Ecological Economics 69 (2010) 2116–2126

Contents lists available at ScienceDirect

Ecological Economics

journal homepage: www.elsevier.com/locate/ecolecon

Understanding the impacts of Costa Rica's PES: Are we asking the right questions?

Amy E. Daniels [a,*], Kenneth Bagstad [b], Valerie Esposito [b], Azur Moulaert [b], Carlos Manuel Rodriguez [c]

[a] U.S. Forest Service, Research and Development, United States
[b] Gund Institute for Ecological Economics, University of Vermont, United States
[c] Conservation International, Costa Rica

ARTICLE INFO

Article history:
Received 28 August 2007
Received in revised form 25 May 2010
Accepted 3 June 2010
Available online 16 July 2010

Keywords:
Payments for environmental services
Ecosystem services
Impact assessment
Costa Rica
Forest
Forest recovery
Forest transition
REDD
Deforestation
Reforestation

ABSTRACT

PES is an increasingly mainstream tool for influencing land-use decisions on private land and Costa Rica's experience provides critical insight. We review findings of PES impacts on forest cover, a proxy for forest-based ecosystem services. National studies conclude that PES has not lowered deforestation rates. Yet in northern Costa Rica, there is evidence of additionality for PES-related avoided deforestation. Moreover, sub-national studies of bi-directional forest cover change, along with farm-level interview data and an understanding of ground-based operations, demonstrate that avoided deforestation is an incomplete measure of PES impact. Sub-national case studies suggest PES is associated with agricultural abandonment and net gains in forest cover via forest regeneration and plantation establishment. Explanations include that forest regeneration has always been an accepted PES modality for some regions. Also, early PES cohorts have an implicit spatial correlation with pre-PES incentives focusing exclusively on reforestation. Without understanding de facto PES implementation, it is impossible to appropriately evaluate PES impacts or discern whether PES outcomes—positive or negative—are due to PES design or its implementation. This distinction is critical in refining our understanding of both the utility and limitations of PES and has some practical implications for PES-style REDD initiatives.

1. Introduction

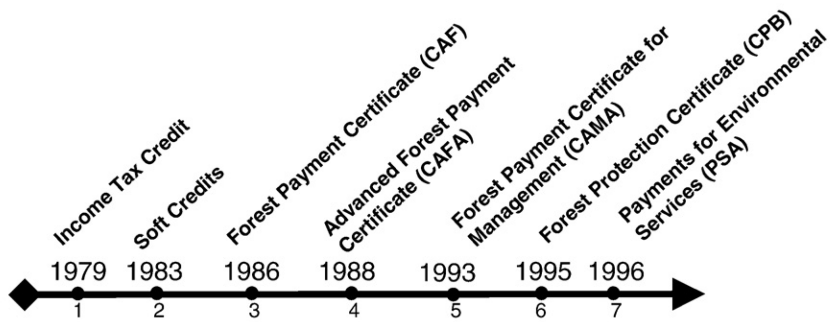
After a couple of decades experimenting with forestry incentives, Costa Rica began its landmark payments for environmental services (PES) scheme in 1997. Turning the former forestry incentives concept on its head, the program pays forest stewards engaged in certain land uses that provide four broad classes of ecosystem services. After more than a hundred and fifty million cumulative dollars invested (FONAFIFO, 2009), ten plus years of experience and over 700,000 ha enrolled over the life of the program, the obvious and critical question is this: What has the impact of PES been on ecosystem service provision? Responding to this is anything but straightforward for a host of reasons that we explore. Yet PES is a key strategy within the broader suite of REDD initiatives (reduced emissions from deforestation and degradation); and as PES becomes an increasingly widespread policy tool for promoting conservation on private landholdings, this question is more relevant than ever. The need to critically review and synthesize our current understanding of the impact of PES in Costa Rica is urgent.

An extensive and dynamic literature exists about Costa Rica's PES. Pagiola (2008) provides a recent overview of the country's experience with PES, whereas Chomitz et al. (1999) provides insight on the initial implementation of the program. Miranda et al. (2006) and Zbinden and Lee (2005) examine participation aspects of PES using case studies in the Caribbean plain of northern Costa Rica. PES is but one component of the country's broader suite of non-traditional conservation approaches including bioprospecting and ecotourism, as detailed in Rojas and Aylward (2003). Though the country pioneered the nation-wide PES scheme in the developing world, it has evolved as part of a broader movement in tropical forest conservation. Wunder (2007) effectively contextualizes this in a discussion of experiences not only in Costa Rica but in Ecuador, Bolivia, Indonesia and Vietnam. Despite this dynamic literature, relatively few studies have addressed the impact of PES in Costa Rica on the origin of the ecosystem services that PES was intended to maintain (i.e. forest).

Our objective is to review PES impact studies and contextualize their findings in a proper ground-based understanding of the evolution of PES design and its de facto implementation through the years. We begin with a brief description of PES evolution and enrollment statistics to date. Then we give an overview of the challenges presented in assessing PES impact on the provision of ecosystem services. Principal among these challenges is the indirect link between PES' target—forest land use—and the actual services that forest ecosystems provide. We review the literature about PES impacts on forest cover and land use, giving context for their findings based on first-hand knowledge and farm-based interview data collected in 2005

* Corresponding author. Tel.: +1 703 605 5251; fax: +1 703 605 5133.
E-mail address: adaniels02@fs.fed.us (A.E. Daniels).

0921-8009/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.ecolecon.2010.06.011



1. Income tax credit given to land owners involved in reforestation activities to offset the costof plantations. The concept was to promote plantations as a way of alleviating deforestation pressure on natural forests. This tax credit targeted large landholders since small holders generally did not pay income tax. Decree No. 10521-AH, Sept. 1979.

2. International funding helped to finance low-interest reforestation loans with long grace periods and extended repayment windows. This initiative was the first of several soft credit incentives, some of which still continue in the present (e.g. FONAFIFO-brokered loans for reforestation). COREMA-AID project.

3. Creates the Certificado de Abono Forestal (CAF). Reforestation investments in plantations are made up front by land owner and compensation is given later through a tradable tax voucher. Article 82 of the Second Forestry Law (No. 7032, La Gaceta 13; Circulo 84 – May6, 1986).

4. Like CAF but compensation is given prior to reforestation investment so that land owners with less capital could participate. Decree No. 18691-MIRENEM-H, Dec. 1988.

5. Established that scientifically-managed timber extraction from natural forests would be eligible for tax vouchers. Decree No. 22452-MIRENEM-H, 1993 (La Gaceta 170, Alcance 6).

6. Established that tax vouchers could be paid for natural forest protection (equal to the CAF vouchers paid for reforestation). Decree No. 23101-MIRENEM-H, April 1994 (La Gaceta 74).

7. Article 22 affirms continuation of tax vouchersfor protecting natural forest, along with other tax benefits. Article 24 provides that land owners voluntarily allowing forest regeneration are eligible for the same benefits. Article 29 details tax benefits for plantation owners. Fourth Forestry Law (No. 7575, Gaceta 72, Alcance 21 – April 16, 1996).

Fig. 1. Timeline detailing the evolution of PES in Costa Rica.

and 2007 in northwest Costa Rica. We emphasize the importance of understanding the implications of PES' gradual evolution and also the regional variability in program implementation for framing appropriate impact assessments. Without this, the attribution of PES outcomes—whether positive or negative—to design, implementation, or other factors is unreliable. Finally, we point out the areas of critically-needed research and highlight some important practical implications for the design of PES-style REDD initiatives.

2. Evolution of PES

Though well-known for its conservation efforts, in the recent past Costa Rica had one of the highest deforestation rates in the world; between 1986 and 1991 Costa Rica lost 4.2% of remaining forest cover per year (Sanchez-Azofeifa et al., 2001). To address this and other environmental issues, the country began building a system of national parks and private reserves in the 1970s, which today encompasses over one quarter of the national territory. Yet deforestation in non-protected areas may continue, isolating parks as forest islands (Sanchez-Azofeifa et al., 2003). Further expansion of non-extractive protected areas is impractical, if not inappropriate, given Costa Rica's population growth rate of 1.7% (World Bank, 2007) and lingering concerns over lack of just compensation for private property incorporated into the current park system (Steed, 2003). PES emerged in Costa Rica partly in response to the need to address land use choices on private property.

