0	0	6.1	9.7
Total	43.8	25.9	43.8	60.2
Points ha ⁻¹		0.6		1.4

Source: Calle (2008)

beauty, and harboring biodiversity. In bundled PES systems (such as the PES system in Costa Rica), landowners are paid once based on a set of priority services. Although explicit bundling and layering are relatively unusual, these PES systems can provide several benefits.

- First, landowners can be rewarded more fully for the services they provide. Because any given PES may be less than the opportunity cost of less desirable land uses, layering different PES can make sustainable land uses more attractive.
- Second, the layering of different PES helps mitigate perverse incentives. For example, under a carbon trading system that does not incorporate other services such as biodiversity protection, watershed protection, or cultural value, landowners will be more rewarded for planting monocultures of fast-growing exotic tree species that sequester large quantities of carbon but that may provide few other services, than for planting slower growing native species that have a greater potential to provide these other benefits.
- Third, layered and bundled PES may improve equitability for poor, rural landholders and indigenous peoples. Forest carbon offsets, for example, represent a potential threat to local sovereignty, particularly in rural areas that have long been politically and economically disenfranchised (IPGSCC 2009). Layered and bundled PES systems that blend different revenue streams associated with different environmental services may help finance reforestation while reducing threats to local control. Carbon markets are developing at the national and international scale, biodiversity, and watershed markets are generally regional, and private agreements regarding scenic beauty or natural pollination are often carried at the local level. This

diversification may allow local people greater access to decision-making processes while creating additional economic opportunities.

LIMITATIONS OF PES SYSTEMS AND FUTURE PERSPECTIVES

As seen from the examples presented here, the successful design and implementation of PES impose several challenges, including:

- (1) The services provided by a wide variety of ecosystems are difficult to quantify. For example, to quantify biomass in order to estimate carbon stocks, trees must be harvested, mathematical models used, and margins of error considered. Extrapolating the values determined for one system to others with different ecological conditions introduces additional error. Even within ecosystems sometimes assumed to be relatively homogenous, carbon stocks can vary substantially. Ecosystem services other than carbon can be even more difficult to monetize.
- (2) Indicators must be used correctly, and are inherently imperfect. For example, different indicators of biodiversity (birds, other animals) can indicate different types of habitat. Species that are easy to identify or count, and species that are well-understood, are preferable. Indicators of water quality and mechanisms to evaluate scenic beauty must also be applied correctly.
- (3) Markets must be established. Who pays for environmental services: governments, open markets, private sources? In practice, this may be the greatest impediment to PES, particularly for true public goods like biodiversity and carbon (Porrás et al. 2008).

- (4) Systems must be established in order to implement payments. These systems include national, state, and local laws and regulations, administrative rules and processes, and certification systems. In some countries, regions differ greatly, complicating administration. Systems must ensure equitable access to PES, confronting issues such as land tenure, unequal access to resources, and different sizes of land holdings.
- (5) High transaction costs must be avoided. The process of establishing, administering, and certifying credits can be costly. Normally, mechanisms that involve other institutions and actions must also be used (such as technical assistance and third-party certification), further increasing transaction costs. High transaction costs are an important barrier to participation when they must be born by poor landholders.
- (6) Leakages due to PES must be avoided. Undesired consequences may result directly or indirectly from PES systems (for example, forest may be cut in order to establish plantations).
- (7) Landholders must be able to adopt the land use changes and management practices begun under PES, continuing them after subsidies end.
- (8) The design of PES has implications for economic efficiency, environmental effectiveness, and equitability; these three concerns sometimes conflict. PES generally involve payments from wealthy beneficiaries of environmental services to poorer providers. In this context, reducing payments to the lowest value needed to induce change (the opportunity cost) raises an ethical issue because PES benefits society, or the richest sectors of society, while not compensating the poor well enough. For example, it has been argued that reducing PES to the opportunity cost might increase participation by the rural poor by allowing smaller farms to qualify as environmental services providers (Wuenscher et al. 2006); however, compensating only for opportunity costs eliminates any real “payment” for environmental services (although PES are more stable than crop production).

In spite of the limitations discussed above, in much of rural Latin America, the combined economic value of PES and forestry related production can make agroforestry, forestry, and forest conservation attractive to landholders when PES systems are implemented. The programs and experiments reported here show strong participation by landholders, indicating that PES are useful locally. Successful PES systems can have both economic and environmental benefits. The Regional Integrated Silvopastoral Approaches to Ecosystem Management Project improved carbon sequestration, biodiversity, beef production, gross income and income per capita of family household among

poor farmers (Ibrahim et al. 2007, 2010). In cases such as this, efforts to redesign the PES system to reduce payments would seem to require a compelling justification.

