Payment for Environmental Services in Costa Rica:
Carbon Sequestration Estimations of Native Tree Plantations

by Alvaro Redondo-Brenes, MFS 2005

Introduction

Due to the direct influence that greenhouse gases like cabon dioxide (CO_2) have on global warming, the increasing level of these gases in the atmosphere has emerged as a major international environmental concern (Shepherd and Montagnini 2001). Between the years 1750 and 2000, the concentration of CO_2 has increased by 31±4% (IPCC 2001). To curb the escalating level of atmospheric CO_2, either the overall level of emissions has to be reduced through pollution mitigation techniques, or emissions have to be captured from the atmosphere and stored in terrestrial and marine ecosystems known as carbon sinks (Andrasko 1990; Constanza et al. 1997). Tropical tree plantations, such as those in Costa Rica, have therefore been suggested as small carbon sinks (Montagnini and Porras 1998; Shepherd and Montagnini 2001; Schroeder 1992; Losi et al. 2003). These plantations may soon serve as a large source for carbon sequestration since their area is expected to increase over the next few decades (Gladstone and Legid 1990; Schroeder 1992; Houghton 1996).

The use of government incentives in Costa Rica – namely, the Payments for Environmental Services Program (PES) – has increased the number of tree plantations in the last two decades, especially on small and medium-sized farms in rural areas (Ortiz and Kellenberg 2002). For instance, the total reforested area with PES (including native and exotic species) from 1997 to May 2002 was 21,838 hectares (Sage-Mora 2002).

Carbon projects that promote agroforestry, small-scale plantations, and natural forest regeneration and preservation, such as the PES in Costa Rica, will improve the livelihoods of small-scale farmers, communities, and indigenous peoples (CIFOR 2002). Thus, studies of carbon sequestration within systems such as tree plantations are a priority since they assess an ecosystem's effectiveness in providing revenues to landowners. The first step to assess carbon sequestration in a system is to estimate its biomass. Biomass accumulation results from basic physiological processes in plants. Plants take up CO_2 from the atmosphere through photosynthesis and store carbon in biomass (Leemans et al. 1996).

The main objective of this research was to estimate aboveground biomass and carbon sequestration in small and medium-sized native tree plantations in the Atlantic and Northern lowlands of Costa Rica, using allometric equations developed by Montero and Montagnini (2004). These allometric equations use mathematical relationships that convert external measurements, such as trunk diameter and sometimes height, to total tree biomass (Losi et al. 2003). This non-destructive method to estimate biomass is highly accurate (above 95%) and provides a model for plantations growing in similar ecological conditions (i.e. location, topography, and climate) and within the same range of diameter and height measurements

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(Montero and Montagnini 2004; Perez and Kanninen 2002, 2003).

Research Sites

Research was conducted in two different groups of plantations (Figure 1). The first group is located in Sarapiqui, in the Atlantic lowlands. The second group, called San Carlos, is located in the North Huetar Region.

Sarapiqui

The study site is located at 10°12'-10°47' north latitude and 84°09'-83°45' west longitude. Mean annual precipitation is 3500-5000 mm, with a minimum precipitation level of 50 mm. Elevation is between 30 and 200 masl. Mean annual temperature is 24°C. The overall topography is flat to undulating terrain. In general, soils belong to the Ultisol and Inceptisol orders. There are various soil limitations, such as slow or impeded drainage and very low to medium fertility (OPSA 1979; Piotto et al. 2003).

Thirteen plantations were evaluated and 62 permanent and temporal plots were measured. These plantations were established between 1990 and 1995 with an association of local farmers, the County Agricultural Center of Sarapiqui (CACSA), and a non-governmental organization (NGO) called the Foundation for the Development of the Central Volcanic Range (FUNDECOR).