The forestry sector in Latin America has a long history of government subsidies through interest-free loans, tax exemptions, provision of seedlings, extension services and even direct payments (Haltia and Keipi, 1997). Costa Rica is no exception. Evolution of forestry incentives began in the late 1970s with tax credits aimed at offsetting costs involved in establishing and managing forest plantations (Fig. 1). From remarkably favorable credit conditions, to tradable tax vouchers, Costa Rica used subsidies to promote growth in the forestry sector. Over time, however, international pressure mounted to eliminate subsidies. An acute financial crisis in the early 1980s saw the country as the first of several Latin American nations to default on international loans (Lara et al., 1995) at a time when its per capita debt load was among the highest in the developing world (Biesanz et al., 1982). Subsidies to the forestry sector were politically unsustainable since Costa Ricans failed to see much contribution from forestry to the local economy. The third World Bank loan, negotiated during ensuing structural adjustments, abolished forestry subsidies (Watson et al., 1998). But Costa Rica articulated the broader social cost of deforestation and the need to compensate private land holders for ecosystem services their forest stewardship provides; this was part of the impetus for designing a mechanism that addresses these externalities.

3. PES Overview

PES was authorized in the fourth national forestry law in 1996 (Fig. 1), which recognizes four environmental services provided by forest ecosystems: biodiversity, watershed function, scenic beauty, and greenhouse gas mitigation through carbon storage and sequestration. Landholders may participate through several land use modalities which currently include (a) reforestation through plantations, (b) protection of existing forest, (c) natural forest regeneration, and (d) agroforestry systems. Table 1 describes these and past modalities in greater detail. Payment per hectare is uniform across all contracts within each modality (Table 1); though beginning in 2009 as part of the latest World Bank financing arrangement of 2006, land with exceptional ecosystem-service value may receive added compensation (World Bank, 2006). Payments range from roughly \$41/ha per year for natural forest regeneration, to a cumulative sum of \$816/ha for a ten year reforestation (i.e. plantation) contract.

Table 1
Legal status of PES modalities over the last decade. The legal citations listed in parentheses are referenced in the citation column on the right.

Modality	Status	Criteria	Current payments	Priority zones
Forest protection	Dates from Forest Law 7575 to present	2 to 300 ha enrolled, up to 600 ha within indigenous areas	$64/ha per year for five year period; renewable	SINAC biological corridors; Existing biological corridors; Protection of AyA hydrologic resources; Unpurchased protected areas; Locations in cantons with MIDEPLAN Social Development indexes lower than 40%
Reforestation	Dates Forest Law 7575 to present	Between 1 and 300 ha enrolled; Maximum 50 ha enrolled; Minimum 50 ha enrolled.	$816/ha over ten-year period	“High potential” forest plantations; Areas with threatened species; Pastures defined as Kyoto lands; Projects under natural regeneration for at least one year
Natural forest regeneration	Dates from first mention in 2005 to present[a]	Minimum of 2 ha	$41/ha per year for five year period; renewable	None specified
Agro-forestry systems	Dates from 2003 to present	350 to 3500 trees per participant; Up to 336,000 trees per joint project, cooperative or indigenous reserve; Specific requirements per ha.	$1.30 per tree, over three year period	Projects with organizations with FONFOFIFO agreements; Land as described in Ministry of Agriculture's Land Use Capacity Report (1995); Areas with specific agreements with FONOFIFO
Forest management	Dates from Forest Law 7575 until 2002	Criteria determined by conservation area	¢123,540 (or about $343) per ha, over five year period	Priority determined by conservation area (SINAC)

[a] In practice, forest regeneration was allowed as a PES land use from the beginning in some regions.

Through 2008, over 89% of PES area had been recruited in the forest protection modality. Depending on the budget, in-coming PES-based forest protection area ranged from as much as 88,829 ha in the 1997 to as little as 20,629 ha in 2001 yet was always more than an order of magnitude greater than reforestation and management modalities (Fig. 2). In practice though, interviews and field-based mapping suggest that natural forest regeneration was sometimes allowed under forest protection contracts at least in northwest Costa Rica. The cumulative forest protection area through 2008 sums to 668,369 ha. This figure includes contract renewals though, and thus over-estimates the spatial footprint of forest protection through PES. The agroforestry is reported by number of trees instead of area. Trees are more often linear in arrangement, such as “living fences,” making this a more appropriate statistic than area.

While available data do not allow for identifying renewed contracts, Costa Rica's national park system with 541,500 ha offers a point of reference for appreciating the significance of PES on the private landholdings landscape. If, for instance, 50% of cumulative area in the forest protection modality (i.e. 50% of 668,369 ha) represents renewed contract area, then the total spatial extent of the PES forest protection modality alone would translate to 62% percent of the area protected in the national system. This is a reasonable renewal estimate based on discussions with FONAFIFO officials. An additional mean of 3489 ha per year has been contracted through the reforestation modality and individual trees in the agroforestry modality have increased over time from 97,381 in 2003 to 656,295 trees in 2008. In the aggregate, PES land uses constitute a significant footprint on the national territory.

Nominally influencing land use management through positive incentives, as opposed to regulatory land use restrictions, on such a large fraction of privately-held land may be unparalleled in the world. Further underscoring the significance of Costa Rica's investment in PES is its relative importance in the national budget. For the first decade of PES, the mean annual budget exceeded $13.3 million USD or 0.43% of Costa Rica's 2006 national budget.[1] To put this in perspective, the entire EPA budget for 2006 comprised 0.0003% of the US federal budget, or a difference of three orders of magnitude relative to this single program within Costa Rica's portfolio of environmental initiatives. This extensive investment highlights the country's commitment to landscape conservation but also the need to rigorously assess PES impact.

[1] Data Sources: PES budget: FONAFIFO, Costa Rica 2006 National Budget: CIA World Fact Book 2007, EPA 2006 Budget: EPA website, US 2006 National Budget: CIA World Fact Book.

4. Framework for Assessing PES Impact

Costa Rica has navigated a complex array of PES program design tradeoffs. One example of this is the fact that the link between forest ecosystem services and PES is largely indirect. The country-wide PES scheme rests on the assumption that forest land use, as prescribed by PES modalities (Table 1), provides some or all of the services mentioned in the law: watershed services, carbon services, scenic beauty and biodiversity-related services. This is true to widely varying degrees. Yet for certain, forest ecosystem services minimally depend on the existence and/or regeneration of forests. As PES is currently designed in Costa Rica, forest cover serves as a proxy for ecosystem services. Forest land use—whether plantation establishment, natural forest protection, natural forest regeneration, or agroforestry systems—serves as the monitoring target without regard to explicit, site-specific indicators of ecosystem services.

This indirect approach is not ideal on many counts. Yet it does offer several clear advantages. Procedures have long been established for remote monitoring of forest cover and, in theory, PES baseline data exists via archived imagery and/or classified land cover time series at the program's inception. Also, having forest land used as the target facilitates cross-site comparisons, relative to more specific site-based criteria like water quality standards, sedimentation rates or stand-based measures of carbon storage. While the broader research community may attempt to define and measure PES impact against specific indicators of specific or bundled ecosystem services, few studies actually do this (though see Morse et al., 2009 for carbon storage analysis in the Caribbean plain of northern Costa Rica).

