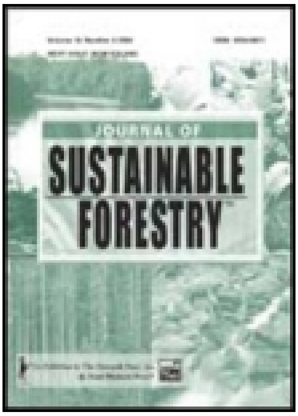

Journal of Sustainable Forestry
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/wjsf20

Environmental Services of Native Tree Plantations and Agroforestry Systems in Central America

Florencia Montagnini [a], Daniela Cusack [b], Bryan Petit [c] & Markku Kanninen [d]

[a] Practice of Tropical Forestry, Yale University, School of Forestry and Environmental Studies, 370 Prospect Street, New Haven, CT, 06511, USA

[b] University of California-Berkeley, Environmental Science, Policy and Management, 151 Hilgard Hall, Berkeley, CA, 94720, USA

[c] San Diego County/Forester, USDA, Natural Resources, Conservation Service, Southern California Watershed Recovery Program, 332 South Juniper Street, NRCS, #110, Escondido, CA, 92026, USA

[d] Center for International Forestry Research (CIFOR), Jalan CIFOR, Situ Cede, Sindangbarang, Bogor Barat, 16680, Indonesia

Version of record first published: 07 Sep 2008.

To cite this article: Florencia Montagnini , Daniela Cusack , Bryan Petit & Markku Kanninen (2004): Environmental Services of Native Tree Plantations and Agroforestry Systems in Central America, Journal of Sustainable Forestry, 21:1, 51-67

To link to this article: http://dx.doi.org/10.1300/J091v21n01_03

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SUMMARY. Besides supplying the growing demand for wood, plantations and agroforestry systems provide environmental services such as carbon sequestration and recovery of biodiversity. Several countries of Central America have recently started incentive programs to encourage plantation and agroforestry development. In Costa Rica, Payment for Environmental Services (PES) provides subsidies to farmers for plantations and agroforestry systems. Funding for these subsidies comes

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Florencia Montagnini is Professor in the Practice of Tropical Forestry, Yale University, School of Forestry and Environmental Studies, 370 Prospect Street, New Haven, CT 06511 USA (E-mail: florencia.montagnini@yale.edu).

Daniela Cusack is Doctoral Student, University of California-Berkeley, Environmental Science, Policy and Management, 151 Hilgard Hall, Berkeley, CA 94720 USA (E-mail: dcusack@nature.berkeley.edu).

Bryan Petit is Project Leader, San Diego County/Forester, USDA, Natural Resources, Conservation Service, Southern California Watershed Recovery Program, 332 South Juniper Street, NRCS, #110, Escondido, CA 92026 USA (E-mail: bryan.petit@ca.usda.gov).

Markku Kanninen is affiliated with the Center for International Forestry Research (CIFOR), Jalan CIFOR, Situ Gede, Sindangbarang, Bogor Barat 16680, Indonesia (E-mail: m.kanninen@cgiar.org).

[Haworth co-indexing entry note]: "Environmental Services of Native Tree Plantations and Agroforestry Systems in Central America." Montagnini, Florencia et al. Co-published simultaneously in *Journal of Sustainable Forestry* (Food Products Press, an imprint of The Haworth Press, Inc.) Vol. 21, No. 1, 2005, pp. 51-67; and: *Environmental Services of Agroforestry Systems* (ed: Florencia Montagnini) Food Products Press, an imprint of The Haworth Press, Inc., 2005, pp. 51-67. Single or multiple copies of this article are available for a fee from The Haworth Document Delivery Service [1-800- HAWORTH, 9:00 a.m. - 5:00 p.m. (EST). E-mail address: docdelivery@haworthpress.com].

Available online at http://www.haworthpress.com/web/JSF

doi:10.1300/J091v21n01_03

from a special tax on gasoline, and from external sources sought by FONAFIFO (National Fund for Forestry Financing).

These plantations and agroforestry systems are established on degraded land by farmers who are often advised by local NGOs (non-governmental organizations) or by research institutions that have practical experience in the region. Gathering information on species selection, plantation silviculture, and environmental services provided by plantations and agroforestry systems is important to the success of these systems. These incentive programs can also serve as a model for starting or modifying similar programs in other countries with comparable ecological and socioeconomic conditions.