Much recent research has focused on opportunities to improve PES design, often by improving the targeting of PES to lands of greater environmental interest or by reducing payments to levels closer to the opportunity costs. Although improved targeting is a worthy goal, the goals of reducing payments should be evaluated from the standpoint of equitability, as well as economic efficiency. Although PES are imperfect, they appear to be a positive development overall. PES programs have been successfully implemented in many locations, but there are not still many documented cases at larger scales (Porrás et al. 2008).

However, new experiences are emerging in Costa Rica which increase participation by small producers and local communities, and in Mexico PES initiatives which were created by rural and indigenous communities and the civil organizations that support them, have encouraged the federal government to include PES in its rural programs (Porrás et al. 2008). In Brazil, rural and indigenous groups have had less influence than in Mexico and have enjoyed less secure access to natural resources, thus emphasis is placed on initiatives intended to expand, defend, and ensure the rights of communities to access natural resources (Porrás et al. 2008). In Brazil, PES initiatives generally come about through partnerships between NGOs such as The Nature Conservancy (TNC), and government agencies, particularly local watershed committees (groups of public and private representatives charged with collecting and distributing water user fees), and the National Water Agency. The National Water Agency created the regulatory framework for PES, called the Water Producer Program, in 2007. TNC has helped build the capacity of local governments and watershed committees to implement PES in the Cantareira Watershed, São Paulo state. This program has been replicated in several states, and implemented at the state level in Minas Gerais (Agência Nacional de Águas 2010).

Another good example of how PES programs can be effectively scaled up is from the experience of the PES program for silvopastoral systems in Colombia that we described in this article (Ibrahim et al. 2007, 2010): FEDEGAN, Federación de Ganaderos de Colombia (National Federation of Cattle Ranchers) has recently received a new loan of US\$42 million from the World Bank for a new 5-year project called “Mainstreaming Sustainable Cattle Ranching” to promote the adoption of environmentally-friendly Silvopastoral Production Systems (SPS) for cattle ranching throughout Colombia’s project areas, to improve natural resource management, enhance the provision of environmental services (biodiversity, land, carbon, and water), and raise the productivity in

participating farms. An important component of this project is increasing landscape connectivity and reducing land degradation on participating cattle ranching farms, through differentiated PES schemes (World Bank 2010).

CONCLUSIONS

As shown by the examples described here, PES can be a tool to finance reforestation, restoration, conservation and changes in land use that enhance rural development. In addition, PES programs can induce attitude changes in farmers, which is a major goal of rural development programs.

The application of PES requires evaluation of the ecosystem services provided, determination of payments, and monitoring of success. The evaluation of environmental services provided by each land use type requires multi-disciplinary teams, including ecologists, economists, and sociologists. Payment level can be determined based on indices that include data on evaluations of environmental services and opportunity costs.

Successful experiments have been conducted in Latin America, including governmental initiatives and projects conducted by NGOs with outside financing. Legislation creates the bases and alignments, and legitimizes the procedures for PES, thereby encouraging institutions and private organizations to implement PES. Conversely, positive experiences from PES programs initiated by NGOs have been adopted by government agencies in several cases. In addition, successful experiences in PES programs have contributed to their being scaled up in Brazil, Colombia and other countries as well. Great potential exists to include larger private initiatives, such as carbon offsets and others. However, other services such as biodiversity and water should be considered so as not to direct the systems toward carbon sequestration alone at the expense of biodiversity or other services. Layered or bundled PES programs help serve this purpose, as explained in the silvopastoral and Costa Rican PES systems.

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AUTHOR BIOGRAPHIES

Florencia Montagnini (✉) MS, PhD, is a Professor in the Practice of Tropical Forestry at the Yale University School of Forestry and Environmental Studies, USA. Her research focuses on variables controlling the sustainability of managed ecosystems in the tropics, with a special emphasis on Latin America. She is currently conducting research on sustainable systems to restore degraded landscapes in Costa Rica, Panama, Brazil, Argentina and Mexico. Address: School of Forestry and Environmental Studies, Yale University, 370 Prospect Street, New Haven, CT 06511, USA. e-mail: florencia.montagnini@yale.edu

Christopher Finney Master of Environmental Management, is a recent graduate of the Yale University School of Forestry and Environmental Studies. He is now a Philanthropy Communications Specialist with The Nature Conservancy in São Paulo, Brazil. Address: The Nature Conservancy, Rua João Moura 444, São Paulo, SP, Brazil. e-mail: chrisfinney@gmail.com