San Carlos

This study site is located in Costa Rica's North Huetar Region. Mean annual precipitation is 2000-4000 mm, with a mean annual temperature of 25°C. The overall topography is flat to undulating terrain. Elevation is between 100 to 400 masl. In general, soils belong to the Ultisol

Figure 1. Research Sites

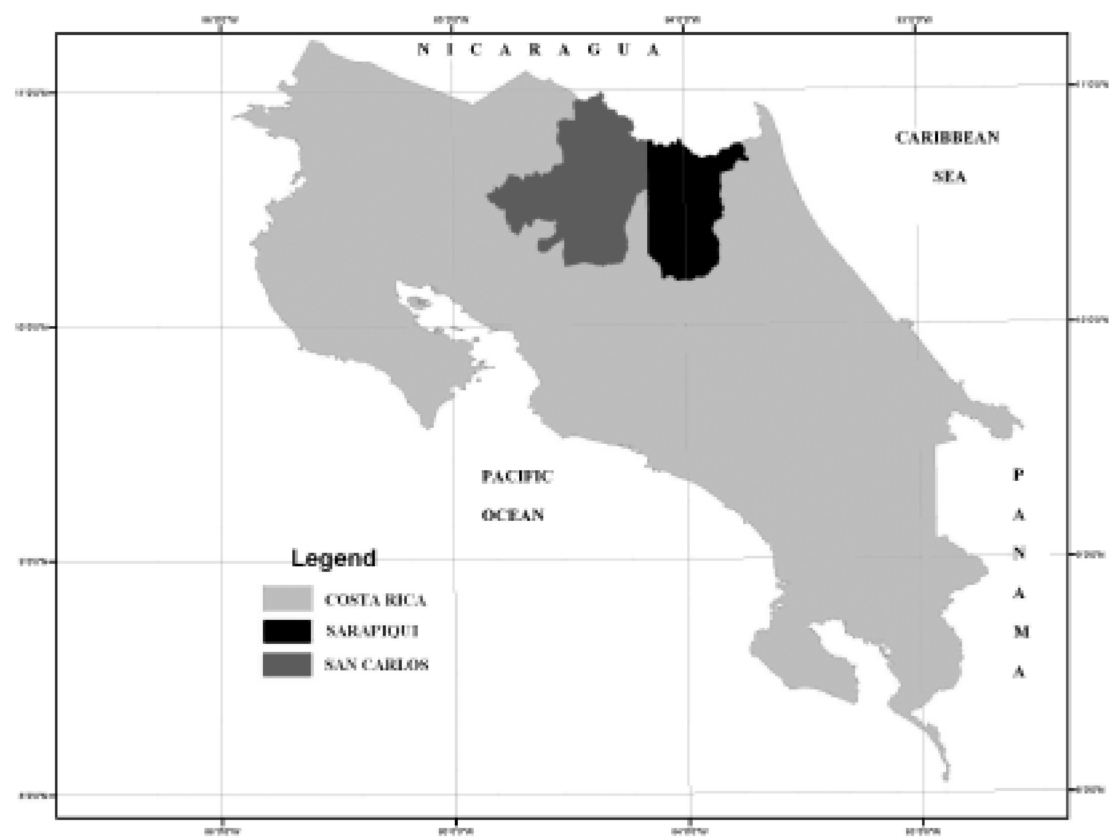

Table 1. Characteristics of tree species grown in the Atlantic and North lowlands of Costa Rica

Species name	Common name	Family	Native range	Growth, habitat
Vochysia guatemalensis Donn. Sm.	Chancho, Mayo	Vochysiacea	Mexico to Panama	Upper canopy, early-mid successional; fast growth
Callophyllum brasiliense Cambess.	Cedro Maria	Clusiaceae	Mexico to South America and the Antilles	Canopy tree. Moderately shade -tolerant; slower growth
Terminalia amazonia (J.F.Gmel.) Exell	Amarillon, Roble Coral	Combretaceae	Mexico to South America and the Antilles	Canopy tree; Heliophyte; moderately fast growth
Virola koschnyi Warb	Fruta Dorada	Myristicaceae	Belize to Panama and Ecuador	Canopy tree, mid-successional; slower growth
Dipteryx panamensis (Pittier) Record & Mell	Almendro	Fabaceae - Papilionoideae	Nicaragua to Colombia	Canopy tree, late successional; slower growth
Hyeronima alchorneoides Fr. Allemao	Pilon	Euphorbiaceae	Belize to the Amazon	Canopy tree; Early - Mid successional; moderately fast growth
Vochysia ferruginea Mart.	Botarrama	Vochysiacea	Nicaragua to Peru and Brazil	Heliophyte tree, durable, rapid growth; found in secondary forests.

Source: Jimenez-Madrigal et al. (2002)

and Inceptisol orders. The principal soil limitations are its acidity, low to medium fertility, and slow drainage (Delgado 2002).

