Market-Based Incentives for the Conservation of Ecosystem Services in Agricultural Landscapes: Examples from Coffee Cultivation in Latin America

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Glossary

Agricultural intensification The increase of yield (i.e., amount of commodity produced per unit area) in agricultural areas through increased inputs of labor, fertilizer, pesticides, etc.

Certification The programs in which farmers contract third-party certifiers to confirm their adherence to specific production criteria, with the cost of certification outweighed by the ability to sell agricultural products at a price premium to consumers.

Ecosystem services The direct and indirect benefits of natural ecosystems for human livelihoods; these are also known as environmental services.

Market externalities A cost or benefit of the production or sale of a product that affects other parties not involved in the transaction and that is not generally reflected in the cost of the product.

Market failure In the context of ecosystem services, when the prices of goods and services do not reflect their true costs of production or consumption (e.g., the true cost of fossil fuel production with respect to impacts on global climate is not reflected in its cost, resulting in environmental degradation).

Nonexcludable service An ecosystem service that a beneficiary will receive regardless of whether or not they compensate the provider (i.e., there is no way to exclude those who do not pay providers for the service).

Opportunity costs The financial benefits that are foregone by making one choice over another (e.g., the potential revenue lost by choosing to grow crops in less productive manner that is more likely to maintain ecosystem services).

Payments for environmental services The voluntary agreements between purchases and sellers by which the beneficiaries of ecosystem services pay those who produce or manage such services in order to incentivize their protection and maintenance.

Shade coffee The practice of growing coffee under a canopy of native or introduced trees to shield the plants from excessive sunlight.

Technification of coffee The process of reducing or eliminating shade cover and at the same time increasing the density of coffee plants; initially promoted by the United States Agency for International Development in the 1970s as a method to reduce impact of coffee leaf rust.

Introduction

Virtually all aspects of human livelihoods and well-being are dependent on the resources and processes provided by natural ecosystems. Known as 'ecosystem services' or 'environmental services,' these are the direct and indirect benefits of natural resources and ecosystem processes for human economies (Millennium Ecosystem Assessment, 2005). Environmental services encompass a diverse range of products and processes, from carbon cycling to cultural and spiritual renewal (**Figure 1**). In addition to providing tangible or intangible benefits for human societies, the majority of environmental services share another characteristic: they are positive externalities, providing a net benefit to society whose value is not reflected in the cost of the direct products and services affected (Polasky, 2012; Salzman, 2009). The positive externalities of environmental services provide an example of market failure (Salzman, 2009); spontaneously arising markets fail to reflect the true value of these services, leaving them vulnerable to overexploitation and degradation.

Agricultural production is itself a provisioning service (Zhang *et al.*, 2007) reliant on a diverse suite of ecosystem services operating at a variety of spatial and temporal scales (Kremen and Miles, 2012). Given that agricultural production comprises approximately 40% of land cover (Foley *et al.*, 2005), managing agriculture in order to maximize the provision of ecosystem services, while minimizing disservices (e.g., soil degradation and pesticide contamination), is a key component of moving toward sustainability in the twenty-first century (Robertson and Swinton, 2005). Diversified agricultural systems are more effective in supporting ecosystem services and minimizing disservices (Kremen and Miles, 2012); however, low-diversity and high-intensity conventional systems have become the norm throughout the world. This situation results from interactions between local history, policy, lack of research, and market failures that compensate farmers for yields but not for positive (or negative) externalities involved in production. In this article, the authors have described relationships between agricultural management and ecosystem service provision for a single crop – coffee, the most important tropical agricultural commodity crop, which is responsible for US$15 billion in exports annually (International Coffee Organization, n.d.). Using this example, the attempts to incentivize biodiversity conservation and compensate producers for the production and maintenance of ecosystem services were investigated. To provide a broader context for this discussion, the article begins with a description of the currently existing market-based mechanisms for conservation in agricultural landscapes, highlighting the advantages and disadvantages of voluntary and regulatory approaches.

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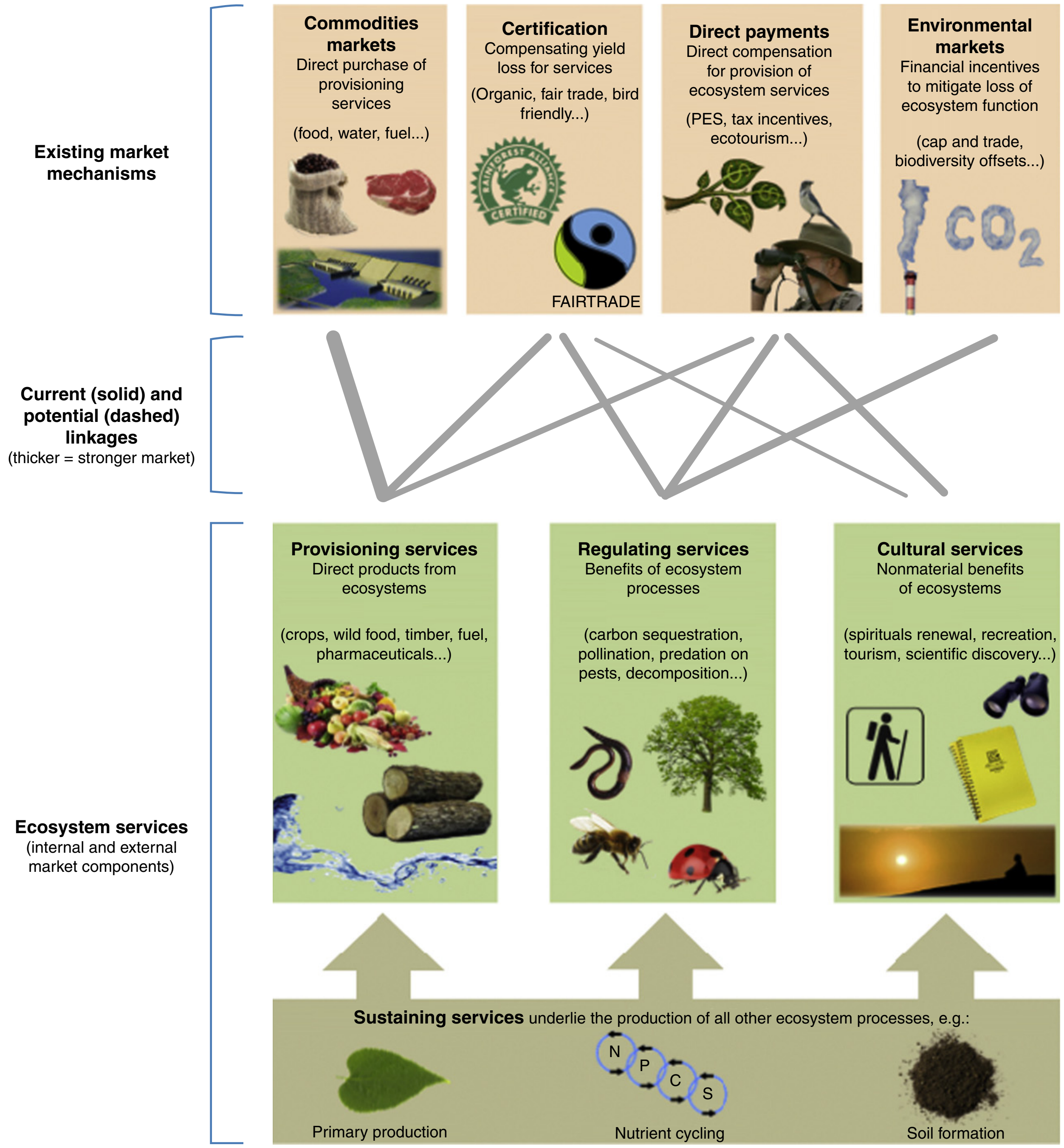

Figure 1 Ecosystem services (ES) and linkages to existing and potential markets (arrayed left to right from voluntary to policy driven); thickness of lines indicates strength of linkage between ES and market. Framework of ecosystem services adapted from Millennium Ecosystem Assessment, 2005. Ecosystems and Human Wellbeing: A Framework for Assessment. Washington, DC: Island Press.

