Agriculture, Ecosystems and Environment 156 (2012) 27–36

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

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

Payment for Ecosystem Services: The roles of positive incentives and information sharing in stimulating adoption of silvopastoral conservation practices

Kelly Garbach[a,b,*], Mark Lubell[a], Fabrice A.J. DeClerck[c]

[a] Department of Environmental Science & Policy, University of California Davis, One Shields Avenue, Davis, CA 95616, USA
[b] Department of Plant Sciences, University of California Davis, One Shields Avenue, Davis, CA 95616, USA
[c] Department of Agriculture and Agroforestry, CATIE 7170, Turrialba 30501, Costa Rica

ARTICLE INFO

Article history:
Received 22 July 2011
Received in revised form 1 December 2011
Accepted 12 April 2012

Keywords:
Conservation
Costa Rica
Payment for Ecosystem Services
Latin America
Silvopastoral
Tropical rangelands

ABSTRACT

Payment for Ecosystem Services (PES) applied to agricultural systems, such as tropical rangelands, seeks to provide multiple services while sustaining food production. However, there is considerable debate regarding the effectiveness of PES programs for changing farmer behavior and enhancing conservation. We interviewed 101 cattle farmers in Costa Rica following the Regional Integrated Silvopastoral Approaches to Ecosystem Management Project (RISEMP) PES pilot (2002–2008). We evaluated adoption of silvopastoral conservation practices—reintroducing trees and shrubs into permanent pastures—that provide varying proportions of public and private benefits; we estimated influence of PES, technical assistance (e.g., farmer training) and information sharing on stimulating their adoption. Our analysis included evaluation of information sharing pathways and accounted for key farm capital characteristics. We found that technical assistance associated with PES had a positive influence on adoption rates, particularly for practices with private benefits of improving rangeland productivity. PES payments alone had the most detectable, positive influence on the adoption of only one type of practice, multistrata live fences, which primarily provides public goods such as biodiversity habitat and carbon sequestration, but are perceived by many farmers to reduce rangeland productivity. Farmers accessed information about management practices through both social and institutional sources. While the RISEMP pilot focused on institutional information sources and technical assistance, future policy design should also include social information networks and consider how farmer-to-farmer communication influences conservation practice adoption.

1. Introduction

Payment for Ecosystem Services (PES) approaches are a core strategy within a growing call for a more direct conservation paradigm that bridges the private interests of landowners and the public benefits of conservation management (Ferraro and Kiss, 2002; Niesten et al., 2004; Scherr et al., 2004; Wunder, 2005). The basic framework of PES is to provide financial incentives to private landowners to implement conservation practices that provide critical ecosystem services such as water and nutrient cycling, pest control, and climate regulation. As agricultural systems must increasingly provide these ecosystem services as well as sustain food production (MA, 2005), the potential for applying PES to farming landscapes has received a great deal of recent attention (Tomich et al., 2004; Wunder, 2007; Wunder et al., 2008). However, there is still considerable debate regarding the effectiveness of PES programs for changing farmer behavior and management practices.

This study evaluates the role of PES in farmer adoption of silvopastoral conservation practices (e.g., reintroducing trees and shrubs) in the tropical cattle rangelands of Costa Rica's Esparza region. Tropical rangelands have become a conservation priority worldwide. In the Mesoamerican biodiversity hotspot, permanent cattle pastures are a primary land use; throughout Central America rangelands account for more than 9 million ha, or 38.7% of the region's terrestrial area (FAO, 2008; Ibrahim et al., 2007). Recent assessments have found more than 50% of these lands to be highly degraded (Szott et al., 2000), which has reduced farm productivity and local livelihoods and diminished provision of ecosystem services (Pérez, 2002). Degradation of natural habitat, biodiversity loss, and increased erosion are the cumulative result of pasture management decisions made by all producers in a region.

Costa Rica is recognized as a pioneer in the PES approach (Sánchez-Azofeifa et al., 2007), however the framework for PES policy and mechanisms were created for forest protection and reforestation and their application to tropical rangelands is quite recent (Ibrahim et al., 2007; Pagiola, 2008; Sánchez-Azofeifa

* Corresponding author at: Agricultural Sustainability Institute, University of California Davis, One Shields Avenue, Davis, CA 95616, USA. Tel.: +1 530 752 5297.
E-mail address: kgarbach@ucdavis.edu (K. Garbach).

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http://dx.doi.org/10.1016/j.agee.2012.04.017

et al., 2007; Wunder, 2007). The Regional Integrated Silvopastoral Approaches to Ecosystem Management Project (RISEMP) pilot, 2002–2008, was a follow-up to the first phase of PES in Costa Rica (1997–2000). Review by Sánchez-Azofeifa et al. (2007) found this initial phase to be an important advance for environmental policy, however reduction in deforestation rates could not be attributed to PES alone. RISEMP promoted silvopastoral conservation practices in Costa Rica, Nicaragua, and Colombia with funding from the Global Environmental Facility and World Bank (Casasola et al., 2007; Ibrahim et al., 2007; Pagiola, 2008; Vaessen and van Hecken, 2009). The main objectives of RISEMP were to use PES incentives to increase adoption of silvopastoral practices in degraded systems, and evaluate the resulting improvements in ecosystem function and socioeconomic welfare (Vaessen and van Hecken, 2009).

The RISEMP pilot illustrates two central knowledge gaps in conserving ecosystem services in agricultural systems. First, PES used in the RESEMP pilot is a policy tool that overlays more general decisions about the adoption of agricultural practices and diffusion of innovations. Diffusion of innovation theory describes how information about agricultural practices spreads through a community of practitioners (Rogers, 2003). As practitioners weigh the potential costs and benefits of new practices, information sharing is a key pathway that can support their adoption (Lubell and Fulton, 2007). Market-based policy tools like PES, which alter the costs and benefits of adopting different practices, cannot be understood without analyzing how the policy incentives interact with the social processes that influence practice adoption.

Second, it is important to determine whether PES is equally effective for all conservation practices regardless of whether they offer primarily private benefits directly to a farmer, or public goods to the broader community and environment. The effectiveness of different policy tools, including PES, depends on the relative levels of private and public benefit produced by the conservation practices being promoted (Pannell, 2008). Positive incentives, such as PES, are expected to be most effective for increasing the adoption rate of practices with high levels of public goods (Pannell, 2008), because these practices are less likely to be spontaneously adopted by farmers. A core tenet of PES is additionality, using policy to stimulate new conservation that would not otherwise take place (Morrison and Aubrey, 2010). Practices that provide sufficient private benefit to farmers (e.g., by increasing farm productivity) are likely to be adopted regardless of PES payments, which calls into question the necessity of investing scarce conservation resources to stimulate practices that would happen anyway.