Nineteen farms were evaluated and 117 permanent and temporal plots were measured. These plantations were established between 1990 and 1995 as part of a project on native species sponsored by the Technological Institute of Costa Rica (ITCR) and an NGO called COSEFORMA (Forestry Development Commission of San Carlos) (Delgado 2002).

Research Species

This project analyzed seven native tree species (local names are in parentheses): *Vochysia ferruginea* Mart. (botarrama); *V. guatemalensis* Donn. Sm. (chancho); *Hyeronima alchorneoides* Fr. Allemao (pilon); *Callophyllum brasiliense* Cambess (cedro maria); *Terminalia amazonia* (J.F. Gmel.) Exell (roble coral); *Virola koschnyii* Warb (fruta dorada), and *Dipterix panamensis* (Pittier) Record & Mell (almendro) (Table 1). Only six species were evaluated at San Carlos since plantations of *Callophyllum brasiliense* were not locatable. These seven species were chosen because they were the most frequently planted by farmers at both locations. In addition, these species are recommended by FUNDECOR and COSEFORMA because the PES are available for reforestation with these species.

Methods

Collection of field measurements

At every plot, I measured the diameter at breast height (DBH), 1.30 m from the ground, for each species of concern. In addition, I measured the total height to the canopy of six to eight trees per plot to extrapolate the height of the rest of the trees within the plots using linear regression. The plot size, number of plantations, and number of measured plots varied from site to site to provide consistency with the research projects that are being carried out in the two sites and because I used the permanent sample plots set up by the organizations mentioned above.

The plot sizes varied within both sites due to variations in plantation shape and size. These plantations varied from 0.1 ha to a maximum of 5 ha. Plot areas were between 225 m^2 and 784 m^2. The number of plantations and number of measured plots varied because I measured as many plantations as were available in each site to increase the sample size and to represent variability along each region.

Data analysis

To estimate aboveground biomass, I used the following equations, which were developed for each species studied by Montero and Montagnini (2004) at La Selva Biological Station, Sarapiqui, Costa Rica:

$\text{Ln}(Y) = a + b\,\text{Ln}(DBH)$ (1)

$\text{Ln}(Y) = a + b\,\text{Ln}(DBH) + c\,\text{Ln}(H)$ (2)

Where

Ln: Natural logarithm

Y: Tree biomass in kilograms

DBH: Diameter at breast height in centimeters.

H: Total height in meters.

a, b, and c: Constant values calculated for each species.

These equations use DBH and total height to estimate aboveground biomass by a tree's component (foliage, branches, stems, and total tree). Each tree species has its own equation for each component (Appendix 1). Equation (1) was used to compute most of the estimates, excluding stem biomass values for *Vochysia guatemalensis*, for which equation (2) was used. I assumed carbon sequestration to equal 50% of a component's present biomass (Montagnini and Porras 1998). The mean annual increment (MAI) for carbon sequestered was calculated by dividing the total accumulated values by the plantation age.

One-way analyses of variance (ANOVA) for different sample sizes were used to determine the statistical significance for differences in carbon sequestration and growth rates between species and locations. In addition, Tukey's pairwise comparisons were used to determine statistically significant differences within each variable that was analyzed. Regression analyses were performed to evaluate relationships between carbon sequestration and growth parameters. For all the analyses, interactions were tested and residual plots were analyzed to ensure that the model assumptions were satisfied. Analyses were performed with SAS System Release 8.2 (2001) and statistical significance was fixed at $P<0.05$.

Results: Carbon Sequestration of Native Tree Plantations

The data for carbon sequestration (Table 2) is presented by the tree components: stem, branches, foliage, and total tree in tons per hectare and by the total carbon values of the corresponding trees in kilograms (See Appendix 1). Overall, I found that the Sarapiqui plantations presented higher carbon values by species than the San Carlos plantations.

In San Carlos, the species that had the highest total carbon sequestration per tree were *V. guatemalensis* (9-10 years) and *T. amazonia* (9-10 years). The lowest values were from *V. koschnyi* (9-10 and 13-14 years). The estimates of carbon sequestration per hectare indicated that *D. panamensis* (13-14 years) and *V. guatemalensis* (13-14 years) were the species with the highest values. The species *V. koschnyi* (9-10) and *V. ferruginea* (11-12) had the lowest values (Table 2).