Evaluating PES impact on forest cover is two-pronged. First, land use management and land cover must be monitored to ensure compliance with the PES modality prescribed by each contract. Monitoring is relatively straight forward in concept but less-so in practice. It requires clear definitions, well-tested and consistently-applied technical procedures for both PES site visits and remote sensing analyses. A second and more assumption-dependent aspect of evaluating impact is determining additionality (see Wunder, 2007 for an overview of additionality in relation to PES and forest cover). Determining additionality involves constructing a plausible counterfactual to each PES contract to serve as a control. Approximating the land use expected without PES typically entails comparative observations before and after and/or simultaneous sampling that matches similar PES and non-PES farms. Modeling may also be used to construct a spatially-explicit null hypothesis landscape. In Table 2 we review the advantages and disadvantages of these approaches. Note, however, that additionality is not explicitly part of Costa Rica's PES

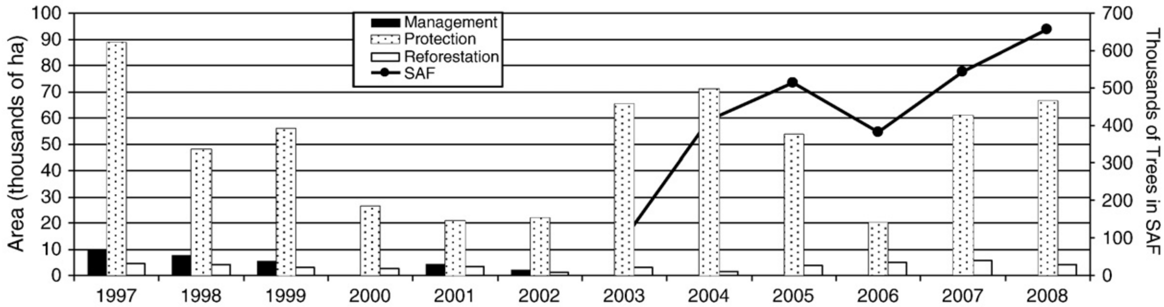


Fig. 2. Time series of the recruited area per modality and number of trees in the agroforestry modality (labeled as SAF for *sistema agroforestal*).

design and is nowhere part of the Forestry Law 7575. Instead, this criterion is externally-imposed, evolving along with the international climate change policy dialogue.

A confounding issue regarding the additionality of PES in Costa Rica is that the law authorizing payments intended to internalize the benefits of ecosystem functioning also prohibits forest clearing (see Article 19, Ley 7575). One interpretation means that in the absence of payments, 89.1% of cumulative PES contract area, i.e. the total forest area conserved through the forest protection modality of PES, would have been conserved anyway via Article 19 if all land holders complied with the law. An alternative interpretation is that PES contracts serve as a necessary pre-condition for the application of Article 19 since the ban on forest clearing probably would not have been politically feasible without PES. As such, the ban on forest clearing and the effect of PES must be examined synergistically; it may be impossible to disentangle what the effects on forest cover are due to payments alone.

5. Important Considerations in Measuring PES Impact

Three interrelated themes are important to consider in measuring the impact of Costa Rica's PES scheme: spatial data considerations, sampling considerations and the effects of institutional path dependency owed to the unique evolution of PES in the country. Regarding spatial data, explicit criteria and technical procedures for regentes (third-party forestry consultants charged with PES monitoring) to follow were slow to come about during initial contract establishment and subsequent monitoring. Only in 2004 did the PES Procedures Manual specify how, where and in what units GPS data should be recorded. Even then, the requirement was only for the purpose of identifying the farm as a point (*Gaceta* 46, March 3, 2004). Data collected prior to 2004 were recorded in a variety of incompatible formats, resulting in unnecessary spatial error when changing the datum and projection in post-hoc fashion. Only in 2006 and later were regentes required to map a polygon corresponding to the ground area (s) contracted for PES within the larger farm. The paucity of adequate spatial data makes satellite-based monitoring a challenge for early years of PES, particularly if it is not coupled with extensive field mapping and verification.

Sampling considerations arise from the dynamic, progressive nature of conservation in Costa Rica and are further exacerbated by uncertainty in spatial data mentioned above. Regardless of the approach taken to evaluate PES impact (see Table 2), any assessment hinges on knowing what area corresponds to PES contracts, what area does not, and what area is ineligible for PES, such as the land in national parks. Whether land corresponding to protected areas established during the time frame of an impact analysis—such as the more than 15,000 ha added from 1996 to 2000—is considered eligible for PES, biases the outcome either way. Moreover, pre-PES forestry incentives accounted for around 140,000 ha of reforestation (plantations) prior to the first cohort of PES (De Camino et al., 2000). Many of these contracts, along with over 22,199 ha of natural forest protection from Forest Protection Certificates or CPBs (Fig. 1f and g), were still in effect during the early years of PES (De Camino et al., 2000). Combined, this is equivalent to 63% of the total area of contracts for the first phase of PES implementation from 1997 to 2000. And this is precisely the period that all PES impact studies have focused on to date (see below).

FONAFIFO is the government entity that has served as the “bank” for PES since its inception and as the implementing unit since 2003. Contrary to what is typically reported, FONAFIFO existed since 1990 to incentivize forestry activities through special-term financing (Article 32, Ley 7216, Gaceta 245 – Alcance 48). Individual forestry professionals involved in this and other pre-PES initiatives were then later involved in PES. This is significant because in most of the country there was no ground-level outreach mechanism in the early years of PES. The well-studied and oft cited case of the non-governmental organization FUNDECOR in the Central Volcanic Range is more the exception than the rule in terms of ground-level outreach. See Locatelli et al. (2008) for discussion on the role of intermediaries.

As a testament to the importance of social networks and information access, land owners participating in pre-PES incentives were disproportionately represented in early cohorts of PES. In 2005

Table 2
Advantages and disadvantages of different research designs for assessing PES impact.

Approach	Advantages	Disadvantages	Studies using approach
Before and after (observational)	Simplicity. Can provide good control for socioeconomic/farm-level variability since land cover of same farms is compared at ≥2 times.	PES is only one of many factors that may drive land use/landscape change; disentangling the drivers of change is challenging at best.	Sanchez-Azofeifa et al., 2007; Morse et al., 2009
Matched samples (observational)	Simultaneous. Can provide effective control for broad-scale socioeconomic trends (e.g. changes in the international beef or timber markets) if such trends affect PES and non-PES farms similarly.	Never possible to match on all relevant variables (e.g., social networks and information access). Broad-scale socioeconomic trends may not affect PES and non-PES farms similarly given the documented difference in their character.	Pfaff et al., 2008; Morse et al., 2009; Sierra and Russman, 2006
Null model (statistical and/or observational)	In theory can control for all confounding variables. Can be made spatially explicit.	Relies heavily on assumptions and more complex null models may be challenging for non-specialists to interpret.	Morse et al., 2009[a]

[a] Authors constructed a very simple, aspatial null model by using farm-based interview data about what PES participants would have done with their land if not for PES and compared the land cover expected under these responses at the aggregate landscape level with the actual observations under the PES scheme.

nearly two-thirds of participants interviewed from 1997, 1998 and 1999 PES cohorts in the northwestern province of Guanacaste had participated in pre-PES incentives or received special-term forestry financing prior to PES ($n = 19$). Yet 60% of non-PES landholders were still unfamiliar with the program in the same region in 2005 ($n = 49$). In the Osa Peninsula Sierra and Russman (2006) noted that the early PES participants were already familiar with past forestry incentives and the individuals who promoted them (i.e. the same regentes who subsequently promoted PES).

In concept, the objective, target and to some degree, the participant profile for pre-PES and PES were quite distinct. Yet evidence suggests that, in practice, land owners arguably perceived little to no difference between pre-PES and PES in the first cohorts of PES. The conceptual difference was far more significant to the international community than to participants or prospective PES participants at that time. Pre-PES programs aimed for reforestation exclusively, implying certain starting land cover and other farm characteristics. The implied spatial correlation between pre-PES and PES contracts through existing social networks and institutional path dependency, significantly affected the de facto impact of PES on forest land cover. Interviews in northwest Costa Rica suggest that regeneration of natural forest was allowed, in practice, within the protection modality. For all of these implementation eccentricities, institutional path dependency is an important consideration for framing adequate evaluations of PES impact on forest land cover.

Altogether, these three interrelated factors reveal that the starting point for PES is rather fuzzy, lacking a clear demarcation in both space and time. The consequence on measuring PES impact is that results are biased positively or negatively depending upon whether and how these considerations are treated. Before-and-after studies should consider how forest owed to pre-PES incentives affects outcome of a PES analysis if considering forest area for an entire landscape. Without doing so, the apparent impact of PES is diluted by considering all forested lands outside of PES as a result of a "business as usual" scenario, whereas at least some of it is owed to (a) CPB, an earlier forestry incentives which only differed nominally from the first cohorts of PES, (b) those wait-listed for PES and/or (c) protected area status established during the study period in question. Similarly, studies employing a farm-level PES and non-PES comparison should take care not to sample farms contracted under pre-PES incentives as non-PES land. In most cases, however, these effects may only be considered qualitatively given the lack of adequate spatial data.