To evaluate these knowledge gaps, we interviewed 101 cattle farmers in Costa Rica's Esparza region and estimated the influence of PES participation on the adoption of silvopastoral conservation practices, controlling for the influence of information from local institutions (e.g., extension and outreach agencies), social relationships (e.g., farmer-to-farmer information sharing such as consulting with neighbors about management decisions), and other variables identified by diffusion of innovation theory. We analyzed the role of PES in stimulating adoption of practices with different mixtures of private economic benefits to farmers (e.g., planting improved pasture grasses and forage banks) and public goods in terms of enhanced ecosystem services (e.g., protecting riparian forests) promoted by RISEMP (Table 1). We found that the technical assistance associated with PES has the most consistent effect on adoption rates, particularly for practices with substantial economic benefits in the form of improved rangeland productivity. PES payments alone had the most detectable, positive influence on the adoption of only one type of practice, multistrata live fences, which primarily provides public goods in the form of ecosystem services including: biodiversity habitat; carbon sequestration; and air purification. Multistrata live fences are perceived by many farmers to reduce rangeland productivity; however some farmers also recognize the potential benefit of shade in supporting livestock productivity by mitigating heat stress in cattle. Social and institutional information sources play a complex role in decisions to adopt conservation practices, depending on the content of social discussion, and correlation between exposure to outreach agencies and participation in PES programs.

1.1. *Case study overview: PES in Costa Rica*

Costa Rica's PES program began in 1997 with the enactment of Forest Law 7575, which provides the legal basis to offer payments to landowners for providing ecosystem services on their lands including: mitigation of greenhouse gases; hydrologic services and water provision; biodiversity conservation; and scenic beauty (Pagiola, 2008). Costa Rica created the National Fund for Forest Financing (FONAFIO) to administer PES contracts funded by revenues from a national tax on fossil fuels, along with additional support from a World Bank loan from 2001 to 2006 and grant from the Global Environmental Facility through the Ecomarkets project. The PES program in Costa Rica continues to evolve: eligible land uses were simplified to forest conservation and timber plantations in 2000; an agroforestry contract was introduced in 2004; and a contract for natural forest regeneration is being introduced.

Reviews of the conservation impacts of the initial phase of PES, which focused on forest protection and services generated by forests, highlighted that deforestation rates could not be attributed solely to PES (Sánchez-Azofeifa et al., 2007). External factors such as declining deforestation rates in the late nineties, falling beef prices, reduced agricultural subsidies, and a limited amount of productive land remaining under forest were critical factors in the broader context for evaluating the impacts of PES on forest conservation (Pfaff and Sánchez-Azofeifa, 2004; Robalino and Pfaff, 2012). Systematic trends in program participation are another consideration that may have constrained program impacts (Arriagada et al., 2009). Arriagada et al. (2009) found that land owners that leave forests unmanaged, wish to protect property rights, and have few viable alternative land uses tended to have higher program participation.

Recommendations that emerged from reviews of program impacts included the need to target PES on lands most vulnerable to land use change to avoid enrolling lands that would have otherwise remained forested (Pfaff et al., 2008). This observation has been echoed in other PES programs in Mesoamerica, including Mexico's Payment for Hydrological Environmental Services program, for which program reviews highlighted that program funds were distributed in areas with low deforestation risk (Muñoz-Piña et al., 2008) and fragmented distribution may have further hindered providing measurable public benefits to downstream users (Alix-Garcia et al., 2009). These observations highlight one of the main critiques of Payment for Ecosystem Services as a policy tool: the need to establish baseline metrics and invest in conservation actions that provide demonstrable, additional benefits.

1.2. *The Regional Integrated Silvopastoral Approaches to Ecosystem Management Project (RISEMP) pilot, 2002–2008*

In Costa Rica PES has been expanded to include cattle farming landscapes only recently in the context of the RISEMP pilot (Ibrahim et al., 2007). RISEMP differed from Costa Rica's existing PES scheme for forest protection in two important ways. First, the RISEMP pilot promoted a suite of silvopastoral conservation practices, which are broadly defined to encompass incorporating trees into permanent pasture systems (Dagang and Nair, 2003; Nair, 1985) and the associated public benefits of biodiversity conservation and carbon sequestration, while decreasing the total area of degraded pasture (Casasola et al., 2007; Ibrahim et al., 2007; Pagiola, 2008). The seven silvopastoral conservation practices included in RISEMP

Table 1
Private benefits and public goods provided by RISEMP silvopastoral conservation practices.

RISEMP silvopastoral conservation practices	Description	Private benefits	Measure of private benefit	Public goods	Measure of public goods RISEMP PES Index		
					C sequestration	Biodiversity	Composite
Improved pasture	Hybrid grass species such as *Brachiaria radicans*, *Brachiaria decumbens* are incorporated into existing pasture areas.	Increase biomass production in pastures; year-round ground cover.	Stocking rates; live weight gain (kg/cow/yr); years to 600 kg LW[a,b] milk production (kg/cow/day)[c]		0.1	0.4	0.5
Simple live fence	Linear plantings of small trees along pasture edges simple fences are pruned regularly and maintained	Harvested foliage can provide cattle fodder; cut branches provide materials for new live fences, structures.	Branches harvested (e.g., branches pruned every 6–8 months); foliage harvested (tons/yr)[d]		0.3	0.3	0.6
Pasture trees-low density	Trees incorporated into existing pastures at low densities (<30 trees per ha)	Trees can provide soil stabilization, erosion protection, and shade to cattle (e.g., mitigation of heat stress).	Milk production (kg/cow/day) and respiratory rate[c]; live weight gain (kg/cow/yr)[b]	Trees can provide some stabilization of soil, erosion protection.	0.3	0.3	0.6
Forage banks	Stands of leguminous shrubs such as *Leucena* are planted adjacent to pasture or crop fields.	Cut forage can supplement pasture grass.	Forage (tons/ha/yr)[e]		0.5	0.4	0.9
Pasture trees – high density	Trees incorporated into existing pastures at high densities (>30 trees per hectare)	Trees can provide soil stabilization, erosion protection, and shade to cattle (e.g., mitigation of heat stress).	Milk production (kg/cow/day) and respiratory rate[c]; live weight gain (kg/cow/yr)[b]	Trees can provide habitat "stepping stones" for birds and other wildlife, stabilization of soil, erosion protection.	0.5	0.5	1
Multistrata (complex) live fence	Linear plantings of large trees growing freely along pasture edges; multistrata fences are not pruned and allowed to grow to develop a full canopy structure (>4 m in height, >4 m in canopy radius)	Trees can provide: stabilization of soil, erosion protection; and shade for cattle offering potential to mitigate heat stress during the dry season.	Milk production (kg/cow/day) and respiratory rate[c]; live weight gain (kg/cow/yr)[b]	Trees can provide wildlife habitat and corridors[f]; stabilization of soil, erosion protection, and carbon sequestration.	0.5	0.6	1.1
Riparian forest	Trees and natural vegetation surrounding water sources, including streams, rivers, or microwatersheds; vegetation is unpruned and trees grow to full canopy structure.	Source of dry season forage, shade for cattle offering potential to mitigate heat stress during the dry season.	Milk production (kg/cow/day) and respiratory rate,[c] live weight gain (kg/cow/yr)[b]	Trees can provide wildlife habitat, erosion protection, protection of water quality, and carbon sequestration and air purification.	0.7	0.8	1.5