Market-Based Incentives: Promise and Pitfalls

Although the importance of ecosystem function for human well-being has long been acknowledged, the ecosystem services framework was first articulated in the 1970s and elaborated in the 1980s (Mooney and Ehrlich, 1997). The development of the service framework came about not necessarily due to the desire to explicitly value services, but rather as a response to the failure of conservation efforts based on appeals to nature's intrinsic value (Norgaard, 2010). Nevertheless, the ecosystem services framework provides a structure in which these functions can be valued and incentivized.

Existing market-based incentives exist along a continuum from entirely voluntary mechanisms to mechanisms dependent on regulatory interventions that integrate market externalities into economies (Figure 1). Commodity markets (e.g., market for timber, agricultural products, etc.) are themselves dependent on provisioning services. However, for the purposes of this article, the focus is on markets for the various sustaining, regulating, and cultural services that comprise the market externalities whose conservation has not been captured by spontaneously arising markets.

Voluntary Mechanisms

Among existing voluntary mechanisms, certification schemes, which indirectly incentivize biodiversity conservation and maintenance of ecosystem services, are the most widely available and applied incentives. These market-based approaches that compensate producers for ecosystem services are widely considered effective at promoting conservation in agriculture, although there are few empirical examples of such markets (Kroeger and Casey, 2007). Producers generally participate in third-party certification schemes with the expectation of a price premium in exchange for compliance with international standards of quality and fairness in production. Dozens of certification schemes exist within the agricultural sector, including well-known examples, such as organic and fair-trade certifications. Although a few of these certifications focus specifically on conservation of biodiversity or ecosystem services, most include related environmental criteria that presumably benefit biodiversity and ecosystem function. For example, organic agriculture appears to have limited, but highly heterogeneous, benefits for biodiversity of certain taxa, such as birds, bats, and invertebrates, that provide regulating services of pest control within farms (Bengtsson *et al.*, 2005; Hole *et al.*, 2005; Fuller *et al.*, 2005).

Despite the widespread adoption of some certification programs, the approach presents many weaknesses in the context of conservation. Certification schemes themselves reflect a shift from compulsory to voluntary participation in market mechanisms for conservation (Hatanaka *et al.*, 2005), in that responsibility for monitoring of standards that has traditionally rested with government agencies is shifted to third-party certifiers; consumers are free to ‘opt out’ by purchasing less expensive (and less sustainably produced) commodities. A review of major agricultural certifications found that most standards fail to provide specific guidelines for targeting the protection of endangered species and none specifically seek to prevent habitat loss (UNEP-WCMC, 2011). Additionally, the cost of certification and the price are a major barrier for small and medium producers to participate in these schemes, thus excluding many producers in the developing tropics. Without wide adoption, the conservation value of certification schemes may be very limited (Gullison, 2003).

Policy-Driven Mechanisms

The ability to opt out of voluntary schemes, such as certifications, necessarily limits the impacts of these approaches in terms of conservation of biodiversity and ecosystem services. Higher impact approaches generally involve national or international governmental mechanisms that compel participation on the part of producers, consumers, or both. One emerging approach in these situations is direct payments for conservation (In some cases, voluntary direct payments are made to producers for the provision of ecosystem services, such as water and erosion control, but these payments generally take place locally and are not sold on a competitive market.). Direct payments for conservation outcomes may be the most efficient means to incentivize conservation of biodiversity (Ferraro and Kiss, 2002) and, by extension, ecosystem services. Direct payments in agriculture may be made to farmers and landowners who through sound management practices may demonstrate a contribution to environmental services, such as water cycling, pollination, and soil. Although a number of small-scale, voluntary payment agreements have arisen (Pagiola *et al.*, 2004), larger scale programs generally occur through government subsidies (based on taxes, grants, or a combination of these two) for conservation or through payments for certain ecosystem services (Pagiola, 2008).

Environmental markets – in which biodiversity conservation interventions or ecosystem services are themselves sold as commodities – are often hailed as the next frontier in conservation practice; however, in practice there are very few examples of functioning environmental markets. Given that these are markets attempting to commodify externalities that are public goods without clear ownership, such mechanisms are unlikely to develop in the absence of national or international regulations limiting use of a readily available public good. Kroeger and Casey (2007) outlined three main reasons for the small number of ecosystem service markets: (1) absence of low cost and easily applicable approaches to quantifying ecosystem service flows, (2) difficulties in estimating the economic value of ecosystem services, and (3) the nature of the ecosystem flows as a public good. Thus, existing environmental markets rely on governmental regulation that creates a demand for ecosystem services. For example, in the United States, mitigation banking for wetlands and endangered species habitat exists as a direct result of government oversight of the issuance of credits and the sale and trade of such to potential buyers wishing to offset negative impacts of development (Bayon, 2008). Similarly, mitigation markets for greenhouse gases exist as a result of state legislation in the United States and regional legislation in Europe, in which farmers and other land managers may apply published standards to cap or capture carbon, selling these credits on voluntary or regulated carbon markets. For example, under the State of California climate change legislation AB-32, agricultural producers are able to sell carbon offsets within the regulatory market through sequestration and ‘additional’ sequestration gained through biodiversity friendly practices, such as minimal tillage and the use of cover crops (Sumner and Rosen-Molina, 2010). Participation in environmental markets is currently limited because of a lack of regulatory pressure, but in the case of existing markets, it is limited because of high transactional costs due to monitoring. Thus, as with certification, these up-front costs may serve as barriers to the small and medium producers who comprise the majority of agriculturalists in the developing world.

As one of the world’s most important agricultural commodities, coffee provides a valuable lens for exploring relationships between conservation, commodification, and globalization. In the following sections of this article, the authors have described various methods of coffee cultivation, focusing on Latin America ('Coffee Cultivation in Latin America'); effects of coffee cultivation on biodiversity and ecosystem service provision ('Coffee, Biodiversity, and Ecosystem Services'); and the existing voluntary and regulatory market mechanisms that have been used to incentivize the conservation of ecosystem services in Latin American coffee cultivation ('Market Incentives to Conserve Ecosystem Services in Coffee'). The authors have focused on the strategies that have shown the most success for conservation of biodiversity and ecosystem services in this important tropical crop and have made suggestions for future directions in market-based methods to incentivize conservation in agricultural landscapes in the tropics.