In Sarapiqui, the species with the highest total carbon sequestration per tree were *T. amazonia* (11-12 years) and *H. alchorneoides* (11-12 years). The lowest values were from *V. koschnyi* (11-12 years). However, no significant differences were found among the seven species (Tukey's test,

Table 2. Carbon sequestration estimations and mean annual increment (MAI) of total carbon of native forest plantations in Costa Rica

Location / Species	Age (Years)	Carbon storage per ha (Mg)				Carbon storage per tree (Kg)	MAI Carbon (Mg ha^{-1} year^{-1})
		Stem	Branches	Foliage	Total		
Sarapiqui							
D. panamensis	9-10	60.6 a	23.0 ab	7.5 ab	91.0 a	128.0 a	10.1 a
D. panamensis	11-12	26.0 (5.7)bc	8.0 (1.9)bcd	2.8 (0.6)cd	36.9 (0.8)bcd	54.7 (11.8)a	3.2 (0.8)bcd
T. amazonia	9-10	58.8 (0.7)ab	15.9 (0.6)abcd	4.4 (0.1)cd	79.1 (1.4)ab	138.1 (16.3)a	7.9 (1.3)ab
T. amazonia	11-12	40.9 (11.3)abc	11.1 (3.4)abcd	3.1 (0.9)cd	55.1 (15.6)abc	151.8 (53.2)a	4.7 (0.1)bcd
H. alchorneoides	9-10	36.1 (12.8)abc	26.9 (14.4)a	3.4 (1.3)cd	66.3 (28.5)abc	120.0 (53.4)a	7.1 (3.4)abc
H. alchorneoides	11-12	24.9 (11.6)c	20.3 (13.6)abc	2.3 (1.1)cd	46.5 (26.2)abc	144.3 (84.8)a	4.0 (2.3)bcd
V. guatemalensis	9-10	40.5 (3.7)abc	2.0 (0.8)cd	1.7 (0.1)cd	44.5 (31.0)abc	81.4 (63.7)a	4.6 (3.5)bcd
V. guatemalensis	11-12	38.3 (11.0)abc	1.5 (0.4)d	1.4 (0.5)d	41.2 (12.6)bc	137.9 (9.7)a	3.3 (1.1)bcd
V. ferruginea	9-10	11.7 (3.7)c	7.8 (3.5)bcd	4.0 (2.3)cd	23.5 (9.4)c	65.3 (11.8)a	2.6 (1.0)bc
V. ferruginea	11-12	19.2 (1.6)c	12.5 (1.3)abcd	4.6 (0.6)bc	36.3 (3.5)bc	132.9 (25.4)a	3.1 (0.3)bcd
V. koschnyi	11-12	13.7 (5.0)c	6.3 (3.2)bcd	2.7 (1.3)cd	22.5 (9.4)c	53.2 (25.9)a	1.9 (0.8)d
C. brasiliense	11-12	36.2 (5.1)abc	15.2 (2.7)abcd	8.5 (1.6)a	60.0 (8.8)abc	103.1 (61.5)a	5.4 (0.7)abcd
San Carlos							
D. panamensis	9-10	25.5 (8.0)abcd	8.4 (2.6)abc	2.6 (0.9)abc	36.5 (11.5)ab	50.8 (12.4)ab	3.5 (1.1)ab
D. panamensis	13-14	31.3 (6.3)abc	9.7 (2.3)a	3.4 (0.8)ab	44.4 (9.3)a	52.8 (12.8)ab	3.3 (0.7)ab
T. amazonia	9-10	20.9 (3.1)abcd	5.1 (0.9)abc	1.5 (0.2)c	27.5 (4.2)abc	67.3 (12.7)ab	2.8 (0.4)abc
H. alchorneoides	9-10	17.8 (2.6)bcd	9.0 (3.1)ab	1.5 (0.3)bc	28.3 (5.6)abc	59.3 (29.2)ab	2.8 (0.6)abc
H. alchorneoides	11-12	18.6 (6.5)abcd	8.5 (5.2)abc	1.6 (0.6)bc	28.8 (12.2)abc	45.2 (23.8)ab	2.5 (1.0)abc
V. guatemalensis	9-10	33.2 (11.8)ab	1.8 (0.6)c	1.5 (0.5)c	36.6 (12.9)ab	75.1 (19.6)a	3.7 (1.3)a
V. guatemalensis	11-12	35.9 (13.7)a	2.2 (0.5)c	1.6 (0.4)bc	39.7 (14.5)ab	65.6 (27.1)ab	3.4 (1.2)ab
V. guatemalensis	13-14	36.1 (3.0)a	2.5 (0.1)bc	1.9 (0.1)bc	40.5 (3.3)ab	56.9 (0.4)ab	3.0 (0.2)abc
V. ferruginea	9-10	11.4 (3.9)d	7.3 (2.4)abc	4.2 (1.4)a	23.0 (6.9)abc	55.6 (12.5)ab	2.3 (0.7)abc
V. ferruginea	11-12	11.4 (2.7)d	5.5 (3.0)abc	2.7 (1.5)ab	20.0 (6.9)bc	40.5 (26.1)ab	1.8 (0.6)abc
V. koschnyi	9-10	8.4 d	2.7 bc	1.3 c	12.4 c	30.9 b	1.2 c
V. koschnyi	13-14	14.1 (4.8)cd	4.9 (2.8)abc	2.2 (1.1)bc	21.2 (8.7)abc	27.0 (12.2)b	1.6 (0.6)bc