This paper presents experiences with native species plantations over the past twelve years in Costa Rica. Data on volume, biomass production and recuperation of biodiversity are presented. We recommend the establishment of government incentives for reforestation and agroforestry systems with native species.

KEYWORDS. Biodiversity, carbon sequestration, degraded lands, mixed plantations, native species, reforestation, subsidies

INTRODUCTION

Tropical plantations provide a variety of environmental services such as wood production, carbon sequestration, and acceleration of forest succession processes (Parrotta, 1992; Lamb, 1998). With relatively high yields, tropical and subtropical plantations have the potential to contribute substantially to global wood production (Evans, 1999; Wadsworth, 1997).

In Central America, results of experiments started in the 1980s have helped to identify promising native and exotic species for reforestation and agroforestry. For example, the Proyecto Madeleña (Timber and Fuelwood Project) of CATIE (Centro Agronómico Tropical de Investigación y Enseñanza) (Tropical Agriculture Research and Higher Education Center) in Costa Rica, focused on six countries: Panama, Guatemala, Nicaragua, Costa Rica, El Salvador and Honduras (Ugalde, 1997). CATIE and other institutions like the Organization for Tropical Studies (OTS), and the Instituto Tecnológico de Costa Rica (Costa Rican Technological Institute) (ITCR) have generated valuable information about growth, productivity, biomass, and financial aspects for native and exotic trees in pure and mixed-species plantations of the humid and sub-humid tropical regions of Central America. The species studied have been estimated to have rotation periods of 12-25 years and projected yields of 250-300 m^3/ha (González and Fisher, 1994; Butterfield and Espinoza, 1995; Montagnini et al., 1995; Montagnini and Mendelsohn, 1997; Haggar et al., 1998; Petit and Montagnini, 2004).

Planting the studied tree species is an attractive alternative for farmers. Firewood from thinnings is an additional source of income. Recently, interest in establishing mixed plantations and agroforestry systems including native tree species has grown among small farmers in Central America (Montagnini et al., 1995; Montagnini and Mendelsohn, 1997; Piotto et al., 2003a; 2003b). Farmers have interest in planting native species because many of the native species whose timber has wide acceptance and an established demand in local markets are becoming increasingly scarce in natural forests due to logging, or in some cases because their extraction has been banned recently. They consider reforesting their farms with valuable species as a viable alternative to past land uses, such as extensive cattle ranching, which became unprofitable and degraded their lands. Most farmers who own small and medium-sized farms are often willing to allocate limited portions of their land to native species, while keeping major portions of their properties for other land uses, including reforestation with better known exotic species, such as *Tectona grandis* (teak) and *Gmelina arborea* (Piotto et al., 2003a; Piotto et al., 2004).

In Costa Rica, the forestry legislation includes incentives for the establishment and management of plantations and agroforestry systems, especially on abandoned pastures and other deforested lands. Due to these incentives, interest in establishing plantations and agroforestry systems has grown among farmers. Nonetheless, farmers and entrepreneurs need better technical information about the appropriate silviculture practices for native species to increase the commercial value of these production systems. More information would be especially valuable for improved plantation and agroforestry systems planning and management.

This paper presents results from experimental native tree plantations in Costa Rica, where growth in mixed and pure-species designs, carbon sequestration, and recuperation of biodiversity were measured. Government incentives for native-species plantations and agroforestry systems are recommended for countries with ecological and socioeconomic conditions similar to those in Costa Rica.

DEVELOPMENT OF PLANTATIONS IN CENTRAL AMERICA

The total area of plantations in Central American countries is shown in Table 1. Costa Rica and Guatemala are the two Central American countries with the largest area of plantations; they also have the oldest government programs that subsidize reforestation, which were started in the early 1980s. These programs generally work in association with non-government organizations (NGOs) that provide technical assistance to farmers in both silvicultural aspects and procedures for obtaining subsidies.

Historically, the wood market in Costa Rica has relied on the exploitation of natural forests. Commercially, wood primarily has been used for furniture, doors for export, and house construction. Reforestation using native species has been evolving over the past two decades. In Costa Rica, various government incentives exist for the establishment and management of plantations and agroforestry systems. Incentives include Payment for Environmental Services (PES) and advanced purchase of timber. With Forestry Law #7575, Costa Rica officially recognized certain environmental services provided by natural forests and plantations in 1996. The environmental services recognized in Costa Rica are defined in the Forestry law #7575: (a) mitigation of emissions of greenhouse gases (carbon fixation and storage); (b) protection of water for urban, rural or hydroelectric use; (c) protection of biodiversity

TABLE 1. Total area in tree plantations in Central America.