[a] Holmann (1999).
[b] Blackshaw and Blackshaw (1994).
[c] Souza de Abreu et al. (2003).
[d] Cherry and Fernandes (2004).
[e] Ibrahim et al. (2000).
[f] León and Harvey (2006).

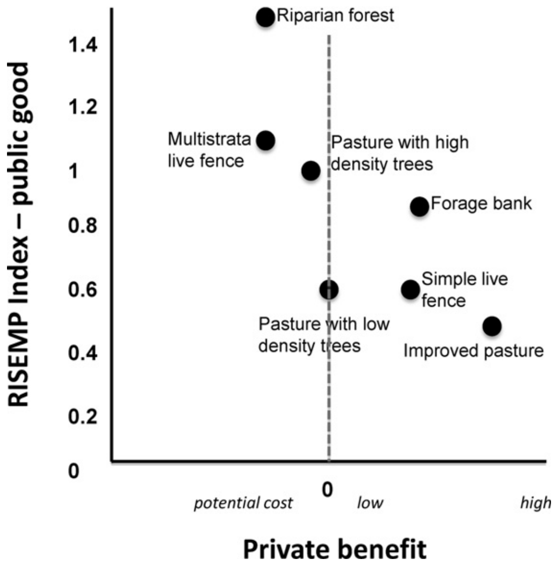

Fig. 1. Variation in public goods, measured as the RISEMP Index, and private benefits in silvopastoral conservation practices promoted by RISEMP. Private benefits that support farm productivity increase right of zero; practices with a potential cost to farmers fall left of the line, neutral to farmers but with varying degree of public goods (vertical distribution).

were: planting hybrid grasses; incorporating trees in live fences (linear plantings of trees along pasture borders); planting scattered trees within pastures; forage banks of leguminous shrubs (*Leucena*), sugarcane (*Saccharum officinarum*), or king grass (*Pennisetum purpureum*) that can be cut for fodder; and protecting riparian corridors (Casasola et al., 2007). The silvopastoral conservation practices have benefits that range from primarily private (e.g., planting hybrid pasture grasses and fodder banks that increase productive capacity by increasing available cattle feed), to primarily public goods (e.g., conserving riparian forest, which provides biodiversity habitat, air and water purification), and those that offer a mix of both (Table 1).

This study builds on previous evaluations of PES initiatives, which have focused exclusively on practices designed to enhance public goods, by evaluating the influence of policy incentives on practices that span a range of private and public benefits. As a metric of public goods, we used the RISEMP index of the relative contribution of each conservation practice to carbon sequestration and biodiversity habitat; payments were based on the composite index score of both over the total area on which the conservation practice was adopted (Murgueitio et al., 2003).[1] Precise metrics of private benefits were not included in the program literature. Thus, we qualitatively ranked them on the basis of existing studies and determined whether practices had relatively greater or fewer private benefits relative to the other practices (Fig. 1). As we discuss in greater detail below, we expected the efficacy of PES to stimulate adoption to vary according to the levels of public environmental and private economic benefits provided by each practice.

A second important difference is that RISEMP emphasized hands-on extension activities (e.g., education, outreach, demonstrations of how to best use plant materials) and was explicitly designed to test the effects of PES with and without technical assistance. Farmers in this pilot were randomly placed into three treatment groups: (1) those that only received payments; those that received only extension assistance; and (3) those that received payment + technical assistance (Casasola et al., 2007).[2] These attributes make the RISEMP pilot ideal for investigating the adoption silvopastoral conservation practices with varying degrees of private benefit and public goods and explicitly identify the role of PES in the broader context of diffusion of innovation. Furthermore, because some farmers received only the payment without technical assistance, it is possible to analyze the effectiveness of the financial incentive alone as well as test for interactions between payment and technical assistance.

1.3. PES in the context of diffusion of innovation

The efficacy of PES for stimulating adoption of a suite of conservation practices with varying benefits is usefully informed by the broader literature on the diffusion of innovation in agriculture. Diffusion of innovation theory (Rogers, 2003) has been used to describe how new agricultural practices are adopted including: hybrid corn (Griliches, 1960); seed machinery and fertilizer following World War II (Evenson and Gollin, 2003); and innovations in on-farm conservation management such as habitat restoration in field edges (Brodt et al., 2009); and conservation tillage (Nowak, 1987). It is crucial to understand how farmers adopt conservation practices on active agricultural lands, as management innovations are increasingly needed to sustain provision of ecosystem services. Farmers may be most likely to adopt conservation practices if they have attributes such as higher education levels, capital, income, farm size and access to information (Prokopy et al., 2008). These attributes generally increase farmers' ability to participate in various pathways to adopting innovations, for example through increased awareness of and ability to attend community meetings. Investigating which pathways support adoption of conservation practices is highly relevant to PES, and particularly pilot programs such as RISEMP, because economic factors alone cannot explain the diffusion of innovations (Brodt et al., 2009; Nowak, 1987; Rogers, 2003).