We highlight these considerations not to argue that PES impact assessment is too difficult or unreliable to attempt. To the contrary, we suggest that by considering how these circumstances may affect analyses and their results, we draw more robust and meaningful conclusions about when, where and why PES is useful or not. These challenges are unsurprising given the limitations in technology, monitoring capacity and the overall nascent state of PES in the mid-1990s. Also, the land use provisions and corresponding technical rules for the Kyoto Protocol were embryonic but have since served as influential context for thinking through PES and related technical specifications. Spatial data considerations that seem obvious or easily feasible now were far less so then; norms for determining baselines and additionality were in their infancy (and are still vigorously debated today for that matter). The reforestation and/or avoided deforestation approach to Kyoto land use provisions was being debated, affecting developing country posturing about their national forest cover trends and also influencing on-going domestic forestry initiatives. As detailed in the next section, different studies take these considerations into account to drastically varying degrees (Table 3).

6. Meta-analysis of PES Impacts on Forest Cover

We found four studies that met the criteria of explicitly addressing the role of PES on forest cover (Table 3) and several studies of forest cover change that indirectly tie in to this discussion on the impact of PES on forest land use in Costa Rica. Of the first group, Sanchez-Azofeifa et al. (2007) and Pfaff et al. (2008) are national studies whereas Morse et al. (2009) and Sierra and Russman (2006) are sub-national studies respectively focusing on the Caribbean plain in the north and the Osa Peninsula in southwestern Costa Rica. All of these studies focus on the early cohorts in the first years of PES implementation, making the considerations described in the previous section particularly relevant to the research design and interpretation of results. Only the regional studies incorporated fieldwork and landholder survey data.

Each study differs in its design for evaluating the effect of PES (Table 2). This facilitates a rich comparison for exploring what we know and do not know about PES impact, but also necessitates great attention to detail in terms of making generalizations. Sanchez-Azofeifa et al. (2007) and Sierra and Russman (2006) do not directly employ a baseline or control to address PES impact or additionality. Rather, both examine whether PES is a significant predictor variable in statistical models of deforestation and farm-level land cover composition, respectively. In contrast, Pfaff et al. (2008) use a sophisticated statistical matching approach to pair PES farms with non-PES farms that are similar in biophysical setting and market proximity. These "matched" non-PES farms serve as a control representing the deforestation rate expected in the absence of PES from 1997 to 2000. Morse et al. (2009) take a different approach still, using farm-level survey data to construct an aspatial null hypothesis or baseline via self-reported land use choices that would have been employed but for enrolling in a PES or pre-PES contract. They also assess PES impact at the landscape level by examining bidirectional forest cover change for landscape regions with and without PES. That is, they compare forest gains, losses, and maintenance in a PES priority region, the San Juan Biological Corridor (2425 km^2), with the surrounding landscape where little attention has been given to PES.

6.1. Review of National PES Studies

Pfaff et al. focused only on the forest protection modality within the PES program. In comparing deforestation rates for PES and non-PES farms they found payments had virtually no impact. Controlling for some of the other confounding drivers of deforestation, the analysis concluded that PES prevented forest loss on less than 0.25% of land enrolled in the program using matched non-PES farm deforestation as the indicator. This means forest would have been conserved on virtually all PES land even without payments. As further evidence to support this conclusion, the authors found that PES contracts were located on areas with very low probability for deforestation (assuming that past drivers of deforestation accurately indicate current risk, which is debatable).

The statistical matching approach for the treatment variable (i.e. PES) in this study is a notable methodological advancement in terms of establishing a plausible control for the evaluation of policy impacts over diverse geographies, as with the case of PES in Costa Rica. While this study provides an excellent first-cut by controlling for market proximity and biophysical setting, other critical factors that affect land use decisions in relation to forest trajectory for Costa Rica were not considered. A follow-up opportunity to make conclusions more robust and meaningful would examine the role of information access and local development context. For example, to what extent do local real estate market trends and tourism intersect with PES in conserving forest? If these factors were controlled for, would PES additionality have been greater or, more likely, would it have been even less than the 0.21% Pfaff et al. estimated?

It is not clear how or whether the study effectively identified the exact forest areas paid for by PES and whether the non-PES sampled areas were actually non-PES (i.e. eligible but not enrolled). This information was key to the analysis. Since the study only considered

Table 3
Summary of studies assessing the impact of PES on forest cover.

	Study	Focus/scope	Analysis	Methods	Considerations[a]	Results	Assessing additionality	Reliability for policy decisions
National studies	Pfaff et al., 2008	National 1997–2000 Protection modality only	Farm-level Compared deforestation rate on non-PES farms w/assumed 100% forest conservation on PES farms. Examined expected deforestation probability for area corresponding to PES contracts (unclear what spatial data was used)	Farm as sample unit (but no fieldwork) Statistical matching algorithms Satellite-image classifications to derive deforestation Controlled for biophysical and socioeconomic variables via statistical matching	(1) Deforestation only (2) No (3) Not considered (4) No (5) Not clear how they determined deforestation area at the farm level given incomplete national records	PES prevented loss of forest on only 0.21% of enrolled land compared to expected forest loss without payments. Found that PES contracts are located on land with very low probability for deforestation, suggesting no additionality.	Innovative statistical pairing of PES and non-PES farms, matched to be similar in terms of biophysical character and accessibility	Moderately reliable
	Sanchez-Azofeifa et al., 2007	National T_1 1986–1997 T_2 1997–2000 All PES modalities (problematic given unidirectional forest change analysis)	Predicted deforestation rate as a function of PES density[b], life zone, topography and market proximity Examined% of PES area occurring ≤1 km of recent deforestation event. Examines national deforestation rate 1960–2005[c] in relation to start of PES	5×5 km wall-to-wall grid without regard to PES contract areas Satellite-image classifications to determine deforestation rate within grid cells. Compared national deforestation rates (aspatial) before and after PES No fieldwork	(1) Deforestation only (2) No (3) Not considered (4) Not clear (5) Poor; PES point data inappropriate for predicting deforestation rate	National deforestation rate decreased from 0.06% in T_1 to 0.03% in T_2. No greater intensity of PES contracts around protected areas compared with broader landscape. No meaningful correlation between PES contracts and deforestation fronts. PES density was not a significant predictor of deforestation rate from 1997 to 2000.	National deforestation rate time series before and after PES policy.[c] No design control, statistical only by looking for correlation between proximity of PES and deforestation fronts, also by testing whether PES density was a statistically significant predictor of deforestation rate.	Unreliable
Sub-national studies	Morse et al., 2009	San Juan Biological Corridor compared with surrounding area (north Caribbean plain) T_1 1986–1996 T_2 1996–2001 All PES modalities	Landscape-level comparison of deforestation in corridor (PES focal area) and surrounding landscape. Compared deforestation rates before and after PES. Quantified connectivity in corridor before and after PES	Farm-level land use interviews used to model expected land cover in the absence of PES. Satellite-based land cover classification, spatially-explicit change trajectories for many forest types and other land cover classes. Plantation forest separated appropriately for analysis.	(1) Bidirectional (2) Yes (3) Yes (4) Not applicable (5) Appropriate; reliable, independent land cover and socioeconomic data	Deforestation in corridor decreased from 1.43% to 0.1% per year after PES; Net gain in forest was 0.5 and 0.6% per year in T_1 and T_2, respectively 50% of PES participants would have cleared or harvested some forest but for PES, indicating 5300 ha of avoided deforestation PES participants had lower farm dependence than non-PES	Comparing deforestation before and after PES for targeted region (corridor) versus untargeted region Farm-level survey data used to model next best land use, if not for PES.	Reliable
	Sierra and Russman, 2006	Osa Peninsula (southwest Costa Rica) 1997–2002[d] Protection modality only	Farm level interviews to obtain self-reported land cover composition[e] Compared land cover for PES and non-PES farms. Tested PES explanatory power for predicting farm land cover composition compared with ag. Production costs	Farm-level interviews and mapping Land cover self-reported in surveys No repeated measures, instead assumed land cover differences in across cohorts represented effects of PES on land use decisions over time use farmer-reported LC	(1) Considers forest, agricultural and *charral* land use/cover. (2) Yes (3) Yes, discussed pre-PES incentives during interviews (4) Not applicable (5) Good: ground-based farm mapping but land cover was self-reported	No difference in% forest for PES and non-PES farms or between later PES cohorts and non-PES farms More *charral* for late PES cohorts than non-PES farms Farms in early PES cohorts had smaller% agricultural land use than later cohorts Neither PES nor ag. Production costs predicted% forest on farms but PES was most significant predictor of% *charral*	Additionality only indirectly and loosely addressed by assuming non-PES farms provided an indication	Moderately reliable

[a] (1) Bi-directional forest cover change analysis? (2) Plantations separated from other forest cover? (3) Pre-PES incentives considered (e.g., CPB)? (4) Treatment of protected areas established *during* study period? (5) Quality of spatial data for questions posed and analyses performed?