Means are significantly different when standard deviations are followed by different letters ($P<0.05$)

P<0.05). The estimated carbon sequestration per hectare suggested that *D. panamensis* (9-10 years) and *T. amazonia* (9-10 years) were the species with the highest values. The species *V. koschnyi* (11-12) and *V. ferruginea* (9-10) had the lowest values (Table 2). I found that plantation location (P=0.0001), species (P<0.0001), and density (P=0.03) were accurate predictors of carbon sequestration. Tree age, however, was not a significant predictor of carbon sequestration (P=0.36).

The MAI for carbon sequestration indicated that, in Sarapiqui, the species with the highest growth was *D. panamensis*, and *V. koschnyi* had the lowest value. In San Carlos, the highest MAI was *V. guatemalensis* and the lowest was *V. koschnyi* (Table 2).

The percentage carbon sequestration in the different tree components (stem, branches, and foliage) was similar in both locations. The carbon allocated in the stems varied from 50% (*V. ferruginea*) to 92% (*V. guatemalensis*). Carbon allocated in the branches varied from 4% (*V. guatemalensis*) to 43% (*H. alchorneoides*). Finally, the carbon sequestered in the foliage varied from 3% (*V. guatemalensis*) to 18% (*V. ferruginea*).

Discussion: Carbon Sequestration of Native Tree Plantations

According to Carpenter, Nichols, and Sandi (2004), reforestation projects on degraded sites, such as the ones included in this study, may have different objectives, among them to reduce erosion, reestablish a variety of native species, and/or establish economically viable commercial plantations. In tree plantations, economic considerations generally are more heavily weighted than in other industrial forest practices due to the higher establishment and tending costs (Hartley 2002). However, tree plantations also offer other environmental services, such as carbon sequestration (Lugo and Brown 1992; Subak 2000; Shepherd and Montagnini 2001).

In Costa Rica, the PES was implemented with the creation of the Forestry Law in 1996. The new law recognizes a range of environmental services derived from natural forests, plantations, and agroforestry systems, such as carbon fixation, hydrological services (including reduced water siltation supplied for hydropower and aquifers), biodiversity protection, and provision of scenic beauty (Subak 2000). On average, the landowner receives US$540 per hectare for establishing new tree plantations, US$210 per hectare for previous established plantations, US$210 per hectare for forest conservation and regeneration, and support for the establishment of trees within agroforestry systems, distributed in percentages over a period of five years (FONAFIFO 2004). The PES program receives revenues from a 5% tax on gasoline consumption, private-sector contributions, as well as the sale of certifiable tradable offsets (CTOs) to foreign investors. In 1997, Norway purchased US$2.0 million in CTOs in exchange for about 230 kt of carbon offsets (Subak 2000).