Information sharing is a key pathway, or mechanism, that can support innovation adoption (Lubell and Fulton, 2007; Rogers, 2003). Information sharing includes communication with extension personnel, researchers, government agencies, local organizations, as well as between individual farmers. It can help enable decisions by spreading awareness about the costs and benefits of management innovations such as conservation practices (Lubell and Fulton, 2007). Farmers that access more information sources have been found to have higher rates of adoption of on-farm conservation practices (Nowak, 1987); gathering information from social contacts may be especially important and can take place through visiting neighboring farms, or consulting with other landowners regarding management decisions. For example, some farmers may observe and then follow the practices of the most successful operations in their community (Lubell and Fulton, 2007) or take cues from neighbors that champion and promote the practices they have found to be most useful (Risgaard et al., 2007).

[1] The seven silvopastoral practices listed may have both public and private benefits depending on the landscape context in which they are implemented (e.g., the main benefit of hybrid grass is enhanced forage on prime land with low erosion potential, but on marginal land with higher erosion potential enhanced ground cover may also have the added benefit of erosion protection). Our aim was to offer an overview of the main types of benefits for each practice when background conditions are held constant (e.g., their relative benefits if each were implemented on farmland with similar productive value in the same landscape context).

[2] Although monitoring and evaluation reports indicate that program participants were randomly assigned (Casasola et al., 2007), interviews with program officials revealed a strong desire for participants that remained committed throughout the duration of the pilot. This may have resulted in some bias in the selection process; for instance, well-connected farmers, such as those with active communication with officials at the Ministry of Agriculture, may have been assigned with increased frequency to the payment plus technical assistance group. Even if no invitation bias was present, farmers may have selectively accepted program participation invitations.

These relationships may have far-reaching policy implications. Robalino and Pfaff (2012) found that deforestation on neighboring land can significantly increase the probability of deforestation at a focal site and policies for agricultural development or forest conservation in one area can positively influence deforestation rates in neighboring (non-target) areas.

PES provides another pathway to facilitate adoption of management innovations. Payments, a financial instrument to encourage positive change, are situated in the broader constellation of policy tools that includes negative incentives (e.g., financial or regulatory instruments to inhibit change) and technology development (e.g., improved land management through strategic planning and other targeted research and development) (Pannell, 2008). In general, policy intervention is desirable before ecosystem services are severely degraded or lost all together, since many ecological processes express nonlinearities and threshold effects (Levin, 1999) and the cost of maintaining these services is often much lower than restoring them after they have been lost (Kremen, 2005). Specifically, through the PES approach, farmers receive payments for adopting land management and resource use that support continued provision of key ecosystem services, with payments made by external beneficiaries (Wunder, 2007). PES is expected to influence decision-making by providing payment to offset undesirable tradeoffs—including financial costs—on the part of the farmer, essentially using a positive incentive to bridge the gap between needs of external users and landowners (Wunder, 2007).

There are several important reasons for simultaneously considering the positive incentives provided by PES and the information sharing pathway highlighted by diffusion of innovation theory. Since information sharing often influences adoption of management innovations (Rogers, 2003), PES programs may be enhanced by recognizing and explicitly building this pathway. The RISEMP pilot included treatment groups in which farmers received payments; another group received payments + technical assistance. Past analysis of these treatment groups assumed that information transfer was enhanced exclusively by technical assistance and the involved institutions. However, given that information may flow through both institutional and social contacts (e.g., farmer-to-farmer), it is important to test this assumption by evaluating the influence of information sources across all PES participants, and not just the group that received technical assistance. Additionally, PES incentives may have a more detectable influence on some practices than others. Previous evaluation of environmental policy mechanisms have found that positive incentives, such as PES, may have the most influence when the target practice or behavior has many public benefits relative to the private benefits for the individual land manager (Pannell, 2008). Thus, PES may have less detectable influence on adoption of practices that have primarily private benefits that directly support farm productivity on individual farms.

These theoretical considerations suggest several testable hypotheses with respect to adopting silvopastoral conservation practices promoted through RISEMP in Costa Rica's Esparza region. *Hypothesis one* is that farmers receiving PES payments are more likely to adopt silvopastoral practices as conservation interventions; this is an evaluation of the effectiveness of PES. *Hypothesis two* refines the first, and states that PES will have the strongest effect on stimulating adoption of silvopastoral practices that primarily enhance public goods. *Hypothesis three* is that information sharing will complement the effects of PES pathways to adoption. Evaluating these three complementary hypotheses allowed us analyze the effects of PES in stimulating adoption of conservation practices in a tropical rangeland system.

2. Research design and methods: evaluating the RISEMP pilot in Esparza, Costa Rica

The RISEMP pilot included 124 farmers in the region divided into three treatments, including farmers that received: payments ($n = 27$); payments + technical assistance ($n = 69$); and technical assistance but no payment ($n = 28$) (Ibrahim et al., 2007). Participating farmers were randomly selected from a list of all of the farms registered with the Ministry of Agriculture and Livestock (*Ministerio de Agricultura y Ganadaria*, MAG) and the Esparza Agricultural Center (*Centro Agricola Cantonal de Esparza*). Participants represented small and medium-sized farm owners that earn their primary income from raising cattle and were willing to sign PES contracts and allow monitoring. Farmers were randomly assigned to groups in the RISEMP program (Ibrahim et al., 2007). The 96 total farms that received PES payment covered 3124.5 ha, representing approximately 60% of the total ranching acreage registered with the Ministry of Agriculture and Livestock (*Ministerio de Agricultura y Ganadaria*, MAG) in the region.

Costa Rica's Esparza region, the site of the RISEMP pilot and our follow-up surveys, covers 432 km^2 on the country's pacific coast (09°50′N and 84°38′W) and experiences a humid sub-tropical climate; temperatures range from 23 to 36 °C, with annual precipitation of 150–200 cm, concentrated primarily between May and November (Calvo, 1994). Dual purpose cattle ranching, for both milk and meat production, is the region's principal agricultural activity (Ibrahim et al., 2007). The seasonally dry climate poses a management challenge, as fodder availability is limited. In contrast, during the rainy months farmers must mitigate the impact of cattle on natural resources including water quality and soil stability.