Country	Plantation area (hectares)	Size of the country (km^2)
Costa Rica	178,000	51,060
Guatemala	133,000	108,430
Honduras	48,000	111,890
Nicaragua	46,000	74,430
El Salvador	14,000	20,720

Source: FAO (2001).

for conservation and sustainable use for scientific, medicinal, research, or genetic uses, by protecting ecosystems and life forms; and (d) natural scenic beauty for tourist and aesthetic purposes. Methods of payment for these services were also established (Campos and Ortíz, 1999). This law allows for payments to owners of forested land and/or plantations in recognition of the environmental services provided. The government through selective gasoline taxes primarily finances the incentives programs, although international sales of carbon credits and loans also contribute to finance the program.

By providing monetary incentives to private land owners, PES could encourage numerous and extensive reforestation projects. PES are made to owners of 2-300 hectares for the conservation and regeneration of natural forest. Owners of more than one hectare are paid for reforestation or plantation establishment. Applications are made at regional offices through the National Fund for Forest Finance (FONAFIFO), which manages funds and issues certificates for PES. Payments are dispersed over five years at varying levels, depending on the type of forestry activity (Campos and Ortíz, 1999). PES are highest for reforestation (establishing of new plantations, generally on abandoned lands from agriculture or cattle), with payments totaling over $600 per hectare over a five-year period, which is almost twice the amount paid for conservation of natural forests. PES for agroforestry systems are given at a rate of $1.00 per tree. PES for plantation establishment could be complemented with other avenues of income generation, such as the advanced purchase of timber. Advanced purchase of timber is generally done by FUNDECOR (Foundation for Development of the Central Mountain Range), a NGO that assists farmers in the technical aspects of forest management and reforestation in the northern region of Costa Rica. This organization pays landowners in advance an average of $75 ha^{-1} yr^{-1} for up to fifteen years for plantations over three-years old. In addition to the annual payments, the landowners receive 80% of the profit from the final timber sale.

Agricultural or cattle ranching activities can generate income soon after the establishment of agroforestry systems, accelerating the recovery of costs incurred by the initial investment. In addition, PES and advanced purchase of timber ameliorate to varying extents one of the primary bottlenecks of reforestation: the high cost of plantation establishment and management.

Selection of Species for Reforestation of Degraded Land

Plantations and agroforestry systems can provide forest products (wood, firewood, mulch) and ecological benefits, such as improved nutrient cycling, soil conservation, and recovery of biodiversity. Species selection depends on the possibility of obtaining the desired products as well as achieving environmental benefits.

In Costa Rica, research on the growth of native and exotic tree species has been conducted since the early 1980s by a number of institutions such as CATIE, OTS, ITCR, other universities, and several international or local development projects. As a result of this research, scientists have been able to indicate which tree species are best for reforestation and agroforestry systems. For example, in the Atlantic humid lowlands of Costa Rica recent experiments have tested growth and agroforestry potential of several native tree species, such as *Terminalia amazonia*, *Virola koschnyi*, *Dipteryx panamensis*, *Vochysia ferruginea*, *Vochysia guatemalensis*, *Hieronyma alchorneoides*, and *Calophyllum brasiliense* (Montagnini et al., 1995; Montagnini and Porras, 1998; Byard et al., 1996; Kershnar and Montagnini, 1998; Horn and Montagnini, 1999; Piotto et al., 2003a; 2003b; Petit and Montagnini, 2004). All these species are frequently grown by farmers as part of plantations or agroforestry systems subsidized by the PES program (Piotto et al., 2003a).

GROWTH AND PRODUCTIVITY OF MIXED AND PURE-SPECIES PLANTATIONS

In Central America, many plantations and agroforestry systems are being established on abandoned agricultural land. Farmers are recognizing the potential for financial returns from plantations. However, these farmers prefer to use native species, of which relatively little is known (Piotto et al., 2003b). While establishment considerations and management practices are known for some native species, productivity levels of native species in plantations and agroforestry systems are mostly unknown (Montagnini et al., 1995; Piotto et al., 2003a). The next step in finding a suitable species for reforestation efforts is to determine the length of each species' rotation cycle and its timber production capacity.