Coffee Cultivation in Latin America: Management Practices, Biodiversity, and Ecosystem Function

Introduced to the New World in the early eighteenth century, coffee cultivation expanded throughout Latin America after countries in the region gained independence from Spanish and Portuguese rule in the 1820s and 1830s, respectively (Pendergrast, 1999). In 2010, coffee plantations comprised more than 5.2 million ha in Central and South America (nearly 4% of total crop area) with a production value exceeding US$5 billion annually (Food and Agriculture Organization of the United Nations, n.d.). Two coffee species are widely cultivated in the Neotropics: arabica (*Coffea arabica*), sought after for its superior flavor, which grows at middle elevations (600–1500 m); and robusta (*Coffea canephora*), used primarily for manufacture of instant coffee due to its harsh flavor and high caffeine levels, which grows below 800 m elevation (Jha *et al.*, 2011). The following discussion applies to arabica coffee, drawing primarily from Latin American examples.

Traditional Coffee Management

Within Latin America, coffee is notable not only for its economic and social importance but also for its variety of growing systems. These various management types can be ordered along a gradient of increasing intensification (Moguel and Toledo, 1999). As intensification increases in coffee systems, the diversity and complexity of tree cover decrease, and coffee plant density rises (**Figure 2**). Depending on a variety of factors (local climate, coffee variety, and use of chemical inputs), yield may also increase with intensification (Soto-Pinto *et al.*, 2000; Perfecto *et al.*, 2005).

As the descendent of an understory plant, coffee is a shade-tolerant species; in traditional coffee production systems, shade trees are maintained to shield the coffee plants from receiving too much direct sunlight. The simplest coffee management systems in Latin America essentially replace the understory of a forested area. Although trees may be thinned, the shade cover is comprised entirely of native species with a multistratum canopy structure (Moguel and Toledo, 1999; Philpott *et al.*, 2008a). These 'rustic' systems generally occur on small scales as part of indigenous management practices (Moguel and Toledo, 1999). More common among small-scale producers are polycultural systems in which coffee is cultivated alongside fruit and timber trees mixed with native forest tree species that provide relatively high-shade cover and a thinner, but still multistratum, tree canopy. In these multicropping systems, noncoffee products may comprise up to one-third of the value derived from a coffee agroforest (Rice, 2008). In addition to producing multiple value streams, these systems are relatively low input. Transitional between traditional and intensive coffee systems are 'commercial polycultures' (**Figure 2**), in which a shade canopy is still maintained over the coffee, but mostly comprised of reduced diversity of planted trees subject to pruning to regulate shade levels.

'Modernization' of the Coffee System

Traditional coffee cultivation escaped the post World War II 'green revolution' largely intact. However, in the 1970s, coffee cultivation in Latin America underwent a rapid process of modernization, with conversion into reduced shade canopies, high-yield coffee varieties, and an increase in chemical inputs and the density of coffee plants (Perfecto *et al.*, 1996; Perfecto and Armbrecht, 2003). This process of 'technification' in Latin America initially began as a response to the arrival of coffee leaf rust (*Hemileia vastatrix*), a devastating fungal disease of coffee. Reducing shade was initially seen as a way to reduce moisture, and hence the spore formation, of the fungus (Perfecto *et al.*, 1996). Supported by funding from the United States Agency for International Development, governments in Latin America implemented modernization programs of shade removal coupled with dense plantings of high-yield coffee varieties that respond well to direct sun and chemical inputs; by 1996, 40% of Latin America's coffee area had been modernized (Rice and Ward, 1996). As the coffee leaf rust has proven less devastating than initially anticipated, the motivation for adopting low-shade systems has shifted to increasing yields (Perfecto *et al.*, 1996).

Intensified coffee systems may include some shade (**Figure 2**), but the height and shade cover is greatly reduced. The shade trees themselves may be a near monoculture of fast-growing trees. In Latin America, these are commonly native nitrogen-fixing species (*Inga* spp. and *Erythrina* spp.), although exotics (e.g., *Grevillea robusta*) may also be used (Perfecto *et al.*, 1996; Jha *et al.*, 2011). These trees may be subject to substantial pollarding and removal of epiphytes to decrease shade cover. In sun coffee, the shade layer is eliminated altogether, with dense plantings of high-yield coffee. Despite the widespread belief that reduced shade increases coffee production, the actual relationship between shade and production on a per plant basis is highly variable and inconsistent across studies (Perfecto *et al.*, 2005). Intensive systems generally do produce more coffee per ha; however, it is unclear whether these increases result from increased planting densities, use of sun-tolerant varieties, or other aspects of management. Low- or no-shade systems generally require higher chemical and labor inputs (Jha *et al.*, 2011).