[b] Defined as the number of PES projects per 5×5 km grid cell area (i.e. sample unit for regression). This is problematic since it is neither spatial nor is any evidence presented that number of projects and total project area (ranging from 2 to 4025 ha) are closely correlated.

[c] Do not cite the source of these secondary data nor the methods used to determine deforestation rate. Methodology (e.g., definition of forest) significantly impacts results (see Fig. 3).

[d] This study did not explicitly specify a study period and did not stratify their sampling approach by cohort. Rather they recorded number of years since PES enrollment with the maximum being 6 as listed in Table 1 of their article. We, in turn, approximated a study period of 1997 to 2002.

[e] Small sample size ($n = 30$) and possible bias against smallest farms since the minimum mapping unit was 30 ha. This is difficult to assess without knowing the distribution of farm sizes.

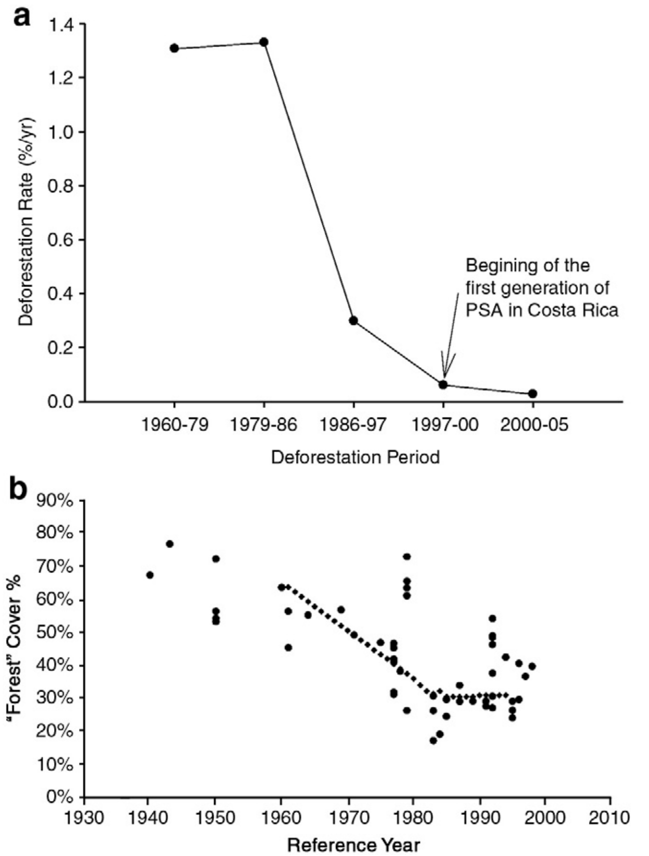


Fig. 3. (a) Time series of national deforestation rates for Costa Rica from unknown data source(s) from 1960 to 2005 with arrow denoting when PES began (reproduced from Sanchez-Azofeifa et al., 2007) (b) National forest cover statistics from published literature as compiled (reproduced from Kleinn et al., 2002). Diamonds represent estimates from FAOSTATS database up to 1994.

the protection modality, how were the 36,484 ha of other PES lands enrolled during the study eliminated from the sample since spatial data are limited at best? Also, how were still-active pre-PES incentives treated in the analysis, such as the 22,199 ha of CPB area? This combined area represents a sizeable area that could not be readily distinguished within what was considered the "non-PES" landscape and this has implications for the results.

Similar to the Pfaff et al., 2008, conclusions from the more generalized non-farm approach of Sanchez-Azofeifa et al. (2007) concurred in finding little PES impact. They concluded that at the national level PES neither lowered the national deforestation rate nor reduced total deforestation. Moreover, only 7.7% of PES payments in Costa Rica were located within 1 km of deforestation fronts, where the authors assumed greatest risk for forest loss. Though the study did not define "deforestation front" or how these fronts were derived, we assume they meant any pixel that converted from forest to non-forest from 1986 to 1997.

Sanchez-Azofeifa et al. (2007) came to this conclusion that PES had no impact on deforestation in a rather indirect way, likely because of spatial data limitations. They used the density of geographic coordinates representing PES contracts (i.e. number of PES points per 5×5 km^2 grid cell—the sample unit in the regression) as one of several multicollinear variables to predict deforestation. PES density does not necessarily correlate closely with PES contract area since project sizes varied from <2 ha to 4025 ha. In predicting deforestation, the coefficient of the PES density variable was not statistically significant with or without other topographic or market-proximity control variables included in the regression. This lack of significance, along with a time series of deforestation rates from 1960 to 2005 (Fig. 3a) underpinned the study's conclusion (Sanchez-Azofeifa et al., 2007).

While illuminative in considering how PES is distributed across the ecoregions of Costa Rica's national landscape, and also in relation to deforestation events, the reliability of this study's conclusions are low (Table 3). No source was given for the deforestation time series (reproduced in Fig. 3a) underpinning their conclusion. If data are based on FAO Forest Resources Assessments (FRA), they are extremely problematic for interpreting in this way owing to the deforestation bias that translates to periodic backwards-projecting statistics revisions (see Grainger, 2010).

In referencing these data, the authors cite different deforestation rates in the text than what is presented in the graph (0.03% versus 0.3%, respectively, for 1986–1997). Using either number for that data point, the trend according to these data is clear. National deforestation already saw a precipitous decline prior to PES—from over 1.3% for 1979–1986 to about 0.1% at the start of PES. The deforestation rate declined only slightly by comparison, after the PES program began (Fig. 3a). This strongly suggests factors other than PES explain the steep decline in Costa Rica's deforestation rate.

Historic forest area data for Costa Rica, however, have varied wildly depending upon data sources, spatial and temporal resolution, the definition of forest used, how secondary forest is treated, the formula used to calculate deforestation rate (Puyravaud, 2003), and other details as shown in Fig. 3b (reproduced from Kleinn et al., 2002). Without knowing where or how the data in Sanchez-Azofeifa et al., 2007 (reproduced in Fig. 3a) were derived, we do not have great confidence in them when examined alongside the great variety of reported forest area statistics presented in Kleinn et al.'s literature review of on forest cover change in Costa Rica (reproduced in Fig. 3b).

The regression analysis in Sanchez-Azofeifa et al. (2007) did not distinguish between PES and non-PES land. That is, the difference in total forest area for a 5×5 km cell at t_1 and t_2 is aspatial. Further, using PES density as the predictor does not directly link the area contracted for PES to the process modeled by the regression (i.e. deforestation rate). Using points (PES density) rather than polygons of contracted forest protection area, means that forest receiving payments for any given point may have been counted in an adjacent cell given the vast range of PES contract areas (2 to 4025 ha). The inability to connect PES contracts to their corresponding geographic space is undeniably the greatest challenge for reliable national-level assessments of PES impact on forest cover. Error in the predictor variable in Sanchez-Azofeifa et al. (2007) likely swamped the small variance in the dependent variable given the very low deforestation rate.

Another challenge in interpreting results for both of the national-level studies stems from the need to account for the roughly 178,000 ha of forest plantations in the country (Food and Agriculture Organization, 2005). This is a significant area equivalent to 81% of PES land under forest protection contracts for the first four years of PES (218,993 ha). Yet neither Pfaff et al. (2008) nor Sanchez-Azofeifa et al. (2007) separate plantation forest in their land cover classifications. This means that plantation harvests were considered no different than the clearing of natural forest, despite that the reforestation modality of PES was designed to alleviate pressure on natural forests precisely by allowing timber harvesting. Not distinguishing plantation and natural forest cover underestimates PES impact.

