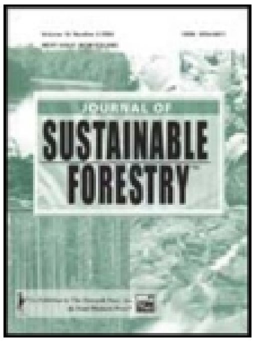

Journal of Sustainable Forestry

ISSN: 1054-9811 (Print) 1540-756X (Online) Journal homepage: http://www.tandfonline.com/loi/wjsf20

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To cite this article: James Gockowski , Mathurin Tchatat , Jean-Paul Dondjang , Gisele Hietet & Terese Fouda (2010) An Empirical Analysis of the Biodiversity and Economic Returns to Cocoa Agroforests in Southern Cameroon, Journal of Sustainable Forestry, 29:6-8, 638-670, DOI: 10.1080/10549811003739486

To link to this article: https://doi.org/10.1080/10549811003739486

Published online: 11 Oct 2010.

Journal of Sustainable Forestry, 29:638–670, 2010

ISSN: 1054-9811 print/1540-756X online
DOI: 10.1080/10549811003739486

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An Empirical Analysis of the Biodiversity and Economic Returns to Cocoa Agroforests in Southern Cameroon

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Arguing that agroforestry associations are important for biodiversity conservation, certification schemes are seeking to differentiate commodities on the basis of the biodiversity included in the cropping system, in order to financially encourage more "wildlife friendly" production systems through market mechanisms. However, biologists and economists have begun to question the overall impact on biodiversity and poverty when relatively extensive "wildlife friendly" agroforestry systems are encouraged in lieu of more intensified systems. Field inventories were taken of the plants utilized from 67 ha of cocoa agroforests (CAFs) in southern Cameroon among 46 households. Two hundred eighty-six plant species were utilized as foods, medicinal plants, timber, and service products. From interviews with household members it was revealed that non-cocoa revenues accounted for one quarter of total CAF revenues. Per capita revenues from the CAF were positively skewed and exceeded the poverty line for 29% of the sampled population.

The authors would like to thank the Sustainable Tree Crops Program and its sponsors, the World Cocoa Foundation and USAID for the funding provided.

This article was initially presented at "Conservation and the Agricultural Frontier: Integrating Forests and Agriculture in the Tropics," a conference organized by the Yale University Chapter of the International Society of Tropical Foresters on April 7–8, 2006 at the Yale School of Forestry and Environmental Studies in New Haven, Connecticut, USA.

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Monetary returns from the CAF increased with increasing agricultural intensification and market access. The findings suggest that intensified use of cocoa fungicides, improved market institutions, and expansion of the CAF area cultivated per household would reduce rural poverty in southern Cameroon. Overall, the plant diversity of CAFs degraded slightly as intensification proceeded.

KEYWORDS southern Cameroon, agricultural intensification, biodiversity, cocoa agroforests, poverty reduction, trade-offs

INTRODUCTION

In recent years the issue of agricultural intensification and its impacts on rural poverty, biodiversity conservation, and environmental services has been the focus of much debate (Lee & Barrett, 2001; Angelsen & Kaimowitz, 2001; Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005). Some hold that intensification of agricultural production is necessary if further forest-to-agriculture land conversions are to be avoided in the face of continued growth in the demand for food and fiber. Others hold that the technical innovations associated with agricultural intensification cause a range of direct and indirect effects on land-use patterns that accelerate tropical deforestation. A priori theoretical predictions are qualitatively ambiguous (Angelsen & Kaimowitz; Pagiola & Holden, 2001) and the outcomes regarding poverty and the environment when agriculture in the humid tropics is intensified remain empirically in question (Lee & Barrett; Green, Cornell, Scharlemann, & Balmford, 2005).

The wet tropical forests of southern Cameroon have been seriously degraded by the smallholder farming systems in this agroecological zone (Essama & Gockowski, 2001). However, the extent of degradation varies according to the cropping system (Gockowski et al., 2005; Vosti, Gockowski, & Tomich, 2005). Cocoa is an important perennial component of the farming system usually grown in indigenously evolved multi-strata agroforestry associations which have demonstrably higher environmental value as compared to the other principal land-use systems. Arguing that agroforestry associations are important for biodiversity conservation, certification schemes including Fairtrade, the Smithsonian Institute ("Bird Friendly®" coffee), and the Rainforest Alliance among others, are seeking to differentiate commodities on the basis of the biodiversity included in the cropping system, in order to financially encourage more "environmentally friendly" production systems through market mechanisms (Cohn & O'Rourke, 2009). However some biologists and ecologists have begun to question the overall impact on biodiversity when relatively extensive "wildlife friendly" agroforestry systems are encouraged in lieu of more intensified systems (Green et al., 2005). The higher yields from intensified cocoa and coffee systems mean that a much smaller area of converted tropical forest is required to produce a given quantity demanded. The biodiversity conserved in the cropping system must be weighed against the biodiversity lost from the conversion of tropical forest.