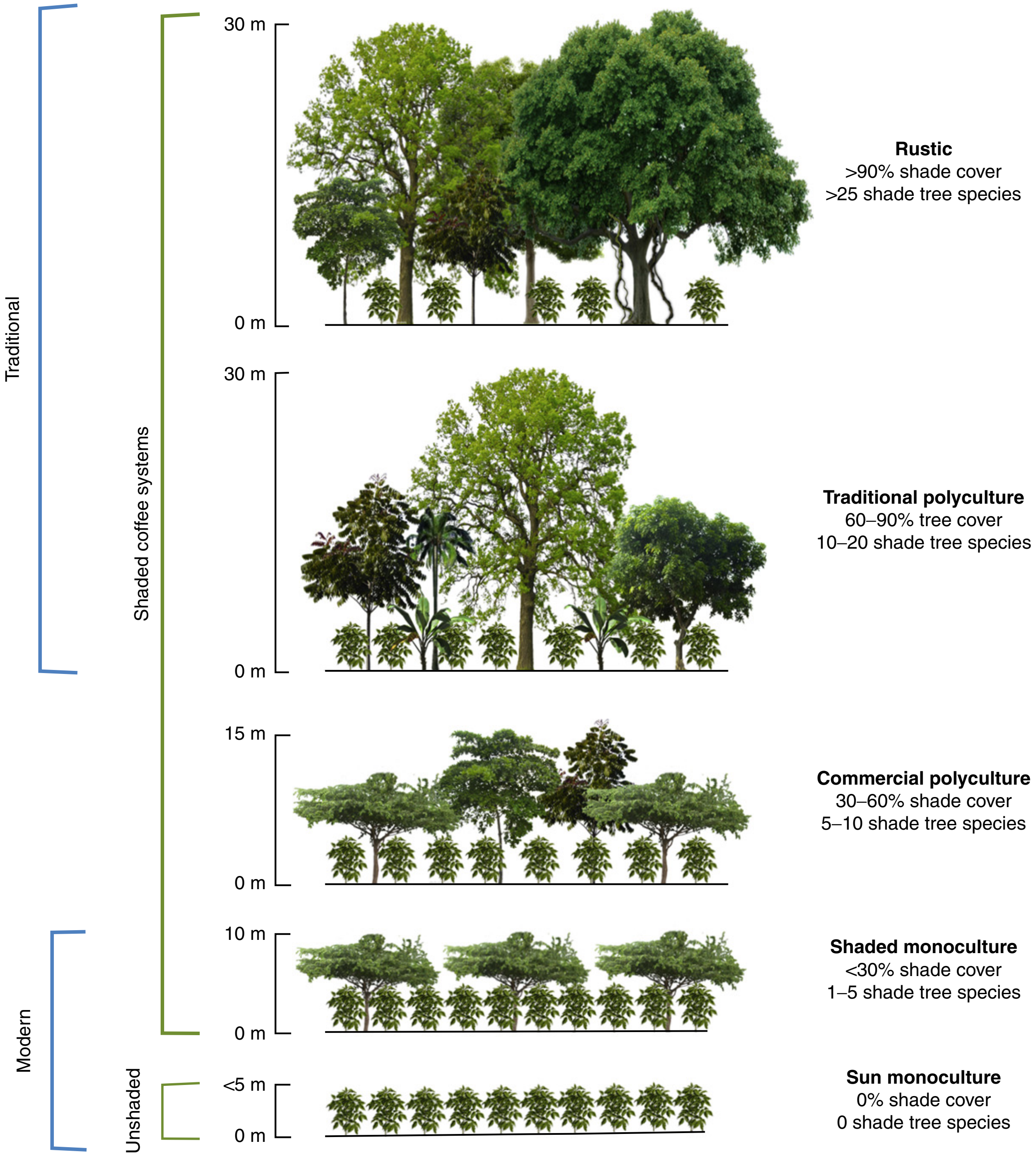

Figure 2 Schematic representation of coffee management systems from the least (top) to the most (bottom) intensive. As intensification increases, canopy height and structural complexity, tree basal area, and shade tree diversity decrease, whereas the density of coffee plants increases. Adapted from Moguel, P., Toledo, V., 1999. Biodiversity conservation in traditional coffee systems of Mexico. Conservation Biology 13(1), 11–21 and Perfecto, I., Vandermeer, J., Mas, A., Soto Pinto, L., 2005. Biodiversity, yield, and shade coffee certification. Ecological Economics 54 (4), 435–446.

Coffee Cultivation, Biodiversity, and Ecosystem Services

Biodiversity conservation in shade coffee plantations

Not surprisingly, these different coffee production systems vary not only in inputs (i.e., labor and agrochemicals) but also in their conservation value and their provision of ecosystem services. The maintenance of biodiversity is one of the most extensively studied ecosystem services provided by shaded coffee plantations (Perfecto *et al.*, 1996; Moguel and Toledo, 1999; Perfecto and Armbrecht, 2003; Donald, 2004; Somarriba *et al.*, 2004; Philpott *et al.*, 2008a).

By definition, traditional shaded coffee systems include a higher diversity of woody plants than modernized coffee plantations (Soto-Pinto *et al.*, 2001; Philpott *et al.*, 2008a; Williams-Linera and López-Gómez, 2008). Similarly, the epiphyte richness is higher in diverse shade coffee than in intensive shade coffee and species numbers are similar between the most traditional systems and forests (Pendergrast, 1999; Hietz, 2005; Solis-Montero *et al.*, 2005; García-Franco, 2008). However, the richness and abundance of herbaceous understory plants may be substantially reduced as a result of coffee layer management (Saldaña-Vázquez and Sosa, 2010). Shaded coffee also facilitates bee-mediated pollen dispersal of native trees within coffee landscapes (Jha and Dick, 2008; Jha and Dick, 2010).

Both migratory and resident birds have been the focus of multiple studies that have demonstrated that the species richness, abundance, and functional diversity of birds decline with increasing management intensity in Latin American coffee plantations (Greenberg *et al.*, 1997; Matson *et al.*, 1997; Calvo and Blake, 1998; Perfecto *et al.*, 2003; Philpott *et al.*, 2008a; Philpott *et al.*, 2009). Several studies have demonstrated high species richness and abundance of bats in traditional coffee systems (Pineda *et al.*, 2005; García Estrada *et al.*, 2006; Sosa *et al.*, 2008; Williams-Guillén and Perfecto, 2010, 2011). Howler monkeys can use diverse shade coffee plantations as foraging habitat (McCann *et al.*, 2003; Estrada *et al.*, 2006; Williams-Guillén *et al.*, 2006). A variety of medium-sized mammals exploit high-shade coffee plantations in Mexico (Gallina *et al.*, 2009) and show a negative response to intensification (Gallina *et al.*, 2008). However, available evidence suggests that small mammal richness is reduced in coffee plantations and does not clearly relate to management intensity within coffee plantations (Gallina *et al.*, 2008). The effect of management intensity on herpetofauna remains largely uninvestigated. Amphibian species richness declines from cloud forest to shade coffee (Pineda *et al.*, 2005), although forest shade coffee ecotones conserve higher amphibian diversity than higher contrast forest corn edges (Santos-Barrera and Urbina-Cardona, 2011).

The effect of agricultural intensification in coffee plantations on invertebrate groups has also received substantial attention. Coleopteran groups show divergent responses: in some cases, richness and abundance in shade coffee actually exceeds that of primary forest (Pineda *et al.*, 2005). In contrast, scarab beetles show decreases in species richness and evenness in sun versus shade coffee, with shade coffee retaining only a quarter of the species richness observed in forests (Nestel *et al.*, 1993). For a variety of arboreal, ground-nesting, and twig-nesting ants, the richness and abundance is reduced in shade coffee and declines with increasing agricultural intensification (Perfecto and Vandermeer, 2002; Perfecto *et al.*, 2005; Philpott *et al.*, 2008a; Larsen and Philpott, 2009). Nevertheless, ants experience significant declines in richness in coffee versus forest in all but the most rustic coffee systems, and forest-adapted species show particularly strong declines (Philpott *et al.*, 2008a). The diversity of native bees is higher in coffee systems with greater tree species richness and canopy cover (Jha and Vandermeer, 2010). Diurnal Lepidoptera are particularly sensitive, as even the small changes in arboreal diversity and structure in traditional shade coffee plantations are associated with substantial declines in species richness (Perfecto *et al.*, 2003).

Fungal and microbial responses to intensification remain understudied, particularly given the importance of these groups in ecosystem function. Mycelial cord-forming fungi decline substantially between cloud forest and shade coffee (Guevara, 2005). Although saptrotrophic fungi have similar diversity and abundance in forest and different coffee systems, there is substantial species turnover between systems; in contrast, endomycorrhizal richness and abundance decline with increasing management intensity (Heredia Abarca *et al.*, 2008). Published information on soil bacteria is virtually nonexistent, although a study in Indonesia demonstrated increased bacterial diversity in shade versus sun coffee (Evizal *et al.*, 2012).

The role of shade coffee in maintaining biodiversity extends beyond the immediate conservation of species richness within coffee plantations. In many regions of Latin America, shade coffee represents the majority of remaining mid-elevation range forest cover (Perfecto *et al.*, 1996; Perfecto and Armbrecht, 2003); agricultural intensification within these zones could result in the loss of habitat for disturbance-tolerant species in this altitudinal zone. Shade coffee also comprises high-quality matrix that facilitates dispersal between forest fragments; as forests become increasingly fragmented in the tropics, highly permeable matrix like shade coffee will be key to countering biodiversity loss resulting from local extinctions by facilitating dispersal between fragments (Vandermeer and Perfecto, 2007; Perfecto and Vandermeer, 2010). The high-quality agroforestry matrix formed by diverse shade coffee plays a key role in maintaining biodiversity at landscape and regional scales (Perfecto and Vandermeer, 2008, 2010). For example, forest fragments in Colombia maintain significantly greater bat species richness than coffee plantations in a landscape dominated by unshaded coffee; however, in a nearby region dominated by shaded coffee, no significant differences were observed in species richness between forest fragments and coffee (Numa *et al.*, 2005).