We surveyed 101 farmers from December 2008 to February 2009, after the RISEMP pilot had closed. We conducted a census of program participants (based on participant lists held by program evaluators at the CATIE Center for Tropical Agriculture (Turrialba, Costa Rica) and Ministry of Agriculture and Livestock (Esparza, Costa Rica) and interviewed as many program participants as possible during the study period. Non-participants were identified at the local cattle auction yard (*subasta*) and invited to participate in interviews. Through personal interviews and field visits to the Ministry of Agriculture and Livestock and individual farms throughout the region, we achieved a 53% response rate from RISEMP participants (66 total: 14 that had received payments; 47 that received payments + technical assistance; 5 that received technical assistance alone). Additionally, we interviewed 35 farmers that had not participated in RISEMP (total $N = 101$).

The survey population adequately reflected the ranching practices in the region, including producers that focused on milk production, meat production and "double production" of both products on cattle farms of varying size and number of on-farm conservation practices (Table 2). Since the RISEMP pilot focused on small and medium-sized farms, and our goal was to conduct a follow-up evaluation, we interviewed only two farmers with holdings greater than 100 ha and our results may under-represent practices of the largest land owners. However, our survey does sufficiently represent the cattle farmers in the region that were engaged in RISEMP (53% of participants) and the region as a whole (50% of cattle farmers registered with the Ministry of Agriculture and Livestock). The survey included 70 questions about farm management practices, perceptions of environment, sources of information, communication with other farmers and farm characteristics; most of the responses were yes/no or 5-point Likert scales. The RISEMP participants received several additional questions about program participation (instrument available online at http://environmentalpolicy.ucdavis.edu/resource/survey-instrument-risemp-follow-esparza-costa-rica).

Table 2
Farm characteristics.

Farmer group	N	Education[a]	(SD)	Farm size (ha)	(SD)	Labor[b] (#)	(SD)	Cattle (#)	(SD)	Milk[c] (%)	Meat (%)	Double (%)
Non PES participants	35	1.1	(0.2)	41.8	(80.1)	3.1	(2.4)	47.0	(98.7)	26	43	31
Technical assistance	5	1.0	(0.2)	8.6	(2.4)	1.6	(0.5)*	11.0	(5.9)	0	100	0
Payment	14	1.0	(0.2)	16.3	(6.7)	2.9	(1.2)	22.9	(11.6)	0	50	50
Payment + technical assistance	47	1.6	(0.8)***	33.1	(22.5)	4.3	(2.2)**	34.8	(28.1)	4	26	70
Total	101	1.3	(0.6)	32.6	(50.2)	3.6	(2.2)	36.2	(61.5)	11	39	50

[a] Education was measured on a scale of 1–3: 1 representing one to six years of formal education; 2 representing 7–12 years of formal education; and 3 representing more than 12 years of formal education.
[b] Labor indicates the maximum number of people available for farm work during peak season including: farm operators, family, and employees.
[c] Milk, meat and double refer respectively to percentage of farms under diary production, meat production, or double when both milk and meat are produced.
Values are significantly different from other farmer groups detected by ANOVA, 95% confidence level
* $p < 0.05$
** $p = 0.001$
*** $p = 0.0001$.

We used logistic regression to evaluate adoption of the seven silvopastoral conservation practices listed in Table 1, accounting for the influence of: PES payments; technical assistance; payment + technical assistance; and information sources. We included two additional aspects in our analysis, farm capital and information sharing, as diffusion theory has emphasized these aspects as potentially important determinants of whether farmers adopt conservation practices (Prokopy et al., 2008). The farm capital variables that we evaluated were: farmers' education level, farm size (ha), labor resources (measured as the total number of laborers in peak season), and total head of cattle. As labor was significantly correlated with education, farm size and cattle (Table 3), and our sample was relatively small ($N = 101$), we selected labor and education as the two variables to represent farm capital. We measured information sharing by asking farmers to name the sources from which they frequently access information and counted the number of local institutions contacted by the producer, such as the Esparza Agricultural Center, a local feed coop that frequently hosts meetings and classes (range = 0–7). We also counted the number of social information sources including: speaking other farmers about management practices; visiting other farms; talking informally with neighbors about farming decisions; and attending community presentations on agriculture (range = 0–4). Separating institutional and social sources allowed us to estimate the influence of both the number and type of information sources on adopting silvopastoral conservation practices.

3. Results and discussion: factors that determine adoption of silvopastoral conservation practices

We found that the most frequently named information-sharing institutions were the Ministry of Agriculture and Livestock (named by 34% of respondents) and the local Esparza Agricultural Center (named by 25% of respondents). Both organizations were active in the RISEMP pilot, suggesting that exposure to institutional information is correlated with participation the PES program; analysis with linear regression confirmed this relationship ($R^2 = 0.30$, $F_{3,97} = 15.95$). Farmers that received payments had the highest number of institutional information sources (mean 1.3; correlation with treatment group, $p = 0.0001$), which was higher than farmers that received payment + technical assistance (mean 0.8; correlation with treatment group, $p = 0.05$) or technical assistance alone (mean 0.2; correlation with treatment group $p = 0.02$). Given that institutional information was embodied within RISEMP participant groups, we excluded it from the overall models of practice adoption to avoid multi-collinearity. Overall, farmers accessed more social information sources than institutional sources (Fig. 2); we included social information as a separate independent variable in the logistic regression as this influence was not accounted for in the RISEMP pilot design.

Prior to modeling the practices individually, we developed a simple linear regression model describing the total number of practices adopted (range 0–7, representing the 7 practices promoted by RISEMP), with dummy variables for each type of PES treatment and measure of farm capital and social information as independent variables (Table 4). The baseline category in this model is non-PES participants, so the slope coefficients on the dummy variables capture the effect of each PES treatment relative to non-participants. The overall model was significant, but the only significant individual factor was participation in payment + technical assistance. The model reflected the differences in the mean total number of silvopastoral conservation practices adopted (Fig. 2): 4.5 for non PES participants (farmers unaffiliated with RISEMP); 4.4 for those that received technical assistance; 4.9 for farmers that received payments alone; and 5.6 total practices for farmers that received technical assistance + payments. These initial results suggest that the combination of payment + technical

Table 3
Correlation among farm capital characteristics.

	Education	Farm size	Labor	Cattle
Education	1			
Farm size	0.60***	1		
Labor	0.24*	0.60***	1	
Cattle	0.05	0.93***	0.54***	1

Pearson's r, 99 df.
Significance at the 95% confidence level
* $p < 0.05$
*** $p = 0.0001$.