Nonetheless, barring the many analytical challenges and data limitations, the general conclusion that PES has not significantly lowered deforestation is likely valid at the national-scale given the lack of both outreach and spatial targeting in PES implementation in the early cohorts, not to mention an already-low net deforestation rate. Analyses of later PES cohorts with better spatial data should yield a far greater understanding of the impact of PES on deforestation. Yet even with better data and a more nuanced analysis, focusing on deforestation alone is a rather incomplete approach, as the review of sub-national PES impact studies reveals in the next section.

6.2. Review of Sub-national PES Studies

In the Osa Peninsula of southwest Costa Rica, Sierra and Russman (2006) found that forest cover—whether primary, intervened or total forest—is not significantly different for PES (all cohorts lumped together) and non-PES farms. The authors then compare non-PES farm composition with PES farms of different contract start dates as a proxy for repeated-measures of forest area on the same farms at different points in time. Even still, no differences existed between forest land cover on PES and non-PES farms regardless of whether the comparison was made with early or late PES cohorts. The authors conclude that there was no difference in initial forest cover conditions nor in pressure to convert forest for PES and non-PES farms.

More compelling, perhaps, are comparisons of other land covers/ uses. PES farms in Osa had nearly five times as much early successional growth or charral as non-PES farms (11.2% of PES farm area versus 2.5%). And agricultural land use on non-PES farms comprised, on average, far greater area on the farm (22.6%) compared with PES farms 7.8%. Further, PES was the most important variable in predicting the proportion of early successional growth on farms whereas PES was not a significant variable in predicting other land cover types (forest or agriculture).

Sierra and Russman (2006) concur with the two national studies on the conclusion that PES has had little direct “additional” impact on conserving standing forest. Indeed, for this study region they found that even non-PES landholders leave three-quarters of their farm in forest anyway. Yet by looking more closely at land cover dynamics beyond just forest area alone, these authors reveal an interesting tendency. They conclude that PES may accelerate agricultural abandonment given the significantly lower fraction of agricultural land use and the much higher fraction of early successional growth on PES farms compared to non-PES farms. These results suggest that the current design of PES may be better suited for landscape restoration than achieving additional forest protection.

The authors make an unstated but critical assumption in drawing this conclusion, however: that farms across different PES cohorts differed only in the year that the PES contract was made. That is, they assume that the comparisons were not revealing differences in land cover composition across PES cohorts, but rather differences in land use choices over time that were attributable to PES enrollment. This assumption is questionable at best given the influence of institutional path dependency described in the Section 5 above. Another reason to believe that PES farms may vary across cohorts is the increased involvement of civil society in promoting PES. In the Osa Peninsula, for example, Conservation International began promoting and targeting areas critical to ecological connectivity between protected areas.

If their critical assumption is not valid, as we suspect, we offer an alternative interpretation of these results which still suggests that the authors have identified a noteworthy trend. In the early years the PES program likely attracted landholders with the lowest opportunity costs, as evidenced by their finding that the earliest PES cohorts had almost zero percent land in agriculture. As PES became a more established land use and/or as parcels comprised exclusively of forest were already enrolled, representation of mixed-use farms increased, as evidenced by their finding of a greater share of agricultural land use on farms in recent PES cohorts compared with farms in early PES cohorts. Capturing more landholders already engaged in non-forest land use suggests the possibility of greater PES additionality via limiting agricultural expansion, ensuring forest in an agricultural mosaic, and diversifying farm income in a way that produces land rent from the provision of ecosystem services rather than agriculture alone. An appropriate follow-up would be to test whether the forest area on these mixed-use farms would have been suitable for agricultural use and using a much larger sample size. If supported, our interpretation of Sierra and Russman's results concurs with their conclusion that in the aggregate and over time, PES plays a role in the abandonment of agriculture, facilitating both forest conservation and expansion relative to a business-as-usual landscape scenario.

In agreement with these findings in the Osa Peninsula, Morse et al. (2009) found that PES played a role in forest expansion in the north Caribbean plain. Over the study period, total forest area experienced a net increase both before and after PES: by 0.5% from 1986 to 1996 and by another 0.6% 1996 to 2001. A spatially-explicit Landsat-based land cover change analysis demonstrated that the net increase resulted from plantation establishment, secondary forest development and reduced loss of natural forest. Forest plantations increased from 1% of the biological corridor in 1986 to 15% in 2001 (Schedlbauer et al., 2008). More than two-thirds of PES participants reported that without payments they would not have reforested their land, suggesting PES had some “additional” impact.

For a smaller subset of this study area immediately surrounding Braulio Carrillo National Park, Schelhas and Sanchez-Azofeifa (2006) concluded little if any forest recovery occurred despite conservation and reforestation efforts. This contradicts the results of Morse et al. (2009) but is explained by the fact that Schelhas and Sanchez-Azofeifa (2006) only examined unidirectional forest loss, used a minimum mapping unit of 3 ha and their study region did not include the area of aggregated reforestation within the broader San Juan Biological Corridor stretching from the national park, northward to the border with Nicaragua.

Similar to findings in the Osa Peninsula, charral was a dynamic land cover in the north Caribbean plain. More area transitioned to either forest or back to pasture than remained charral in either time step of the analysis. Though Morse et al. (2009) did not focus on the role or patterns of charral transition, we interpret data published in their appendix to compare with transitional vegetation dynamics in Sierra and Russman (2006).

This reveals a dynamic but dominant trend of charral transitioning to forest instead of pasture. The area of charral in the northern landscape decreased drastically after PES was implemented: 9% loss from 1996 to 2001 compared with 2.25% decline for the decade prior to PES. In the decade before PES, 10,060 ha converted from charral to various classes of forest, compared with 7170 ha that converted to pasture. Pre-PES forestry initiatives played an important role in conversion to forest (Schedlbauer et al., 2008) The succession of forest from charral after PES was implemented was even more dramatic, however, with nearly twice as much charral transitioning to forest (9280 ha) than returned to pasture (4300 ha). These data suggest that forest land uses gained in relative attractiveness compared with leaving land in a transitional state of charral. While no direct attribution to PES can be made based on these observational data alone, this is a dynamic worth exploring, particularly in light of agreement across different regions of the country.

In terms of deforestation in this region, loss of natural forest was reduced from 1.43% per year before PES to 0.10% per year after the program went into effect. This is a significant decline and the timing suggests that PES played a role. Morse et al. (2009) modeled land use expected without PES and without the ban on forest clearing, revealing that up to 5300 ha of this avoided deforestation was owed to PES. This is the area under forest protection contracts represented by the 40% of surveyed PES landholders who indicated they would have otherwise converted forest to agricultural uses if not for payments. Hence, unlike all other impact studies, PES demonstrated additionality for some of this forest retention, or “avoided deforestation,” compared to a business-as-usual scenario in northern Costa Rica.

Prior to PES, 61% of forest loss occurred inside the PES focal region of the San Juan Biological Corridor. Of the greatly reduced deforestation in the second time step (1996 to 2001), only 7% occurred inside this Corridor and 93% occurred outside where little emphasis had been given to PES. Spatial prioritization of PES contracts in this corridor region may have been among the most coordinated and targeted efforts in all of the country since this area was the focus of unique aid/financing arrangements (Schedlbauer et al., 2008). These results of Morse et al. (2009) suggest that spatial targeting of PES can indeed produce greater additionality if implemented—as is being attempted now in recent cohorts across the country. More convincing of the effect of PES in retaining forest cover in the Corridor would be to know the area of PES contracts in the study landscape surrounding the Corridor, if any. The authors do not disclose this, however, possibly owed to a lack of spatial data as discussed above.

Other sub-national studies cite PES as having a role in forest cover expansion but without explicitly measuring PES impact. Rather, these studies look at the complex and interrelated factors affecting land use such as agricultural intensification, labor migration, real estate development, conservation policies/agendas and changing commodity prices (Arroyo-Mora et al., 2005; Calvo-Alvarado et al., 2009; Daniels, 2010; Kull et al., 2007). These studies note net increases in forest cover in the northwestern province of Guanacaste and in the Guabo Valley of the central Pacific coast. All cite PES as playing a role in the observed forest expansion.