Coffee plantations occur in a broader landscape context that can also affect their productivity and provision of ecosystem services. Even landscapes dominated by intensified coffee production often conserve forest fragments, at least in areas too steep to cultivate (Williams-Guillén, personal observation), and farmers may maintain forest fragments specifically for the provision of ecosystem services (Chandler *et al.*, 2013). In northern Costa Rica, members of a local cooperative have adopted an 'Integrated Open Canopy' system, in which smallholder farmers intensify production in a 2–3 ha area and maintain forest on an area of equal size (Arce *et al.*, 2009). At the farm scale, these IOC systems have higher productivity and harbor significantly higher bird diversity than nearby shade coffee systems (Chandler *et al.*, 2013). However, the extent to which this farm-scale diversity translates into increased provision of ecosystem services (e.g., pest control in the case of birds) remains unknown.

Biodiversity and ecosystem function in shade coffee plantations

Less-intensive coffee production systems contribute to a variety of local-, regional-, and global-scale ecosystem services (Jha *et al.*, 2011). As with other agricultural crops, coffee production is dependent on processes, such as pollination, predation, and climate and water regulation. Diverse shade canopies contribute to nitrogen cycling and soil nutrient content (Aranguren *et al.*, 1982; Beer, 1988; Grossman, 2003). High-shade systems are also buffer against variable climates through increased soil moisture (Lin, 2010) and by reducing variability in microclimate variables (Lin, 2007). Increased shade cover and complexity correlate with reduced disturbance from extreme weather events (Philpott *et al.*, 2008b). These factors directly affect the production and quality of coffee fruits. Although production is widely believed to be higher in lower shade systems, high- and medium-shade systems show few differences in overall yield (Lin, 2009); when controlling coffee plant density, moderate-shade produces the highest yields (Soto-Pinto *et al.*, 2000). Shade cover can increase the quality of coffee produced (Muschler, 2001; Vaast *et al.*, 2005), particularly at lower elevations; this is an important consideration as climate change reduces the optimal areas for coffee cultivation (Jha *et al.*, 2011). Shade coffee can also reduce labor and herbicide inputs, as shade cover decreases the growth of competing herbaceous vegetation (Beer *et al.*, 1997; Muschler, 2001).

A variety of regulating services mediated by animal biodiversity also increase coffee production. Although coffee can be wind pollinated, its fruit set and quality is increased in the presence of nonnative (Roubik, 2002) and native (Klein *et al.*, 2003; Ricketts, 2004) bees. As a result of proximity to forest fragments that harbored increased diversity of native bees, the pollination services to a single coffee plantation in Costa Rica were valued at approximately US$60 000 per year (Ricketts *et al.*, 2004). Pollination services provided by native bees are associated with increased bee diversity (Klein *et al.*, 2003; Ricketts, 2004). The richness and diversity of native bees is increased in diverse shade coffee systems (Jha and Vandermeer, 2010); pollination services are, therefore, presumably enhanced in traditionally managed shade coffee, although the interaction between coffee management intensity and the presence of forest fragments in the landscape remains unexplored.

Although coffee is a well-defended plant, it is vulnerable to attack by a variety of insect pests that are, in turn, limited by the diverse assemblages of predators found in shade coffee. Exclosure experiments have demonstrated that birds, bats, and lizards limit the abundance of herbivores in coffee plantations (Borkhataria *et al.*, 2006; Williams-Guillén *et al.*, 2008; Johnson *et al.*, 2009). The abundance of bat predators increases with decreasing management intensity (Williams-Guillén and Perfecto, 2010, 2011), and the effectiveness of bird-mediated predation decreases in low-shade coffee (Perfecto *et al.*, 2004), suggesting that biocontrol by these generalist vertebrate predators is negatively impacted by intensification.

The coffee berry borer (*Hypothenemus hampei*, Coleoptera: Curcolionidae) is the most devastating insect pest of coffee (Damon, 2000). Native to Africa, the life cycle of this pest makes it difficult to control, as it spends the majority of its lifespan within coffee beans (Vega *et al.*, 2009). However, a variety of generalist predators impact the populations of this pest. In Jamaica, exclosures designed to keep birds from foraging in shade coffee resulted in doubling the proportion of coffee berry borer infestation (Kellermann *et al.*, 2008; Johnson *et al.*, 2009). The pest control services provided by vertebrate predators in coffee plantations have been valued at US$75–310 $\text{ha}^{-1}\,\text{year}^{-1}$ in terms of pest damage prevented (Karp *et al.*, 2013; Kellermann *et al.*, 2008); several bird species identified as important for berry borer and insect pest control, such as the Tennessee warbler (Philpott *et al.*, 2009) and rufous-capped warbler (Karp *et al.*, 2013), rely on trees in coffee farms for foraging or are more abundant in farms with more tree cover and most likely would provide limited benefits in intensive sun coffee systems due to the lack of shade cover.

The ecosystem services produced by shade (vs. sun) coffee production extend far beyond the local farm scale. Coffee cultivation contributes to watershed conservation, soil protection, and buffering negative effects of extreme weather events (Jha *et al.*, 2011). Shaded systems have more favorable and stable microclimates and suffer reduced water loss (Lin, 2007). Higher shade systems also suffered reduced landslides in the wake of a major hurricane (Philpott *et al.*, 2008b). Shade coffee also forms high-quality matrix that facilitates the dispersal of native wildlife across longer distances and between protected areas (Jha *et al.*, 2011). Increased permeability of matrices of shade versus sun coffee increases movements of key pollinators, seed dispersers, and predators, enhancing the ecological stability of protected areas in mountainous regions and at the same time providing increased opportunity for provision of ecosystem services within farms.

At a global level, one of the most critical ecosystem services that shaded coffee systems can provide is the sequestration of carbon, thus mitigating climate change. Tropical agroforestry systems may sequester more than 200 MT of carbon per ha (Albrecht and Kandji, 2003) in plant biomass and soil. In Mexico, carbon stocks were 22 times higher in coffee plantations than in maize cultivation (Soto-Pinto *et al.*, 2010), whereas in Togo, inclusion of even a simple shade layer over coffee increased carbon stocks by 3.5 times to 81 MT per ha (Dossa *et al.*, 2008). However, practices, such as fertilization and use of nitrogen-fixing shade trees could increase the emissions of other greenhouse gasses from coffee plantations, indicating that careful consideration of inputs and shade trees must be made in order to evaluate the overall impact of shade coffee on climate change mitigation (Jha *et al.*, 2011). Nevertheless, in a warming world, shade cover will most likely play a critical role in maintaining coffee cultivation as current growing regions become suboptimal due to increasing temperatures, changes in precipitation patterns, and more frequent hurricanes, all of which can be buffered through a shade canopy (Jha *et al.*, 2011).