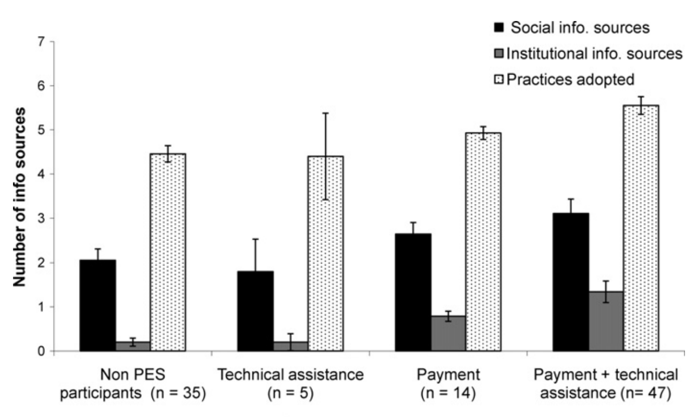

Fig. 2. Number of social information sources, institutional information sources, and total silvopastoral conservation practices adopted across farmer groups.

Table 4
Influence of PES, farm capital, and social learning on total number of silvopastoral practices adopted.

	Estimate	Standard error	*z*-Value	*p*-Value
Intercept	4.024	0.312	12.880	0.0001***
Technical assistance	0.024	0.797	0.030	0.976
Payment	0.175	0.367	0.477	0.634
Payment + technical assistance	0.791	0.209	3.778	0.0001***
Education	0.003	0.109	0.030	0.976
Labor	0.085	0.049	1.752	0.083
Social information	0.118	0.073	1.604	0.112

Adjusted $R^2 = 0.193$, $F_{6,94} = 4.99$, $p = 0.05$.
*** Significance at the 95% confidence level, $p = 0.0001$.

assistance is the most effective tool for stimulating adoption of conservation practices (Table 4). However, the estimates were not very large, partly because not all of the individual practices are equally affected by PES participation; thus it was important to model individual practices.

3.1. Adoption of different practices with private benefits vs. adoption of practices with public benefits

Rates of adoption for silvopastoral conservation practices across PES treatment groups provided initial evidence that PES may be most effective for practices with relatively higher public goods (Fig. 3). There are two classes of practices to consider from an empirical standpoint: those with 100% adoption within one (or more) of the PES groups, and those exhibiting variance within the PES groups. Practices that had 100% adoption by at least one group included: improved pasture; simple live fences; and low density tree plantings. These practices had very high adoption rates overall because they provide substantial private benefits directly to the farmers in the form of increased productivity.

When there was no variance in practice adoption within a PES category, it was impossible to estimate a statistical model that compares treatment groups; technically this is a problem of perfect prediction. Therefore we used *t*-tests to see if non-participants have adoption rates significantly lower than 100%, as observed in the PES groups. These tests suggest that PES participation slightly increased adoption rates for improved pasture, simple live fences, and low-density pasture trees. However, technical assistance alone did not increase simple live fence adoption, and payment alone did not influence low density pasture trees. Among these practices with very high adoption rates, payment + technical assistance had the most consistent effect—there was 100% adoption rates of these three practices in that group. In addition, payment alone was not associated with higher adoption rates, except in the special case of improved pasture.

In contrast, adoption of riparian forest, forage banks, and multistrata live fences showed more variable adoption rates (Fig. 3). These practices provide more public benefits in terms of enhancing ecosystem services (Fig. 1; Table 1) and in some cases there may be trade-offs with private benefits. For example, multistrata fences may reduce forage availability by shading out grasses along pasture edges (Garbach, 2012); farmer interviews revealed a concern that forage banks attract wildlife and pests such as snakes and rats despite their primary purpose of increasing feed available to livestock. It is important to note that our estimates of public goods were based on the RISEMP index of each practice's contributions to biodiversity habitat and carbon sequestration (Murgueitio et al., 2003). While it is not a precise field measure, this approach provides helpful estimate of the relative contributions of each practice. Riparian forests had the highest public goods score (1.5) of the suite of silvopastoral practices studied, and relatively few private benefits (Fig. 1); multistrata live fences score for public goods was high (1.1), also with few associated private benefits. In contrast, forage banks had a moderate score for public goods (0.9), but much lower than riparian forest, and was among the practices with greatest private benefits (Fig. 1; Table 1). Practices with fewer direct private benefits for farmers (or direct tradeoffs) are more likely to be responsive to PES payment incentives.

As multistrata live fences, conservation of riparian forests, and forage banks exhibited variance within PES categories (Fig. 3), these practices were amenable to the use of logistic regression models to evaluate the effects of PES payments and technical assistance (Table 5). Each PES treatment group was evaluated separately, with the baseline category being non-participation in PES; other independent variables included the measures of social information and farm capital suggested by diffusion of innovation theory. Including labor, education and social information in our analysis allowed us estimate the effects of PES accounting for other influences on decision-making, which have been identified by diffusion theory as factors with strong potential to influence practice adoption. We found that PES participation had the most significant effect on the adoption of multistrata live fences, with all of the PES treatment groups having about an equal effect on adoption probability. Importantly, multistrata live fences were the only practice where payment alone had a significant association with adoption rate (90% confidence level). However, technical assistance also had a significant effect, which is consistent with the idea that payment or technical assistance provides sufficient incentives to increase adoption. PES did not significantly affect adoption of forage banks, although the size and direction of the coefficient estimates were

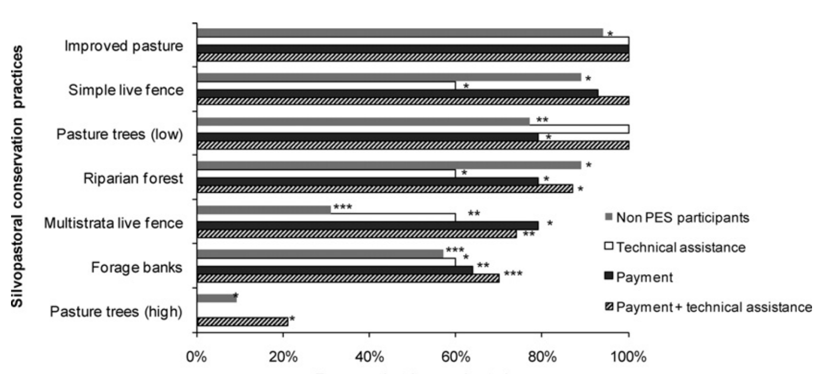

Fig. 3. Adoption rates of silvopastoral conservation practices promoted by RISEMP varied significantly among farmer groups for riparian forest, multistrata live fences, and forage banks. In contrast, adoption rates were high across all groups for improved pasture, simple live fences, and pasture trees at low density. *Adoption that is significantly different from 100%, one-tailed *t*-test, 90% confidence level, $p < 0.05$.