7. Discussion

At the national level, PES had virtually no additional impact on lowering deforestation because forest would have been conserved on PES sites even without payments. In contrast, a sub-national analysis—arguably the most rigorous, grounded and data-intensive assessment performed to date—concluded that PES appreciably lowered the deforestation rate in some places compared to a business-as-usual approach (Morse et al., 2009). "Rates" of deforestation are aspatial though. This means that a lower deforestation rate can result from declines in forest area lost and/or via development of forest cover on non-forested land. In Costa Rica's north Caribbean plain, spatially-explicit analysis of land cover conversions from one class to another suggests that forest regeneration and reforestation efforts play a dominant role in explaining the lowered deforestation rate.

Indeed, evidence suggests that the most significant contribution of PES in influencing land use choices may have been toward forest expansion through natural regeneration and plantation establishment (Morse et al., 2009; Sierra and Russman, 2006), a dynamic missed altogether by unidirectional analyses of Sanchez-Azofeifa et al. (2007) and Pfaff et al. (2008). Other sub-national studies of forest cover change in Costa Rica also indicated that PES contributed to forest expansion in four regions of the country (Daniels, 2010; Kull et al., 2007; Sierra and Russman, 2006; Morse et al., 2009). Yet results also suggest forest expansion was already occurring by 1997 when PES began, influenced in some cases by pre-PES forestry incentives, along with other changes affecting both the economics and culture of land use.

The difference in findings at the national and sub-national levels is less a question of scale dependency and more a matter of how the analyses were framed. Sub-national studies considered farm-level interview data, bidirectional forest cover change, pre-PES incentives, and also distinguished between natural and plantation forest cover. In contrast, the national analyses focused exclusively on deforestation without considering nuances of PES implementation or the role of institutional path dependency. The latter implies a spatial correlation between pre-PES incentives (i.e. reforestation) and early PES contracts. This, plus the rather fuzzy delineation of PES in both time and space (see Section 5), explains why Sanchez-Azofeifa et al. (2007) unsurprisingly found no spatial correlation between PES and deforestation at the national level.

Land use dynamics have changed radically for many parts of Costa Rica in recent years. Projecting deforestation risk forward in linear fashion using models built on historic drivers of deforestation is not likely to indicate the best or most efficient allocation of PES contracts on the whole. PES was designed to compete with, what was a couple of decades ago, the next-best land use: extensive cattle ranching (Castro et al., 2000). Yet Costa Rica transitioned from a primarily agrarian economy to a service-based one as highlighted in 1994 when the tourism industry surpassed all other economic sectors in earning foreign currency. The Ministry of Agriculture has incentivized the intensification of cattle ranching in recent years, and real estate development and urbanization are now key drivers of land use change in some parts of Costa Rica (Daniels, 2010). In 2004 alone, nearly three million square meters of new construction were permitted (Estado de la Nacion, 2006).

In light of de facto PES implementation, results from sub-national studies and our own experience, we offer one hypothesis regarding the precise decision space significantly impacted by PES. That decision space is defined by a relatively specific set of circumstances—but circumstances that happen to be widespread in recent years in Costa Rica: where landowners with some minimum threshold of off-farm income (or who are absentee) are faced with the annual or semi-annual decision to clear early successional growth through burning and cutting, PES tips the balance toward forest regeneration. Without payments, however, the potential future restrictions on forest clearing and/or the cultural habit of land clearing dating back to the social function doctrine would otherwise impede or retard forest recovery despite decreased land use competition. Exploring this hypothesis in different regions of the country would shed light on the underlying context that determines whether PES is a useful tool or not, and how PES design might be tweaked if future objectives include more significant impact on the loss of standing forest.

Other questions that our meta-analysis highlights include to what the role of PES is in the persistence of forest expansion trends in different parts of the country. Fifty-nine percent of PES reforestation participants in the northern plain indicated they would replant after plantation harvest (Morse et al., 2009). Would this be the case without payments or would landholders, for example, sell/lease land for conversion to pineapple plantations?

Shifts in the patterns and drivers of Costa Rican land use, forest cover dynamics in the eastern United States suggest one plausible trajectory for the country. In the eastern US, forest cover expanded in the early 20th century following agricultural abandonment (Evans, 2010). Despite decreased agricultural land use, however, forest area has contracted in recent decades owing to urbanization and other competing land uses (Drummond and Loveland, 2010). Costa Rica could use the current economic downturn to dedicate part of PES toward addressing forest loss via urbanization and coastal development. Complementing natural-area selection criteria, increased targeting forested land at the urban interface may be valid. Precedent is already set for this in the Heredia watershed of Costa Rica's populous and ever-growing Central Valley (Kosoy et al., 2007).

Another contemporary force affecting land use is the escalating demand for biofuels. Biofuels production, and in particular energy policy that dictates its relative profitability, impacts forest cover on marginal lands in the eastern United States (Evans, 2010) and in the tropics (Lapola et al., 2010). Similarly, considering threats to forest from escalating biofuel demand as Costa Rica strives to meet its 2021 mandate for carbon neutrality, may be relevant for future spatial targeting of PES contracts.

8. Conclusions

The role of PES in forest expansion is poorly understood at the national level in Costa Rica since it has never been examined. Landholder absenteeism and the non-farm-dependent tendency of PES participants on the whole (Sierra and Russman, 2006; Morse et al., 2009; Zbinden and Lee, 2005) suggest that Costa Rica's economic transition from an agrarian economy could be an important precondition for PES efficacy. REDD initiatives will undoubtedly include using PES as a mechanism to address deforestation in countries, or in regions of some countries, that are largely agrarian and/or with extensive forest-frontier dynamics. Hence, the issue of development context and "starting conditions" merits deep consideration with possibly differing implications for PES as a forest recovery tool versus an instrument to prevent the loss of standing forest. Costa Rica's PES design and implementation experience may offer more insight on the former than the latter.

Costa Rica's PES has successfully contributed to the restoration of degraded lands, reflecting the de facto interpretation and implementation of its initial design phase (1997 to 2000) and the influence of pre-PES programs on its early implementation. Its focus on marginal lands in implementation translated to little impact on preventing the loss of standing forest. Though by the mid to late-90s when PES began there was relatively little deforestation to prevent compared with historical trends. Achieving greater PES additionality for "avoided deforestation" requires reconsidering design and implementation explicitly toward that end. Spatial targeting is increasingly part of current PES implementation (World Bank, 2006). Future impact assessments will reveal the efficacy of targeting in this context and with far more reliable results with the advent of better spatial data.

Evaluating spatial targeting should include metrics for overall landscape connectivity, however, since Morse et al. (2009) demonstrated increasing isolation of natural forest patches despite reduced deforestation and net forest expansion. Targeting should also encompass landscape-level ecosystem services provision and move away from the exclusive-focus on forests in tropical latitudes. For example, intensification of land use in northwest Costa Rica has facilitated dramatic forest recovery on marginal lands, but with negative impacts on wetlands in low lying areas which have become the focus of agricultural crop production (Daniels and Cumming, 2008).

PES in Costa Rica is not an objective per se but an instrument for influencing land use toward the continued or enhanced provision of forest-derived ecosystem services; whether it is an appropriate tool or not depends on the context, which changes over time. PES may have had little "additional" impact on deforestation at the national level—difficult to say without further analysis and given results to the contrary in northern Costa Rica—but it has had considerable influence on promoting forest expansion in some regions. Costa Rica's program was initially designed to reward landholders for ecosystem services provided by forest without regard to deforestation risk (i.e., additionality was not part of the forestry law). As our meta-analysis demonstrates, an understanding of the ground-level context is essential to ensure that questions about PES impact are actually relevant and to evaluate PES outcomes in a meaningful way.

Acknowledgements

Thanks to the land owners who shared their time and experience, along with officials in MINAE and FONAFIFO for invaluable consultations. The first author is grateful to a NASA Fellowship for funding fieldwork. We thank the participants from the workshop Payments for Ecosystem Services: From Local to Global, held in March 2007 in Heredia, Costa Rica and hosted by the University of Vermont's Gund Institute for Ecological Economics and the Universidad Nacional de Costa Rica's International Centre of Economic Policy for Sustainable Development (CINPE), with funding from the Blue Moon Foundation. Finally, we thank three anonymous reviewers for their helpful comments.