Despite the system's reputation for sustainability, coffee cultivation can generate substantial ecological disservices. Deforestation, erosion, nutrient loss, and instability of microclimate can all result from the conversion of forest or high-shade systems to low-shade or sun coffee. In Latin America, coffee cherries are commonly processed via a 'full wash' method to remove coffee pulp and mucilage from the fruit before drying; although this produces a higher quality bean, the process produces large amounts of effluents that can contaminate local water supplies (von Enden *et al.*, 2002). Use of agrochemicals in coffee plantations presents immediate threats to workers applying chemicals (often without the use of adequate protective gear) as well as to local communities living with runoff. The most commonly used insecticides for coffee berry borer control, endosulfan and chlorpyrifos, are highly toxic (Jaramillo *et al.*, 2006). Plantings in extremely steep areas may lead to erosion, and replacement of forest with coffee leads to biodiversity loss and potentially reduced watershed protection and climate mitigation.

Market Incentives to Conserve Ecosystem Services in Coffee

Existing Mechanisms

Given its economic and social importance, not surprisingly a number of mechanisms falling under the broad umbrella of Payments for Ecosystem Services exist for coffee. These schemes include certification of preferred production systems, direct payments to producers from governments or individuals, and participation of farmers in environmental markets.

Certification schemes

Certification programs are the most widespread and well-recognized mechanisms for compensating farmers for conservation of biodiversity and provision of ecosystem services. Under such programs, farmers adopt specific production criteria established by third parties, contract auditors to inspect and verify adherence, and receive in return the right to sell and market their product as certified. Although such systems may involve substantial costs for producers, the expected benefit is the ability to sell their crops at a price premium to consumers willing to spend more to support such systems. Certified coffee (e.g., organic, fair trade, etc.) accounts for approximately 10% of global production (Jha *et al.*, 2011). These certification and labeling initiatives are voluntary and private, without governmental mandate (Raynolds *et al.*, 2007).

Certified organic agricultural production is an example of a certification scheme familiar to most readers, in which production without the use of agrochemicals results in a more valuable crop. Organic certification is applied to a variety of crops globally; in case of coffee, organic certification generally involves the use of composting organic material, improvement of soil nutrient content, and prevention of erosion and soil runoff (Giovannucci and Koekoek, 2003); organic certification makes no demands with respect to tree cover or maintenance of forested areas. Thus, although organic production may improve provisioning of ecosystem services related to soil conservation, intensive organic systems may provide reduced regulating and provisioning services than traditional – but not organic – shade coffee plantations. For example, when canopy structure is held constant, organic production had no effect on the diversity or abundance of trees or birds in Nicaraguan shade coffee (Martínez-Sánchez, 2008).

A second widespread certification program applied to coffee is Fair Trade, which promotes price premiums for smallholder farmers and cooperatives exporting from the developing to the developed world. Although Fair Trade criteria focus on social and economic aspects of production, they also include limitations on the use of toxic agrochemicals, buffer zones around water resources, and ban the use of genetically modified crops (Jha *et al.*, 2011; Raynolds *et al.*, 2007). As is the case with organic certification, there are few provisions to ensure the maintenance of shade cover that enhances the provision of ecosystem services, although Fair Trade certification may have positive impacts on the provision of water and reduce agrochemical contamination as a result of measures meant to insure worker safety. Nevertheless, the focus on small producers may indirectly promote shade coffee, because smallholder farmers tend to use less labor-intensive shaded systems (Perfecto *et al.*, 2005). More recently, UTZ certification has become available for coffee and other tropical export crops with broadly similar criteria to those of Fair Trade (Giovannucci and Koekoek, 2003) focused on compliance with local labor and environmental laws.

In the 1990s, coffee certification programs that emerged focused on the certification of ‘eco-friendly’ coffee, more explicitly taking into account production methods and their effects on biodiversity and ecosystem service provision (Raynolds *et al.*, 2007). The Smithsonian Migratory Bird Center’s Bird-Friendly® program is among the most stringent of these, requiring organic production, the use of at least 10 shade tree species with minimum heights of 12 m, three canopy layers, maintenance of lianas, and a minimum shade cover of 40% (Smithsonian Migratory Bird Center, 1998). Participants are small producers, and this certification comprises a small proportion of exports in the certified coffee market (Raynolds *et al.*, 2007). Although the provision of ecosystem services in Bird-Friendly® versus noncertified shade coffee has not been quantitatively evaluated, such management would presumably provide the widest variety of services. Rainforest Alliance’s ‘Sustainable Agricultural Network’ standards include a variety of social and ecological criteria; the latter are less stringent than those of the ‘Bird Friendly’ program but include provisions for maintenance of diverse shade trees on farms with a minimum shade cover of 40%, protection of natural ecosystems and riparian buffers, wastewater treatment, use of integrated pest management techniques, and reduced agrochemical use (Hughell and Newsom, 2013). A recent contrast of certified and noncertified plantations in Columbia suggests that such certification has a positive impact on the provision of ecosystem services: certified farms had higher water quality and healthier streams, increased arthropod species richness, increased use of ‘best management’ practices, and increased revenues (Hughell and Newsom, 2013).

Direct payments

With direct payments, rather than receiving a price premium for coffee produced using methods that maintain ecosystem services, coffee producers receive direct payments from beneficiaries, usually through an institutional intermediary. Thus, incentives for maintaining ecosystem services are not tied to coffee commodity prices, which can undergo large and rapid price fluctuations (Jha *et al.*, 2011).

Although Payment for Environmental Services (PES) schemes have received widespread attention and are considered a promising approach, relatively few real-world examples exist from the tropics (Wunder, 2006). Despite widespread recognition of the potential to incorporate shade coffee production into PES for carbon sequestration and watershed protection (Rosa *et al.*, 2004; Montagnini and Nair, 2004), only a few initiatives specifically target small-scale shade coffee production (Méndez *et al.*, 2010a). Moreover, coffee plantation owners who maintain forest fragments on their properties could conceivably receive payments under

Costa Rica's PES program that rewards landowners for maintaining forested areas.

An example of a localized PES scheme involving coffee production comes from Honduras, where the community of Jesús de Otoro relies on water from the Cumes River (Kosoy *et al.*, 2007). This source of drinking water was becoming contaminated due to coffee cultivation upstream. A local grass roots water council of elected representatives (JAPOE, Council for Administration of Water and Sewage Disposal) created a PES scheme with the assistance of the nonprofit organization PASOLAC (Program for Sustainable Agriculture in the Hillsides of Central America), in which downstream users pay a fee of approximately US$0.06 per household per month to compensate upstream farmers for adoption of improved waste management practices and protection of forests (Kosoy *et al.*, 2007). Although downstream users report improvements in water quality, the low payments to upstream producers have hampered adoption, covering only 70 of the 200 ha identified as high priority for participation (Porras and Neves, 2010).

Tax incentives and agrotourism may also be seen as forms of direct payments in exchange for ecosystem services. The latter in particular is well developed in coffee plantations. In the Soconusco region of Chiapas, Mexico, several of the large coffee plantations have established tourist hotels and restaurants catering to weekend visitors and international tourists interested in bird watching and hiking (Anonymous, 2009).