Results of the present study depicted that native forest plantations from 9 to 14 years old were sequestering on average between 12.4 to 79.1 Mg ha^{-1} of carbon. In addition, the MAI of sequestered carbon was between 1.2 to 10.1 Mg ha^{-1} $year^{-1}$. These carbon values are in the range of values for tropical tree plantation species worldwide, such as *Pinus caribaea* (Caribbean pine), *Leucaena spp.* (leucaena), *Casuarina spp.* (Australian pine), *Pinus patula* (Mexican weeping pine), *Cupressus lusitanica* (Cypress), *Senna siamea* (Siamese cassia), *Acacia nilotica* (gum Arabic tree), and *Azadirachta indica* (neem), which have values between 8 and 78 Mg C ha^{-1} (Schroeder 1992). However, the values reported in this study are lower than the values found for primary forests in Costa Rica, which are on average 110 Mg C ha^{-1} (IPCC 2001), and they are also lower than a 20 years old plantations of *Tectona grandis* (teak) in Panama which averaged 104.5 Mg C ha^{-1} (Kraenzel et al. 2003). In addition, MAI of carbon found in the present study was similar, if not higher, than the biomass accumulation in natural forests greater than 60 to 80 years old and logged forests (1-2 Mg C ha^{-1} $year^{-1}$) (Lugo and Brown 1992), biomass accumulation in secondary forests from 0 to 20 years old (2-3.5 Mg C ha^{-1} $year^{-1}$) (Brown and Lugo 1990; Silver, Ostertag, and Lugo 2000), biomass accumulation in plantations worldwide (1.4 to 4.8 Mg C ha^{-1} $year^{-1}$) (Brown, Lugo, and Chapman 1986 in Lugo and Brown 1992), *Gmelina arborea* (melina) plantations in Costa Rica (7 Mg C ha^{-1} $year^{-1}$), and restoration programs in the highlands of the Virilla river in Costa Rica (2 to 3 Mg C ha^{-1} $year^{-1}$) (Subak 2000).

In Costa Rica, aboveground biomass accumulation and carbon sequestration has been studied over the last decade (including the species that are a part of this study) for both younger plantations (Montagnini and Sancho 1994; Stanley and Montagnini 1999; Montagnini 2000; Shepherd and Montagnini 2001) and for plantations with similar ages and species of the present study (Redondo and Montagnini, in preparation). Studies of plantation from four to eight years old indicated that fast growing species such as *Jacaranda copaia* and *Vochysia guatemalensis* were the species with the best production of aboveground biomass and carbon sequestration (Montagnini and Sancho 1994; Stanley and Montagnini 1999; Montagnini 2000; Shepherd and Montagnini 2001). At La Selva Biological Station, in forest plantations from 12 to 13 years old, Redondo and Montagnini (in preparation) found that the most productive species were *Terminalia amazonia*, *Callophyllum brasiliense*, and *Dipteryx panamensis*. According to these results, it seems that fast growing species (i.e. *V. guatemalensis*) accumulate biomass and carbon in the first stage of their lifespan, but before they are 10 years old, forest plantations including moderate to slower growing species (i.e. *D. panamensis*, *T. amazonia*, *and C. brasiliense*) may accumulate more biomass and carbon within the system than the former. The latter species also may sequester more carbon over a longer period of time due to their longer rotation cycles of around 20 to 30 years, in comparison to fast growing species, which have rotation cycles between 13 and 15 years (Petit and Montagnini 2004).

The outcome of the present research shows that the seven species that were a part of this study had varying carbon sequestration values due to intrinsic species growth characteristics and stand management. It is also important to highlight that the carbon sequestration estimates obtained in this research have to be used with caution. In some plantations, the range of tree species' diameters was higher, especially for the fast growing species, than those used by Montero and Montagnini (2004) to develop the allometric equations. In addition, some of these equations do not consider variations in wood specific gravity within species, locations, and within individuals of the same species due to specific growth conditions (Elias and Potvin 2003; Baker et al. 2004). Thus, an overestimation of those values is expected. In a study of native species carbon sequestration estimation with species growing in tree plantations in Panama and Costa Rica, Losi et al. (2003), using also allometric models in a different range of trees, resulted in an overestimation of 10.2% in the carbon stock values for *D. panamensis* plantations. Therefore, we can expect an overestimation similar to the estimated by Losi et al. (2003), or even higher.

Conclusions: Importance of Native Tree Plantations

The results of the present research enhance the criteria elaborated with previous research findings to improve species choice for reforestation and silvicultural management in Costa Rica, and in other regions with similar ecological features. Moreover, they support the concept that tropical plantations can serve diverse economic, social, and ecological functions that may ultimately help reduce atmospheric CO_2 accumulation (carbon sinks).