As researchers continue to demonstrate the benefits of native species and mixed-species plantations, they will also continue to influence the method and type of plantations and agroforestry systems being implemented by the farmers. The diversity of species in plantations (both native and exotic species) has been increasing (FAO, 2001). Also, many local farmers seek to use mixed-species plantations (Piotto et al., 2003b). Well-planned, mixed-species plantations provide more diverse products than pure-species plantations. Mixed-species plantations diminish market risk, reduce incidence and severity of certain pathogen attacks, and complement ecosystem resource use (Wormald, 1992; Montagnini et al., 1995).

Volume Yield and Rotation Times of Native Species at La Selva, Costa Rica

For twelve years, we measured growth and productivity of twelve native species on three experimental plantations growing in mixed and pure-species plots at La Selva Biological Station in the humid Atlantic lowlands of Costa Rica. The twelve native species studied were: Plantation 1: *Jacaranda copaia* (Aubl.) D. Don, *Vochysia guatemalensis* D. Sm., *Calophyllum brasiliense* Cambess, and *Stryphnodendron microstachyum* Poepp. et Endl.; Plantation 2: *Terminalia amazonia* (Gmell.) Exell., *Dipteryx panamensis* (Pittier) Record & Mell, *Virola koschnyi* Warb, and *Paraserianthes guachapele* (Kunth) Harms; Plantation 3: *Hieronyma alchorneoides* Fr. Allemao, *Balizia elegans* (Ducke) Barnaby and Grimes, *Genipa americana* L., and *Vochysia ferruginea* Mart. The plantations were designed based on species growth, form, economic value, farmer preference, and potential impact on soil fertility recuperation (Montagnini et al., 1995). Plantations were in completely randomized blocks with four replications and five treatments: four pure-species plots per species and one mixed-species plot with all four species. Initial spacing was at 2 meters × 2 meters, and each plot was 32 meters × 32 meters with a total of 256 trees per plot. Thinnings at years 3 and 6 left trees at 4 meters × 4 meters spacing. In each mixed-species plot, a systematic design was used to maximize species interactions (Montagnini et al., 1995). In each plot, individuals from the four species were alternated by row.

Measurements performed in 2002 were done on ten surviving species (all of those mentioned above except for *S. microstachyum* and *P. guachapele*, which had suffered severe pest attacks). Growth equations were constructed for each of the ten species. The growth equations of six of the species were third degree equations and, thus, could be used for volume extrapolations. These six species included *C. brasiliense*, *V.*

guatemalensis, *J. copaia*, *V. ferruginea*, *G. americana*, and *B. elegans*. Rotation ages and expected merchantable volumes were calculated from the growth equations (Table 2).

Yield projections are still being refined because thinning compensations have exaggerated predicted harvestable volumes for some species. However, trends can still be extrapolated from the results. As calculated from the results of the experiment, *J. copaia* has a relatively short rotation age of 6.5 years, after which trees of this species slow their growth quickly in a manner typical of most fast-growing species. At this age, trees of this species are of merchantable size and can be harvested. The rotation ages for the other four species range from 13.2 to 18.5 years (Petit and Montagnini, 2004).

Two of the three species comprising Plantation 1, *V. guatemalensis* and *J. copaia*, grew faster in mixtures than in pure plantations, while *C. brasiliense* grew significantly slower in the mixed-species plantations. We determined the ideal rotation age of the mixed-species plantations to be 8.5 years and its corresponding yield to be 403 m^3/ha. Subsequently, we compared the productivity of the mixed-species plantation to that of each of the single-species plantations. The mixed-species plantation produced more merchantable wood over time than any of the other pure plantations from this experiment. The mixture was approximately 21% more productive than the most productive of the single-species plantations (Petit and Montagnini, 2004).

In Plantation 2, *Virola koschnyi*, *Terminalia amazonia*, and the mixed-species plantations had the highest growth increments in volume. Plots with the highest productivity in Plantation 3 were *Vochysia ferruginea*,

TABLE 2. Rotation age and merchantable volume of six species at La Selva Biological Station, Costa Rica.

Species	Rotation Age (years)	Merchantable volume at time of harvest (m^3/ha)
C. brasiliense	18.5	296
V. guatemalensis	13.5	417
J. copaia	6.5	255
V. ferruginea	13.3	363
G. americana	13.2	76
B. elegans	8.8	139

followed by the mixed-species plantations, *Balizia elegans,* and *Hieronyma alchorneoides* (Piotto et al., 2003b; Petit and Montagnini, 2004).