Environmental markets

In the case of environmental markets, the ecosystem service itself is marketed and sold as a commodity to a beneficiary (usually an institution rather than individual) in the context of a dedicated market, usually subject to oversight by a regulatory body (Stuart *et al.*, 2010). Carbon credits and offsets are the most prominent example of such markets and the one with great potential but limited implementation in agroforestry systems, such as shade coffee.

One of the few success stories involving the sale of carbon from coffee plantations comes from the Scolel Te' program in central Chiapas, Mexico. The program was designed for researchers at the University of Edinburgh with the express goal of creating a market for the ecosystem services generated by agroforestry systems (Tipper, 2002). In this program, participating farmers develop plans for sustainable agroforestry and reforestation; based on estimates of carbon sequestered, they receive ex-ante carbon offset payments (US\$12 MT^{-1} C in 2002; Tipper, 2002). The program is managed by the nonprofit AMBIO, which evaluates farmer management plans and estimates the amount of carbon to be sequestered as a result of the planned management and reforestation interventions. The program has grown rapidly: as of 2010, nearly 2500 registered producers managing more than 9500 ha of land had enrolled, and approximately US$109 500 worth of payments were made in 2010 (Quechulpa Montalvo and Esquivel Bazán, 2011). The program has additional social and educational benefits for producers through training and educational opportunities. This community-based carbon credit framework has since been consolidated as the Plan Vivo Standard, with registered projects across the globe subject to long-term third-party monitoring and selling Plan Vivo Certificates representing 1 MT of reduced or avoided carbon emissions (Anonymous, 2008). The up-front costs of entry into certification plans and green markets are often a deterrent to the participation of smallholder farmers; thus, the Plan Vivo standard represents one of the few success mechanisms by which the majority of producers in developing nations have access to these emerging markets. Nevertheless, the short fallings of these mechanisms are as numerous as their successes.

Failure and Weakness of Current Market Mechanisms to Conserve Ecosystem Services

Although market-based mechanisms for incentivizing the provision of ecosystem services have shown some early successes (Hughell and Newsom, 2013; Quechulpa Montalvo and Esquivel Bazán, 2011), the limited number of programs as well as the failure of well-established certification programs speaks of the weakness of currently existing schemes. Aside from the single study commissioned by Rainforest Alliance (Hughell and Newsom, 2013), no other research that has explicitly contrasted the provision of ecosystem services (or reasonable proxies, such as bee diversity as an indicator of pollinator services) in certified versus noncertified coffee farms is known. Thus, despite the sound and fury, the certification that serves to protect biodiversity or ecosystem services with coffee farms or other agricultural systems remains largely an article of faith. There is a clear research need for studies to investigate the ecological (rather than socioeconomic) effects of certification schemes.

As mentioned previously, certification schemes, such as Fair Trade and organic, may do little to directly safeguard a variety of ecosystem services, which is a weakness of the major certification programs if they are not explicitly linked to parallel programs that emphasize conservation of ecosystem function (Philpott and Dietsch, 2003). The volatility of current agricultural markets contributes to undermining the efficacy of certifications in maintaining biodiversity and ecosystem services. In the late 1990s, coffee prices underwent a precipitous decline in the wake of market liberalization, the dissolution of agreements setting international coffee prices, and a glut of production from Southeast Asia (Bacon, 2005); as a result, the labor costs of harvesting coffee exceeded the prices the cherries could fetch, with the result that coffee crops were left to rot on the plants (Williams-Guillén, personal observation). At one Costa Rican shade coffee farm, pollination services had been valued at >US$60 000 per year (Ricketts *et al.*, 2004); nevertheless, in the wake of the 'coffee crisis,' the plantation was transformed from coffee to intensive pineapple production (McCauley, 2006). Ecosystem services tied to the valuation of a crop are as vulnerable to market fluctuations as the crop itself.

It has been suggested that coffee certification itself could lead to more deforestation (and hence reduced provision of ecosystem services at regional scales) because an increase in coffee prices could incentivize expansion of coffee production into forested areas (Rappole *et al.*, 2003; Tejeda-Cruz *et al.*, 2010). However, despite price premiums received by smallholder producers of organic and Fair Trade certified coffee, overall impacts on household livelihoods are insignificant for most metrics as a result of limited per household production and inability to sell entire harvests at certified prices (Méndez *et al.*, 2010b). Many types of certification are outside of the reach of small-scale producers due to up-front costs associated with enrollment (Gobbi, 2000). Although certified coffee is a growing sector, at present it comprises less than 2% of global coffee production (Méndez *et al.*, 2010b), and production for some markets currently outpaces demand (Giovannucci and Koekoek, 2003). Thus, although certification produces financial benefits for large-scale producers and highly organized cooperatives, as a measure for incentivizing the maintenance of ecosystem services in coffee plantations (and other agricultural landscapes), it is inadequate to protect ecosystem services as currently practiced – price premiums in general fail to offset increased production costs, and relatively few consumers in developed nations are interested in voluntarily paying for the 'real' cost of their coffee that integrates the externalities of human and ecosystem health.

The dearth of examples of the use of direct payments for ecosystem services speaks to some of the main challenges in the use of this system in developing nations. Such schemes depend on strong, transparent government agencies or institutions capable of regulating payment mechanisms; however, weak governance and corruption are the norm in the global south. Sustainable funding for direct PES is a second challenge, even for well-established programs: despite taxes to beneficiaries, Costa Rica's PES program relies partially on loans and grants from development agencies (Pagiola, 2008). The example of direct PES to coffee producers in Honduras highlights the need for payments to realistically offset the opportunity costs (i.e., the revenue lost by making a different choice, in this case, choosing not to invest in wastewater treatment). Low payments to producers have hampered adoption, resulting in low adoption rates and limited protection of the watershed. This example speaks of the broader issue of valuation within the design of PES schemes. Without accurate estimates of the monetary benefits of provisioning of ecosystem services, it is difficult to assess appropriate payments to providers (Kroeger and Casey, 2007). Given the impossibility of carrying out quantitative studies to estimate ecosystem service value in every local context, the development of spatially explicit modeling tools to estimate values and trade-offs between services is a key advance that will facilitate small-scale PES implementation (Kroeger and Casey, 2007; Tallis and Polasky, 2009). Initiatives, such as InVEST, promise to provide such tools (Nelson *et al.*, 2009), although their utility in real world situations remains largely untested.

Kroeger and Casey (2007) outline additional weaknesses in market-based approaches, which are apparent even in the relatively successful example provided by Scolel Te' example. Carbon sequestration provides an example of a nonexcludable service: beneficiaries will receive the service of carbon sequestration whether or not they pay to support reforestation and agroforestry. Thus, voluntary markets and programs will often fail to produce the funding needed to provide adequate payment to farmers, because it easy for beneficiaries to avoid payment and 'cheat the system.' For example, market fluctuations, the effects of economic recession, and other factors can result in low sales of carbon credits and hence reduced payments to Scolel Te' participants (Quechulpa Montalvo and Esquivel Bazán, 2011). Such market fluctuations effectively cause an increase in opportunity costs; if payments do not increase in tandem to offset these increases, producers may leave programs to pursue more intensive or expanded agriculture. The limited standards and monitoring protocols, coupled with a lack of global leadership to institute cap-and-trade programs, form a major limitation of environmental markets. Because large-scale environmental markets are unlikely to develop in the absence of regulations compelling participation on the parts of beneficiaries, such market-based mechanisms will remain limited in the current climate of market liberalization and deregulation.