The difference in carbon sequestration values may suggest two scenarios. First of all, if our objective is to accumulate carbon in the short term, species such as *V. guatemalensis* and *V. ferruginea* are two of the best options due their fast growth. On the other hand, if the objective is carbon sinks in the long term, species such as *D. panamensis* and *C. brasiliense* are the best options, because those species presented the highest values of carbon sequestration to date, and they also have longer rotation cycles.

The PES program in Costa Rica is an example that may be implemented in other tropical countries. A program like this not only benefits the whole society with the environmental services provided by the native tree plantations (i.e. carbon sequestration, soil and water conservation, scenic beauty, biodiversity, and restoration of degraded lands), but it also may benefit with economic incentives to small and medium landowners, who do not have access to bank loans to invest in reforestation programs or in other agricultural alternatives in degraded lands.

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Appendix 1. Allometric models to estimate aboveground biomass in kilograms for seven native tree species in Costa Rica (Adapted from Montero and Montagnini 2004)

Species	Component	Equation	r^2
C. brasiliense	Stem	Ln (Biomass) = -2.570 + 2.454 * Ln (DBH)	0.98
	Branches	Ln (Biomass) = -5.773 + 3.226 * Ln (DBH)	0.92
	Foliage	Ln (Biomass) = -6.825 + 3.379 * Ln (DBH)	0.95
	Total tree	Ln (Biomass) = -2.829 + 2.704 * Ln (DBH)	0.98
V. guatemalensis	Stem	Ln (Biomass) = -3.867 + 2.048 * Ln (DBH) + 0.697 * Ln (H)	0.99
	Branches	Ln (Biomass) = -1.872 + 1.202 * Ln (DBH)	0.92
	Foliage	Ln (Biomass) = -4.661 + 2.014 * Ln (DBH)	0.95
	Total tree	Ln (Biomass) = -2.815 + 2.428 * Ln (DBH)	0.97
V. ferruginea	Stem	Ln (Biomass) = -1.776 + 1.804 * Ln (DBH)	0.99
	Branches	Ln (Biomass) = -10.100 + 4.285 * Ln (DBH)	0.99
	Foliage	Ln (Biomass) = -12.761 + 4.976 * Ln (DBH)	0.86
	Total tree	Ln (Biomass) = -3.252 + 2.492 * Ln (DBH)	0.95
V. koschnyi	Stem	Ln (Biomass) = -3.679 + 2.481 * Ln (DBH)	0.98
	Branches	Ln (Biomass) = -9.279 + 3.962 * Ln (DBH)	0.96
	Foliage	Ln (Biomass) = -8.988 + 3.610 * Ln (DBH)	0.89
	Total tree	Ln (Biomass) = -4.132 + 2.755 * Ln (DBH)	0.98
D. panamensis	Stem	Ln (Biomass) = -2.831 + 2.747 * Ln (DBH)	0.99
	Branches	Ln (Biomass) = -6.137 + 3.534 * Ln (DBH)	0.93
	Foliage	Ln (Biomass) = -6.256 + 3.197 * Ln (DBH)	0.95
	Total tree	Ln (Biomass) = -3.011 + 2.947 * Ln (DBH)	0.99
T. amazonia	Stem	Ln (Biomass) = -2.473 + 2.501 * Ln (DBH)	0.99
	Branches	Ln (Biomass) = -4.876 + 2.844 * Ln (DBH)	0.99
	Foliage	Ln (Biomass) = -5.456 + 2.622 * Ln (DBH)	0.93
	Total tree	Ln (Biomass) = -2.538 + 2.614 * Ln (DBH)	0.99
H. alchorneoides	Stem	Ln (Biomass) = -3.136 + 2.591 * Ln (DBH)	0.96
	Branches	Ln (Biomass) = -8.615 + 4.234 * Ln (DBH)	0.98
	Foliage	Ln (Biomass) = -6.404 + 2.876 * Ln (DBH)	0.95
	Total tree	Ln (Biomass) = -1.696 + 2.224 * Ln (DBH)	0.98

Biomass is in kilograms per component; DBH – diameter at the breast height (centimeters); H – total height in meters; r^2 measures the proportion of the variance of the Ln (Biomass) explained by the equation.