We contribute to this debate through an empirical assessment of the economic returns to, and the levels of biodiversity conserved in, the cocoa agroforests (CAFs) of southern Cameroon. We also examine how these values vary over a spatially defined gradient of market access and agricultural intensification. The intra- and inter-household distribution of cocoa agroforest income reveals the poverty alleviation potential of these indigenously developed systems.

Limited sampling of the diversity of cocoa agroforests in southern Cameroon has revealed their relatively high levels of biodiversity (Aulong, 1998; Sonwa, 2004), but knowledge of the household benefits accruing from associated non-cocoa products and the trade-offs between cocoa and non-cocoa production is scant (Gockowski & Dury, 1999; Aulong). This study further substantiates the vascular plant diversity of cocoa cropping systems in southern Cameroon on the basis of extensive field surveys and establishes the utility of this diversity in the 1ivelihoods of cocoa farmers.

Documentation of the products associated in cocoa production systems may contribute to a broadening of research focus among West African cocoa research institutions. Nearly all research and innovation development on cocoa production systems in West Africa is focused on the cocoa component. The neglect of the non-cocoa component in these systems can lead to counterproductive innovations and recommendations which could possibly cause total revenue to decline (although cocoa income may have increased). This study highlights the mixed associations that characterize Cameroonian cocoa agroforests and the need for systems-oriented research. Documentation of how farmers themselves have modified these systems in response to market demand and agricultural intensification suggest possible directions for future research.

The article is constructed as follows: the first section discusses the methods used in collecting primary data and describes the gradient of agricultural intensification and market access over which the study was defined. This is followed by presentation of results and findings on plant diversity in cocoa production systems, the productivity of various production inputs, and income and distributional outcomes associated with these systems. The discussion section focuses on four broad areas. First, it begins by considering the interrelationships among shade levels, blackpod disease, fungicide use, and cropping system productivity. Second, the contribution of the CAF to household livelihoods through both consumptive use and the revenues generated by the various components of these systems is considered. Third, the impact of agricultural intensification and market access on structural changes in CAFs is explored. Finally recommendations are given for the development of simplified commercial systems for the two most common cocoa-fruit tree associations and a call for project initiatives targeting the development of intensified CAF systems among the rural poor.

METHODS

Field Data Collection

Three sources of primary data form the basis of the analysis: (a) a structured survey of 90 cocoa producing households in the Lékié, Mefou Afamba, and Mvila administrative divisions (30 in each division) of southern Cameroon (Figure 1); (b) an inventory of non-timber plant products from 67 ha of CAFs; and (c) an inventory of timber species conducted on the same 67 ha of CAFs inventoried in (b) above.

Interviews were conducted with 10 cocoa producing households in each of nine villages purposively selected from three administrative divisions, using a structured questionnaire in order to characterize the cocoa and non-cocoa component of CAF cropping systems with a focus on the management and value of non-cocoa commodities. The basis for the selection of the nine villages was their recent participation in a farmer field school (FFS) training on integrated pest and crop management for cocoa conducted by the International Institute of Tropical Agriculture (IITA). The resulting acquaintance of the interviewed subjects with IITA facilitated farmer cooperation. From the list of FFS participants in each village, five were randomly selected (six in one case) for interview and field inventory. Two alternative participants were identified to replace households that might not be able to participate. To augment the survey's degrees of freedom, an additional five cocoa producing households per community were randomly