Strategies and Opportunities for Improving Conservation of Ecosystem Services through Market Incentives

Lessons from Successful Programs

The Scolel Te' program provides one hopeful example for a successful PES approach in the developing Latin America. Because the program was designed to seek payments for traditional agroforestry practices already familiar to many producers (as opposed to seeking to radically change production techniques), adoption rates were high (Tipper, 2002). Nevertheless, other PES programs focused on modifying production systems have also met with success. For example, a program in Nicaragua used PES to incentivize the adoption of silvopastoral systems by ranchers, funded by the global environment facility; the program was well received by participants and produced improvements in indicators of ecosystem health (Pagiola *et al.*, 2007). Most participants maintained the improved systems after the end of the official project period and guaranteed payments, and the municipal government introduced tax incentives for producers (Svadlenak-Gomez, 2009). However, sustained funding for payments and weak local governance remain challenges for the long-term survival of the program (Svadlenak-Gomez, 2009).

PES schemes related to food systems can also serve to fill gaps in service and enforcement in the case of weak institutions with limited resources. A second example of a successful PES program comes from southwestern Nicaragua, where the Non-governmental organization (NGO) Paso Pacífico partnered with a government-administered wildlife reserve and local fishing communities to develop a performance-based incentives program to curtail the poaching of sea turtle eggs for local and national consumption (Smith and Otterstrom, 2009). Through this program, would-be turtle egg poachers are offered a modest payment in exchange for committing to protect a turtle nest by becoming 'nest protectors.' On successfully protecting a turtle nest, 'nest protectors' are then given a payment for each nest successfully protected. The price paid is above the market price for eggs. These performance-based incentives are a form of direct payments for conservation with the buyer being the environmental NGO. During the course of the program, poaching on the participating beaches dropped from nearly 100% to 15%. A key component of the program's success was participation of local community representatives in developing payment mechanisms, timely payment of incentives that were on a par with opportunity costs, and transparency on the part of Paso Pacífico in the administration of the program. As with many PES programs, a key limitation was sustained funding: despite the program's success, it continues in a limited capacity on only one beach due to limited funding streams from granting agencies. Future options for developing sustainable funding streams include linking to incipient biodiversity markets, in which fisheries companies could, for example, purchase 'turtle credits' to fund the protection of nesting beaches to offset the accidental mortality of juvenile and adult sea turtles incurred during fishing.

Opportunities and Future Directions for Payments for Environmental Services in the Agricultural Landscapes of Latin America

Although the past years have seen some development of market-based mechanisms for conservation of ecosystem services in agricultural landscapes, such schemes remain a promise rather than a reality for the vast majority of producers in developing regions even when considering only the relatively valuable crop of coffee. A variety of factors, from volatile markets to weak governance, remain a barrier in using such incentives to promote conservation among agriculturalists of the global south. A recurring theme in the success of PES programs in Latin America has been the involvement of local nongovernmental institutions with close ties to the communities targeted for payments; these communities often present well-organized, semiautonomous governance, echoing arguments that local social movements must play a key role in successful conservation in developing nations (Perfecto *et al.*, 2009). Partnership with academic institutions in the development of program structures has also played a key role in successful examples, particularly in larger scale programs. Finally, programs designed with systematic input from local communities have been a clear component in success, particularly when the involvement of local governmental bodies reinforces norms and incentives. 'Top–down' approaches have produced some success, particularly when based on modifications of already-established policies (Pagiola, 2008). However, when such approaches overlook meaningful community participation, they often fail, whereas 'bottom–up' approaches based on interventions suggested by target communities tend to fail due to lack of resources; this situation highlights the need for 'hybrid' approaches that unite the resources of larger institutions with the insight and momentum of local, grassroots organizations (Méndez *et al.*, 2010a). In Latin America's developing nations, NGO intermediaries with close connections to local producers and relationships with institutional representatives are a key link in the design and effective implementation of PES schemes.

Given the limited availability of environmental markets and the technical and economic barriers to certification schemes, direct payments for conservation may be the most feasible approach in Latin America, at least in the short term. It is believed that small NGOs with conservation goals, meaningful relationships with small-scale producers, and the knowledge necessary to negotiate agreements with private industry and government stakeholders are a key nexus in uniting a variety of stakeholders to generate demand for the conservation of biodiversity and ecosystem services and biodiversity in the working landscapes that will most likely characterize much of the tropics in the twenty-first century.

Conclusion

Ecosystem services are fundamental to the success of agriculture, and agricultural production can produce a number of ecosystem services and disservices at local, regional, and global scales; nevertheless, examples of market-based mechanisms to conserve these services are limited (Kremen and Miles, 2012; Kroeger and Casey, 2007; Power, 2010). Although several existing mechanisms have the potential to compensate farmers in the developing world for conserving and maintaining ecosystem services, at present these programs are at incipient stage and have demonstrated both promise and pitfalls.

The most successful programs involve participation of governmental, nongovernmental, and academic institutions; integration of top–down and bottom–up solutions and mechanisms; and buffering smallholder producers against fluctuations in market prices (of both agricultural and ecological commodities). Demand for agricultural products in low- and middle-income countries is expected to double by 2050 (Food and Agriculture Organization of the United Nations, 2011); without concerted attempts to internalize the market externalities of ecosystem services, this increased demand will undoubtedly result in massive environmental degradation and the ultimate failure to provide adequate resources for the majority of the world's human population. Market-based incentives can play a key role in safeguarding ecosystem services in agricultural areas, but their implementation is limited by lack of adequate policy and regulatory mechanisms, sufficiently large incentives to offset opportunity costs, and the failure of stakeholders to unite top–down and bottom–up approaches that integrate the regulatory capacity of governments with participatory action from producers to design appropriate local models for compensation.

Within the developing world, weak governance and inequitable distribution of resources are fundamental barriers to the optimal function of market-based mechanisms. In these cases, nonprofit organization, academic institutions, and grassroots community organization play vital and complimentary roles in developing appropriate and effective methods to protect interests and sustainability of local and global populations. Much of the current degradation in ecosystem services has resulted from the market failures inherent to neoliberal priorities of deregulation and privatization; expecting market-based interventions to resolve problems caused by markets themselves is more likely a losing proposition. Ultimately, market-based approaches to conservation are only one component of a larger toolkit that incorporates concepts of the intrinsic value of nature and also a focus on economic productivity, social equity, and sustainable livelihoods (Perfecto *et al.*, 2009).

See also: Agroforestry: Complex Multistrata Agriculture. Agroforestry: Practices and Systems. Biodiversity and Ecosystem

Services in Agroecosystems. Biodiversity: Conserving Biodiversity in Agroecosystems. Natural Capital, Ecological Infrastructure, and Ecosystem Services in Agroecosystems

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