References

Arroyo-Mora, J.P., Sanchez-Azofeifa, G.A., Rivard, B., Calvo, J.C., Janzen, D.H., 2005. Dynamics in landscape structure and composition for the Chorotega region, Costa Rica from 1960 to 2000. Agric. Ecosyst. Environ. 106, 27–39.

Biesanz, R., Biesanz, K.Z., Biesanz, M.H., 1982. The Costa Ricans. Waveland Press, Prospect Heights, IL.

Calvo-Alvarado, J., McLennan, B., Sanchez-Azofeifa, A., Gavin, T., 2009. Deforestation and forest restoration in Guanacaste, Costa Rica: putting conservation policies in context. Forest Ecology and Management 258 (6), 931–940.

Castro, R., Tattenbach, F., Gamaz, L., Olson, N., 2000. The Costa Rican experience with market instruments to mitigate climate change and conserve biodiversity. Environ. Monit. Assess. 61, 75–92.

Chomitz, K.M., Brenes, E., Constantino, L., 1999. Financing environmental services: the Costa Rican experience and its implications. Sci. Total Environ. 240, 157–169.

CIA, 2007. The World Fact Book – Costa Rica. Available at https://www.cia.gov/cia/publications/factbook/geos/cs.html, accessed on May 2, 2007

Daniels, A.E., 2010. Forest expansion in northwest Costa Rica: conjuncture of the global market, land use intensification and forest protection. In: Nagendra, H., Southworth, J. (Eds.), Reforesting Landscapes: Linking Pattern and Process. Springer, New York, pp. 227–252.

Daniels, A.E., Cumming, G.S., 2008. Conversion or conservation? Understanding wetland change in northwest Costa Rica. Ecol. Appl. 18, 49–63.

De Camino, R., Segura, O., Arias, L.G., Pérez, I., 2002. Costa Rica: forest strategy and the evolution of land use. World Bank Evaluation Country Case Study. The World Bank, Washington, DC. Series 148.

Drummond, M., Loveland, T., 2010. Land-use pressure and a transition to forest-cover loss in the eastern United States. Bioscience 60, 286–298.

Estado de la Nacion, 2006. Duodecimo informe estado de la nacion en desarrollo humano sostenible. Programa Estado de la Nacion, San Jose, Costa Rica. (ISBN: 9968-806-37-4).

Evans, T.P., 2010. Threats to forest transition in the midwest United States. In: Nagendra, H., Southworth, J. (Eds.), Reforesting Landscapes: Linking Pattern and Process. Springer, New York, pp. 175–204.

Food and Agriculture Organization, 2005. State of the World's Forests. FAO, Rome, Italy.

Grainger, A., 2010. The bigger picture — tropical forest change in context, concept and practice. In: Nagendra, H., Southworth, J. (Eds.), Reforesting Landscapes: Linking Pattern and Process. Springer, New York, pp. 15–43.

Haltia, O., Keipi, K., 1997. Financing Forest Investments in Latin America: The Issue of Incentives. Inter-American Development Bank, Washington, DC.

Kleinn, C., Lenin, C., Morales, D., 2002. Forest area in Costa Rica: a comparative study of tropical forest cover estimates over time. Environ. Monit. Assess. 73, 17–40.

Kosoy, N., Martinez-Tuna, M., Muradian, R., Martinez-Alier, J., 2007. Payments for environmental services in watersheds: insights from a comparative study of three cases in Central America. Ecol. Econ. 61, 446–455.

Kull, C.A., Ibrahim, C.K., Meredith, T.C., 2007. Tropical forest transitions and globalization: neo-liberalism, migration, tourism and international conservation agendas. Soc. Nat. Resour. 20, 723–737.

Lapola, D.M., Schaldach, R., Alcamo, J., Bondeau, A., Koch, J., Koelking, C., Priess, J.A., 2010. Indirect land-use changes can overcome carbon savings from biofuels in Brazil. Proc. Natl Acad. Sci. 23, 3388–3393.

Lara, S., Barry, T., Simonson, P., 1995. Inside Costa Rica—The Essential Guide to Its Politics, Economy, Society and Environment. Resource Center Press, Albuquerque, New Mexico, USA.

Locatelli, B., Varinia, R., Salinas, Z., 2008. Impacts of payments for environmental services on local development in northern Costa Rica: a fuzzy multi-criteria analysis forest policy and economics. For. Policy Econ. 10, 275–285.

Miranda, M., Dieperink, C., Glasbergen, P., 2006. Costa Rican environmental service payments: the use of a financial instrument in participatory forest management. Environ. Manage. 38, 562–571.

Morse, W.C., Schedlbauer, J.L., Sesnie, S.E., Finegan, B., Harvey, C.A., Hollenhorst, S.J., Kavanagh, K.L., Stoian, D., Wulfhorst, J.D., 2009. Consequences of environmental service payments for forest retention and recruitment in a Costa Rican biological corridor. Ecol. Society 14 (1), 23 online] URL: http://www.ecologyandsociety.org/vol14/iss1/art23/.

Pagiola, S., 2008. Payments for environmental services in Costa Rica. Ecol. Econ. 65, 712–724.

Pfaff, A., Robalino, J.A., Sanchez-Azofeifa, G.A., 2008. Payments for environmental services: empirical analysis for Costa Rica. Working Paper Series of the Terry Sanford Institue of Public Policy. Duke University, Durham, NC. USA. Available at http://sanford.duke.edu/research/papers/SAN08-05.pdf. accessed on May 22, 2010.

Puyravaud, J., 2003. Standardizing the calculation of the annual rate of deforestation. For. Ecol. Manage. 177, 593–596.

Rojas, M., Aylward, B., 2003. What are We Learning from Experiences with Markets for Environmental Services in Costa Rica? A Review and Critique of the Literature. International Institute for Environment and Development, London.

Sanchez-Azofeifa, G.A., Daily, G.C., Pfaff, A.S.P., Busch, C., 2003. Integrity and isolation of Costa Rica's national parks and biological reserves: examining the dynamics of land-cover change. Biol. Conserv. 109, 123–135.

Sanchez-Azofeifa, G., Harriss, R.C., Skole, D.L., 2001. Deforestation in Costa Rica: a quantitative analysis using remote sensing imagery. Biotropica 33, 378–384.

Sanchez-Azofeifa, G.A., Pfaff, Al., Robalino, J.A., Boomhower, J.P., 2007. Costa Rica's payment for environmental services program: intention, implementation, and impact. Conserv. Biol. 21, 1165–1173.

Schedlbauer, J.L., Sesnie, S.E., Morse, W.C., 2008. Efficacy of environmental service payments for forest conservation in Costa Rica's San Juan – La Selva Biological Corridor. Integr. Manag. Coastal Freshwater Syst. 2 (2), 31–35.

Schelhas, J., Sanchez-Azofeifa, G.A., 2006. Post frontier forest change adjacent to Braulio Carrillo National Park, Costa Rica. Human Ecol. 34, 407–431.

Sierra, R., Russman, E., 2006. On the efficiency of environmental service payments: a forest conservation assessment in the Osa Peninsula, Costa Rica. Ecol. Econ. 59, 131–141.

Steed, B., 2003. Completing the mosaic: the conservation of private lands in Costa Rica. Journal of Land, Resources, and Environmental Law 173, 173–180.

Watson, V., Cervantes, S., Castro, C., Mora, L., Solis, M., Porras, I.T., Cornejo, B., 1998. Making space for better forestry: Costa Rica country study. Policy that Works for Forests

and People Series No: 6. International Institute for Environment and Development, London.
World Bank, 2006. Scaling up and mainstreaming payment for environmental services in Costa Rica. Project Appraisal. Environmentally and Socially Sustainable Development, Latin America and the Caribbean Regional Office.
World Bank. 2007. Key Development Data & Statistics. Available at http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/, accessed May 2, 2007
Wunder, S., 2007. The efficiency of payments for environmental services in tropical conservation. Conserv. Biol. 21 (1), 48–58.
Zbinden, S., Lee, D.R., 2005. Paying for environmental services: an analysis of participation in Costa Rica's PSA program. World Dev. 33, 255–272.