Table 5
Factors influencing adoption of multistrata live fences, conservation of riparian forest, and use of forage banks.

	Multistrata fence		Riparian forest		Forage banks	
	Estimate	(SE)	Estimate	(SE)	Estimate	(SE)
Intercept	−2.406	(0.85)**	2.302	(1.45)	0.224	(0.67)
Technical assistance	1.942	(0.79)*	−1.827	(1.32)	0.045	(1.01)
Payment	1.935	(1.04)	−0.914	(0.83)	−0.022	(0.67)
Payment + technical assistance	1.467	(0.56)**	−0.065	(0.8)	0.371	(1.25)
Education	−0.676	(0.39)	0.590	(0.47)	0.205	(0.34)
Labor	0.346	(0.12)**	0.136	(0.29)	0.024	(0.1)
Social information	0.596	(0.19)**	−0.462	(0.22)*	−0.059	(0.14)

Multistrata live fence: McKelvey & Zavonia R^2 = 0.394, AIC = 117.28, residual deviance 103.28, and df = 94.
Riparian forest: McKelvey & Zavonia R^2 = 0.208, AIC = 86.208, residual deviance 72.208, and df = 94.
Forage banks: McKelvey & Zavonia R^2 = 0.24, AIC = 143.79, residual deviance 129.79, and df = 94.
Values are significantly different from other farmer groups detected by ANOVA, 95% confidence level
* $p < 0.05$
** $p = 0.001$

consistent with the trend of forage bank use being more prevalent among farmers in the payment + technical assistance group (Fig. 3).

Evaluating the three practices individually provided additional insight into the how farm capital characteristics can influence conservation practice adoption. In particular, farms with higher levels of labor input (and thus larger farms) had more exposure to social information through farmer-to-farmer communication, and were more likely to adopt multistrata live fences. The influence of these characteristics is one reason the coefficient for the technical assistance group in the multistrata live fence model is about equal to the other PES groups, despite a visibly lower overall adoption rate (Fig. 3). The technical assistance group had a small average farm size and therefore lower predicted adoption rates. Accounting for farm capital characteristics and social information sharing in the models (Table 5) better isolated the effect of the PES incentives and technical assistance.

To further investigate the influence of PES on adoption of multistrata live fences, we ran the model using a dummy variable for payment, a dummy variable for technical assistance, and an interaction effect for payment and technical assistance. This is an equivalent to the operationalization of the models in Table 5. We found that, for adoption of multistrata live fences, estimated coefficients for technical assistance and payment were similar (≈1.94), but their interaction was negative (−2.41), suggesting that there were no synergistic effects of the combination. Rather, the negative interaction term indicates that technical assistance and payment may act as substitutes for one another.

Conservation of riparian forest had an unexpected negative correlation with social information; in contrast we did not find a significant effect of farm capital or social information on adoption of forage banks. Our results suggest that PES did not affect implementation of riparian forest protection. In fact the highest frequency of riparian forest protection was observed in the non-PES group. However, it is important to note the broader context of Costa Rica's forest protection law 7575 when interpreting the influence of the predictor variables on adopting practices to protect riparian zones. The 7575 forest protection law states that riparian forest and a 50-m zone on each side are legally protected. Protection of riparian zones is mandatory and thus is less subject to incentives from PES. The few farmers that indicated that they did not actively protect riparian forest ($n = 14$) were predominantly those who did not have streams or riparian zones on their property. In one regard, the lack of findings regarding riparian forest protection is similar to the findings for the high adoption rate practices like improved pasture, where private incentives for adoption effectively crowded out PES payments; however, for riparian forests, PES incentives were crowded out by mandatory restrictions.

A critical consideration for policy design is whether policy incentives will stimulate conservation practice adoption beyond the impetus to adopt them based on private benefits, previously existing polices, or other social factors. In the literature on market-based policies like PES, this consideration is implicit in the concept of *additionality*, where policy incentives stimulate new conservation that would not otherwise take place (Morrison and Aubrey, 2010). Our evaluation of the suite of practices promoted by RISEMP suggests that policy incentives may have the most impact on practices with relatively more public benefits and relatively fewer private benefits. This consideration may help decision-makers strategically prioritize conservation investments by identifying practices with many private benefits as having a high probability of adoption, particularly when supported by information sharing (e.g., technical assistance or farmer-to-farmer), and focusing incentives on practices that provide public goods.

Our results suggest that policy incentives did not have a detectable influence on conserving riparian forest beyond existing protection under Costa Rica's forestry law 7575. This is one example of how policy incentives may be constrained to have minimal impact for one type of conservation practice. This supports findings of previous evaluations of PES, which have highlighted the importance of targeting policy investments on areas at high risk of land use change, in which public benefits may be lost without policy intervention (Muñoz-Piña et al., 2008; Pfaff et al., 2008; Sánchez-Azofeifa et al., 2007). Our results do not to negate the importance of conserving riparian forest, but rather highlight the need to consider how policy incentives could be used to complement existing regulations in order to achieve the criteria of additionality.

Nevertheless, our results should not be interpreted as supporting eliminating any investment in conservation programs for private practices with high adoption rates. One potential strategy is targeting incentives in high-risk areas and strategically supporting social information sharing (e.g., through field days, farm demonstrations, community events co-organized by well-connected farmers) in an effort to maximize positive influence on both target regions and neighboring areas, an effect documented by Robalino and Pfaff (2012). Furthermore, providing information and incentives to subsidize the adoption of practices with private benefits may provide spillover effects for the adoption of practices with public benefits, for example by increasing the level of trust between landowners and conservation agencies. High levels of trust between farmers and other conservation policy stakeholders can support program participation (Lubell, 2007), and could even encourage landowners to accept smaller payments to engage in conservation behavior. These are key issues for further research on how PES programs have differential effects depending on the mix of private and public benefits provided by a particular practice.