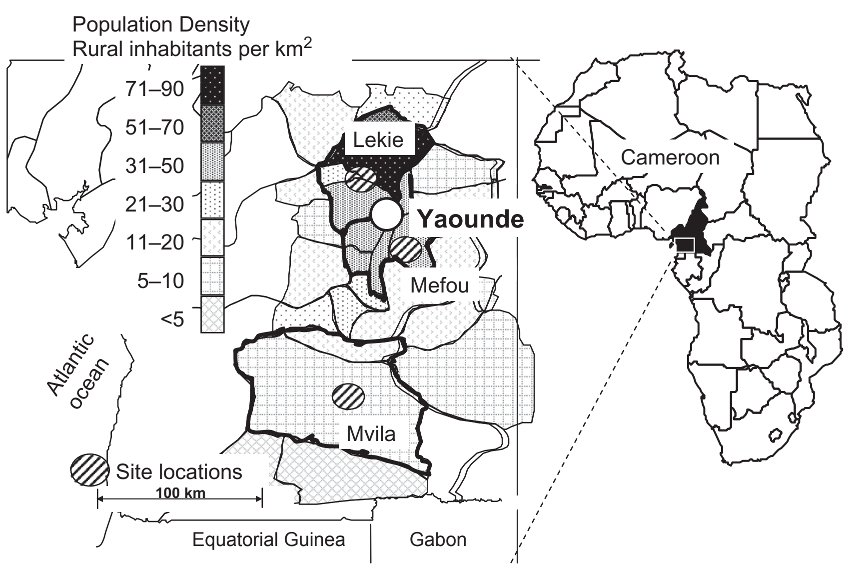

FIGURE 1 Location of research sites in relation to population density and access to the Yaoundé (constructed by authors using 1987 Cameroon population census data).

selected for interview. Thus, 90 cocoa producers were interviewed and 46 CAFs inventoried with the participation of the cocoa producer.

Two inventories were completed on farms meeting a size (1 to 2 ha) and maturity (at least 20 yr in age) requirement. If the farmer's field did not meet the requirements they were replaced by the alternates. The first inventory identified taxonomically all trees with either a realized or potential economic exploitation as timber according to a classification made by the Cameroon Ministry of the Environment and Forests (MINEF). All timber tree individuals in excess of 10-cm diameter at breast height (dbh) were counted and their dbh measured. The second field inventory was farmer-guided, and involved the taxonomic identification of all species in the cocoa farm that were used for either food, medicinal, or other services; i.e., the non-timber forest products (NTFPs). The individuals of all tree species including introduced fruit species were counted for the entire farm, while the abundance of herbaceous plants was subjectively evaluated on a 3-step scale.

Estimations of Diversity and Species Importance

Using data gathered from the NTFP species inventory, the commonly reported Shannon index of diversity (Krebs, 1972) was calculated for each sampled cocoa farm as:

$$H_j = -\sum_{i=1}^{s} (p_i)(\log_2 p_i),$$

where:

H = index of species diversity for farm j,
S = number of species, and
p_i = proportion of total sample belonging to ith species.

In order to measure dominance in terms of overall tree density, fruit tree counts from the NTFP inventory were added to the timber tree inventory database and the following index computed for each sampled farm:

$$\text{Community dominance index}: \ \text{CDI} = \text{percentage of abundance contribyted by the two most abundant species} = \frac{y_1 + y_2}{y} \times 100,$$

where abundance is measured by density and:

y_1 = abundance of most abundant tree species,
y^2 = abundance of second most abundant tree species,
y = total abundance for all tree species.

Cocoa Production Analysis

Cocoa production was modeled using a Cobb-Douglas double-log form that combines the results from the producer interviews on production levels and input usage with the plant inventory data to examine the relationship between biodiversity and fruit tree diversification on cocoa production. The model estimated was:

$$\ln Y_i = \alpha_0 + \beta_1 \ln FAMLAB_i + \beta_2 AGELAB_i + \beta_3 AGELAB_i^2 + \beta_4 \ln LAND_i + \beta_5 \ln FUNG_i + \beta_6 \ln H_i + \beta_7 \ln FRUIT_i + \beta_8 LEKIE_i + \varepsilon_i,$$

where:

Y = cocoa output of farm i;
FAMLAB = number of family members who contribute labor to cocoa production;
AGELAB = mean age of family members contributing family labor;
LAND = amount of land in cocoa production on farm i;
FUNG = quantity of cocoa fungicides applied on farm i;
H = Shannon's index of biodiversity for farm i;
FRUIT = the number of avocado, mango, and African plum fruit trees associated with cocoa production on farm i;
LÉKIÉ = equal to one if farm is in the Lékié division, zero if not;
ε = normally distributed residual error term.