Mixed plantations, if planned according to the characteristics of each species, can in general produce more wood than pure-species plantations. Mixtures of fast-growing species and slower-growing species produce harvestable wood at different rotation times, with faster growing species producing timber of less value (e.g., *Jacaranda copaia*) and slower-growing species (e.g., *C. brasiliense*, *D. panamensis*) producing more valuable wood. The more valuable wood also constitutes a longer-term sink for fixed carbon (e.g., construction timber, furniture, wood crafts) than timber of less value, whose uses may be relatively shorter-lived (e.g., boxes, poles, fuelwood). As different species have different rotation times, the land in a mixed-species plantation is in use for a longer period of time than if planted with just one fast-growing, short rotation species. This diminishes incentives for changing to other land uses, keeps a vegetative cover that protects the soil, and serves other environmental services such as biodiversity conservation as well (Montagnini and Porras, 1998).

Biomass and Carbon Accumulation in Mixed and Pure-Species Plantations

As determined from measurements of biomass from thinnings at ten years of age in Plantation 1, pure plantations of *Vochysia guatemalensis* had the highest biomass, followed by *Calophyllum brasiliensis* (Table 3). In Plantation 2, the highest biomass per hectare was measured on *Dipteryx panamensis* and *Terminalia amazonia*. On Plantation 3, *Hieronyma alchorneoides* had the highest biomass, followed by *Vochysia ferruginea*.

From the aforementioned results, we have determined which species are the best options for increasing biomass accumulation and carbon sequestration in plantations. The values of mean annual aboveground biomass production for the fastest-growing species of our experiments lie within the ranges reported elsewhere for fast-growing plantations of commonly-used exotics in the humid tropics (Montagnini and Porras, 1998). Values for the two slower growing trees in pure plots, *C. brasiliense* and *D. panamensis,* are similar to ranges reported for relatively slower-growing species.

This information can be used for programs aimed at compensating for carbon sequestration by specific land uses (plantations or agroforestry). We are currently using a simulation model (CO2FIX) to estimate carbon sequestration for each species and plantation mixtures (Masera et al., 2003; Nabuurs et al., 2002).

TABLE 3. Above-ground biomass (Mg/ha) of ten native tree species in plantation at La Selva Biological Station, Costa Rica.

	Foliage	Branch	Stem	Total
Plantation 1 (10 years old)				
Calophyllum brasiliense	**11.7**	**21.5**	**59.4**	**92.6**
standard deviation	*8.4*	*13.6*	*31.3*	*52.9*
Vochysia guatemalensis	**4.4**	**10.3**	**110.9**	**125.6**
standard deviation	*2.5*	*14.8*	*80.7*	*84.3*
Jacaranda copaia	**1.5**	**3.2**	**85.0**	**89.8**
standard deviation	*1.3*	*5.7*	*46.8*	*18.2*
Plantation 2 (10 years old)				
Dipteryx panamensis	**10.5**	**30.7**	**164.0**	**205.3**
standard deviation	*5.9*	*19.8*	*84.8*	*106.9*
Terminalia amazonia	**9.3**	**29.1**	**126.5**	**164.9**
standard deviation	*4.9*	*16.4*	*69.6*	*82.6*
Virola koschnyi	**3.9**	**8.2**	**61.9**	**74.1**
standard deviation	*2.3*	*5.5*	*32.2*	*39.6*
Plantation 3 (9 years old)				
Genipa americana	**2.1**	**9.6**	**35.0**	**46.6**
standard deviation	*2.1*	*12.1*	*26.7*	*40.8*
Hieronyma alchorneoides	**4.7**	**27.1**	**87.6**	**119.4**
standard deviatin	*3.2*	*18.0*	*43.2*	*62.5*
Balizia elegans	**1.3**	**5.1**	**34.6**	**41.0**
standard deviation	*1.4*	*5.9*	*19.4*	*26.3*
Vochysia ferruginea	**5.4**	**11.5**	**61.3**	**78.1**
standard deviation	*3.9*	*10.6*	*32.0*	*44.4*