4. Conclusions

Adoption of silvopastoral conservation practices is an important example of management innovation that can help sustain ecosystem services in tropical rangelands. PES is a market-based tool designed to reshape conservation behavior using positive incentives, in particular providing payments to stimulate conservation practices that provide public benefits. Our results suggest that the effectiveness of PES varied considerably across different types of practices, at least partially in response to the mix of private and public benefits provided by each. Multistrata live fences were the only conservation practice for which PES payments alone increased adoption rates at our study site. Landowners had little incentive to spontaneously adopt multistrata live fences, which provide measurable ecosystem services as public goods, such as fostering bird diversity (Garbach, 2012), but multistrata fences are viewed by many landowners as potentially reducing forage availability. Additionally, there is a preference for farms that look orderly; simple fences in the region are regularly pruned and appear tidy, while unpruned multistrata fences appear disheveled in comparison. Much like the neighbor with a weedy front yard compared to the one with an immaculate lawn, live fences can be perceived as indicators of education or refinement, with a pruned look being most desirable. As one farmer noted, "*Trees compete with grasses, making my job more complicated*. . .*To some neighbors it also looks bad, uneducated*" (Farmer interview #74). Despite the demonstrated conservation value of multistrata live fences, their visual appearance and perceived negative impact on forage productivity may hinder adoption rates. Additionally, farmers signaled that trade-offs and management complexity may hider adoption. "*Although I appreciate large trees [in multistrata fences], and animals visit them, my pasture grass suffers*" (Farmer interview #22). "*Big live fences are complicated*. . .*they are not adept for high winds or other bad conditions. It's difficult to manage well*" (Farmer interview #26). PES directly changes these motivations by providing payments for the provision of public goods.

For practices that were widely adopted by most farmers, PES payments alone had a much smaller effect, but adoption was enhanced by technical assistance (Garbach, 2012). Technical assistance appears to have been particularly effective for incorporating simple live fences and low density tree plantings into permanent pasture systems. Even for practices with lower overall adoption rates like multistrata live fences, technical assistance appears to have been equally effective as payments for increasing adoption rates. Furthermore, payments and technical assistance appear to be substitutes and not complements; there was no positive synergistic or interactive effect between the two policy tools. This may occur because information transmission and relationship building occurred even in the group that received payments alone.

The importance of technical assistance in combination with payments is often overlooked in discussions of market-based policy tools like PES, where theory usually focuses on how payments change adopters' motivations. However, technical assistance can directly reduce the costs of practice adoption by providing information or even directly subsidizing material costs. For example, the RISEMP program included technical assistance on how to incorporate new plants and occasionally provided cuttings and other materials to use (F. Casasola, personal communication). Technical assistance is a particularly powerful tool for conservation practices that provide substantial private benefits—diffusion of innovation theory predicts that once a landowner understands how to achieve these benefits, she or he will adopt the practice. It is important to think broadly about the benefits of relationship building. Technical assistance and support for farmer-to-farmer communication networks may build trust that enhances understanding of potential benefits of conservation practices and helps to ensure that they are sustained over time.

Our findings also have interesting implications for how information about conservation practices is transmitted through social and institutional pathways. Social information had a significant positive influence on adoption of multistrata live fences, which—because of their provision of public goods—are more likely to feature free-riding and collective action problems (Lubell and Fulton, 2007). In these cases, the social capital and social norms associated with community interaction can promote behavior change (Lubell and Fulton, 2007). Social learning can take place on several levels: farmers are informed by their own direct observations, learn from others in their communication network, and may be influenced both by how others learned of a practice and whether their neighbors' experience was positive or negative (Conley and Udry, 2001). In the case of riparian forests and forage banks, where social information had a negative or no influence on adoption rates respectively, our qualitative interviews suggest that social discussion may include information about the costs of these practices. For example, a mandatory law like riparian forest protection may create social discussion about its unfairness to local rural livelihoods. This is often seen in the United States when federal or state agencies attempt to impose regulations on agriculture. Forage banks were the only practice that some farmers reported abandoning due to wildlife conflicts, in particular the increased presences of rats, snakes, and other pests. Hence the influence of social information on adoption rates depends heavily on the content of the information being exchanged.

Information transmitted by outreach agencies is another pathway predicted by diffusion theory to influence adoption rates. But in the case of the RISEMP pilot, we found that institutional information was heavily correlated with the application of policy tools. Of course, this is expected in the case of the PES groups that explicitly received technical assistance, which was provided through contact with outreach organizations. But even in the case of the farmers that received payments only, contact with outreach organizations was significantly higher than non-participants. The financial incentives provided by PES do not exist in a social vacuum; they are coupled with a variety of information about program participation, how to implement conservation practices, and promotional communication designed to persuade landowners to change behavior. Thus it is important to understand how the economic incentives provided by PES interact with the social processes identified by diffusion of innovation theory.

The next phase of PES policy development and research requires more detailed analysis of farmer communication networks and decision-making processes in order to understand how different policy tools influence behavior. In particular, quantitative analysis of the social networks (Scott, 1988) through which farmers and other stakeholders interact may help outreach and extension professionals communicate expected benefits of a silvopastoral practice. It may provide additional insight into how thought leaders within local farmer networks can provide feedback on farmers' experience, including difficulties, with implementing a new practice.

From a policy design perspective it will be important to determine how farmers evaluate the relative benefits of conservation practices. Less than 2% of the farmers we interviewed indicated that they took regular field measurements of the performance of new management practices. The remainder responded that they evaluated things "*al ojo*," by eye, or by comparing their results with the practice to those achieved by family members or relatives using the same practice. Informal performance measurement could be supplemented with more detailed research on the economic and environmental benefits of different practices, not only to provide demonstrable benefits to farmers, but also to better evaluate the overall environmental outcomes associated with PES.

Acknowledgements

We are grateful to M. Ibrahim and the GAMMA Group at CATIE for access to office and lab facilities and F. Casasola for facilitating introductions to farmers who participated in the RISEMP pilot and officials at the Costa Rica's Ministry of Agriculture and Livestock. We thank V. Eviner, members of the Eviner and Lubell labs, T. Tomich and one anonymous reviewer for helpful comments on this manuscript. This research was funded by the University of California Davis and the University Outreach and International Programs (UOIP) with additional support to K.G. through a Fulbright Fellowship.

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