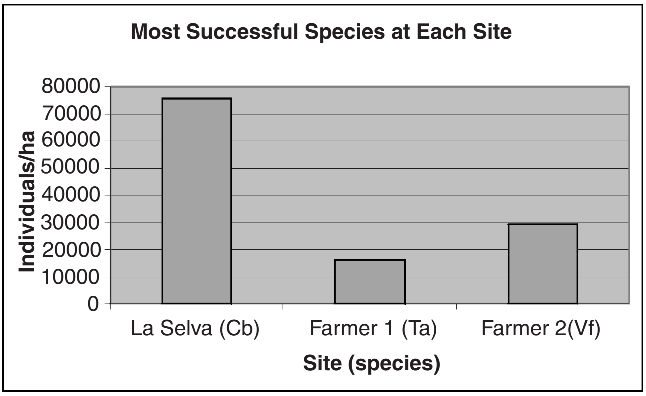
CONTRIBUTION OF PLANTATIONS TO CONSERVATION AND RECUPERATION OF BIODIVERSITY

At La Selva Biological Station, several studies have reported that plantations can accelerate the recuperation of plant diversity in the understory (Guariguata et al., 1995; Powers et al.,1997; Montagnini et al., 1999; Carnevale and Montagnini, 2002; Cusack and Montagnini, 2004). In Plantation 1, at 7 years of age, *Vochysia guatemalensis,* the mixed-species plantations, and *Calophyllum brasiliense,* had the highest abundance of woody regeneration in the understory. In Plantation 2, also at seven years, *Terminalia amazonia*, *Virola koschnyi* and the mixed-species plantation had the highest diversity of woody species regenerating in the understory. In Plantation 3, the highest number of woody species was under the mixed-species plantation, followed by *Hieronyma alchorneoides* and *Vochysia ferruginea* (Montagnini, 2001).

These are promising indicators for the use of these plantations as accelerators of natural forest succession in the region. In our research, tree plantations facilitated forest regeneration, influencing numbers of tree individuals, as well as species diversity. There was a larger abundance of individuals and species diversity in the mixed than in the pure plantations. Birds and bats had dispersed the majority of the regenerating individuals. The different tree species in the plantations generated different shading and litter accumulation conditions, influencing germination and survival of regenerating individuals. Species selection in reforestation projects influences the proportion of regeneration in each phase (colonization, establishment, growth and survival) (Carnevale and Montagnini, 2002).

Very few woody species were found in the control, natural regeneration plots. The lack of perches for seed dispersers and invasion by herbaceous vegetation that outcompetes the tree seedlings in their growth are factors that might have impeded the establishment of woody species in the control. In another of our studies, we compared understory woody regeneration on 10-year-old, medium-sized (~15 ha) plantations belonging to farmers in the Atlantic humid lowlands of Costa Rica. Two plantations belonging to regional farmers were compared with results from La Selva Biological Station. In this study, blocks of six native timber species were present at each of the sites. In accordance with previous results, understory regeneration was significantly higher on planted plots than on abandoned (control) pastures at each site, which were dominated by ferns (Cusack and Montagnini, 2004). Surprisingly, a different timber species was most successful for recruiting understory regeneration at each site (Figure 1). At La Selva Biological Station, *Vochysia guatemalensis* had significantly higher understory woody regeneration than other species. At the first farmer's plantation, *Terminalia amazonia* was most successful, while *Vochysia ferruginea* had the most regeneration at the second farmer's plantation. Site, more

FIGURE 1. Understory woody regeneration for the most successful timber species at La Selva Biological Station and two private farms in the Atlantic humid lowlands of Costa Rica. Cb: *Calophyllum brasiliense;* Ta: *Terminalia amazonia*; Vf: *Vochysia ferruginea.*



so than a particular species, can be an important factor influencing the success of planted species at recruiting understory regeneration.

In this study, we also compared dispersal vectors for regenerating species present at each site. At La Selva Biological Station, there were significantly more woody species dispersed by birds and bats than at the other two sites. Also, more individuals per hectare were present at the La Selva plantations than at the farmers' plantations (Figure 1). The high level of bird and bat dispersed species at La Selva implies that these plantations were being used as habitat by these animals. The fact that there were more bird and bat dispersed species and more individuals per hectare at La Selva Biological Station might be attributed to the proximity of these plantations to non-fragmented forest, while the farmers' plantations were farther away from natural forests.

CAN ENVIRONMENTAL SERVICES PAY FOR REFORESTATION IN CENTRAL AMERICA?

From the studies discussed here, we have found that native-species plantations have valuable social and economic functions, including the provision of forest products, carbon sequestration, and recuperation of biodiversity. Government policies that promote reforestation through incentives or other means are necessary for the successful reforestation of degraded areas. It is recommended that incentives promoting reforestation through plantation establishment and management follow similar models to those that have been successful in Costa Rica. It is also recommended that, in addition to establishment of new plantations, owners of existing plantations be allocated incentives on a yearly basis to continue proper management. The Forest Service of each country should control the payment of incentives. NGOs should assist landowners with species selection and technical aspects of plantation establishment and management.

Finding low-cost methods to sequester carbon is emerging as a major international policy goal in the context of increasing concerns about global climate change. Mitigating the accumulation of carbon dioxide and other greenhouse gases in the atmosphere through forest conservation and management was discussed as early as in the 1970s. It was not until the 1990s that international action was initiated in this direction. In 1992, several countries agreed to the United Nations Framework Convention on Climate Change (UNFCCC), whose major objectives were: developing national inventories of greenhouse gas emissions and sinks, and reducing the emission of greenhouse gases (FAO, 2001). At the third meeting of the FCCC in 1997 in Kyoto, Japan, the participating countries, including the United States, agreed to reduce greenhouse gas emissions to 5% or more below 1990 levels by 2012 (*http://unfcc.int*). The Kyoto Protocol, which emerged from this meeting, provides a mechanism by which a country that emits carbon in excess of agreed-upon limits can purchase carbon offsets from a country or region that manages carbon sinks. Although the United States' withdrawal from the treaty in 2001 has considerably weakened its implementation, the Kyoto Protocol represents a major international effort related to carbon sequestration (Montagnini and Nair, 2004). The adoption of the Kyoto Protocol in 1997 triggered a strong increase in investment in plantations as carbon sinks, although the legal and policy instruments and guidelines for management are still debated (FAO, 2000). A number of countries have already prepared themselves for the additional funding for the establishment of human-made forests. The 1997 Costa Rica national program was the first to establish tradeable securities of carbon sinks that could be used to offset emissions and to utilize independent certification insurance.

Can environmental services pay for reforestation in Central America? In Costa Rica, US $14 million were invested in the payment for environmental services in 1997, which resulted in the reforestation of 6,500 ha, the sustainable management of 10,000 ha of natural forests, and the preservation of 79,000 ha of private natural forests (Nasi et al., 2002). Eighty percent of this funding originated nationally from the tax on fossil fuels, while the other 20% came from the international sale of carbon from public protected areas. Recently, the World Bank provided a US $ 32.6 million loan to Costa Rica to fund the PES through a project called 'Ecomarkets' and was accompanied by a grant from the Global Environment Facility (GEF) of approximately US $ 8 million (Nasi et al., 2002).

In Costa Rica, the demand for PES is much higher than the funding currently available; it is estimated that the funding available could only cover 15-30% of the demand (Nasi et al., 2002). This suggests that forest owners are willing to take payments for the environmental services provided by their forests, even if probably these payments do not always fully compensate the farmers for their investment. According to recent studies, most of Costa Rican society is willing to internalize the costs of maintaining the ecological functions and environmental services from forest ecosystems, especially in the case of water. In a study carried out by CATIE, it was found that most Costa Ricans agree to pay in the form of taxes for the environmental services provided by forests. It was also found that the environmental services valued most by Costa Ricans is water protection, followed by biodiversity protection, mitigation of greenhouse gases, and scenic beauty (35%, 25%, 20% and 20%, respectively) (Nasi et al., 2002).

Apparently, the public is willing to even make additional payments for water consumption, as is currently done by the private water company, Servicios Públicos de Heredia (Heredia Public Water Company). This company charges the consumer an additional tax based on water consumption. These funds are used by the company to pay farmers who own land where the water company operates for forest protection and reforestation. The company also uses the funds to purchase affordable land that holds water reservoirs.

CONCLUSIONS

Mixed-species plantations, if planned according to species characteristics, can produce higher wood volume than pure-species plantations. Fast and slow-growing species in the same plantations have rotations of varying lengths, and they yield short and long-term products.

In the plantations studied, tree regeneration in the understory was more successful in plantations than in abandoned pastures. Mixed-species plantations demonstrated good results for recuperating understory biodiversity. As seen in these studies, native-species plantations have social and economic functions, provide forest products, contribute to the rehabilitation of degraded areas, promote atmospheric carbon sequestration, and restore biodiversity.

Government incentives or other methods are needed to promote reforestation of degraded lands. It is recommended that incentives for the establishment and management of native-species plantations follow the successful Costa Rica model.

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