The labor input on the farms could not be accurately determined by a one-visit survey. Instead, as a proxy measure, each household member contributing labor to cocoa production was enumerated (*FAMLAB*) and the mean age of contributing members determined (*AGELAB*) to test whether or not an aging workforce is having a negative impact on cocoa production (Assoumou, 1977). Land in cocoa production (*LAND*) and the quantity of fungicides (*FUNG*), measured in dollar expenditures and applied to control blackpod disease, are both expected to have a positive impact on cocoa production. The model includes the Shannon index of biodiversity (H) and the number of fruit trees (*FRUIT*) included in the farm; both of these variables are expected to have negative impacts on cocoa output due to the competition for biophysical resources (Green et al., 2005; Steffan-Dewenter et al., 2007). The dummy variable (*LÉKIÉ*) indicating a farm in the Lékié administrative division is included to account for unmeasured differences in soil resources and market institutions relative to the other two divisions.

The Humid Forest Ecoregional Benchmark and the Intensification/Market Gradient

The surveyed villages and administrative divisions all lay within the 15,000 km^2 Humid Forest Ecoregional Benchmark area (Figure 1). The benchmark was delineated by researchers at IITA to strategically capture gradients of biophysical, economic, and demographic conditions in the humid forests of West and Central Africa (Gockowski et al., 2004; Douthewaite et al., 2005).

All of the study sites are on the central plateau of Cameroon with average elevations between 550 m to 750 m. Soils fall into the FAO grouping of Orthic Ferrasols and the topography varies from level–undulating to rolling–hilly terrain. Soil pH in the Mvila villages is acidic (pH $<$ 5.0) while less so in Mefou and Lékié sites. Annual rainfall ranges from 1450 mm to 1800 mm falling in a bimodal season pattern and increases from east-to-west (Santoir, 1995). The heaviest rains fall in April–May and September–October with a short dry season occurring in July–August and a longer dry season from mid November–February. The natural climax vegetation is semi-deciduous broadleaf tropical forest in the northeast regions and wet evergreen broadleaf forests (the Atlantic coastal forests) in the southwest.

Smallholder farming in the benchmark is subsistence-oriented and very diversified with production largely dependent on household labor, land, and natural capital. The use of physical capital is remarkably limited, consisting of a few simple hand tools, knapsack fungicide sprayers, and chainsaws that are available for hire. Most households are self-sufficient in food crop production, which is mainly assured by the groundnut/cassava-based mixed food crop field managed by women. Surpluses from this small (less than 0.25 ha on average) fallow rotational cropping system also augment household incomes (in particular women's cash income). Overall, cocoa production is the predominant source of cash income for three out of four households in the benchmark.

The three field sites were deliberately chosen to represent variation in measures of cropping intensification and the institutional development of market supply chains linking producers with 1.6 million consumers in the capital city of Yaoundé.

The Lekié sites are characterized by high population densities, relatively good all-weather access to Yaoundé with an abundance of transport options, and a developed private input supply sector. As a result, land is more intensively cropped; i.e., shorter fallow periods (a median value of 4 yr), with a higher frequency of agrochemical use. In the Lékié sites, market women commonly transport basins of fruits such as mangos, avocados, and African plums to Yaoundé via the ubiquitous "clando" village taxi services which operate on a daily basis here with relatively high frequency.

The Mefou and Lékié sites are approximately equidistant to Yaounde but because population densities in Mfou are lower and road infrastructure less developed, institutional linkages with Yaoundé are less developed. Input markets are also less developed and abundant land resources have resulted in more extensive production systems with longer fallow periods (a median value of 6 yr).

In the Mvila sites, 180 km to the south, farmers have access to abundant forest land but are constrained by labor and capital. As a result, their production systems tend to be more extensive with long fallow periods (an average of over 6 yr). Low population densities coupled with poor road infrastructure have limited the development of the supply chain to Yaoundé and raise the unit cost of transport limiting commercial opportunities.

On the basis of the above analysis, the sites can be qualitatively ranked in terms of market development and agricultural intensification as follows: Mvila < Mefou < Lékié. The effect of site differences in agricultural intensification and market institutions on structural and management parameters of CAFs are analyzed using one-way ANOVA tests.

Cameroon is the world's fifth largest cocoa producer with annual output ranging from 150,000 to 180,000 t in recent years. About half of national production comes from the Southwest Province and the rest from southeastern Cameroon production systems similar in nature to those described here. In Lékié in the mid-1990s, only 63% of households had cocoa production systems versus 96% and 74% in the Mvila and Mefou divisions, respectively (Gockowski et al., 2004). Because of the higher population densities in the Lékié, shaded cocoa agroforests were estimated to account for 23% of total land area in the Lékié versus 9 and 4% in the Mfou and Mvila divisions, respectively, in 1995. Impacts on landscape ecological functions will depend on the extent and nature of cocoa cultivation; the spatial importance of CAFs in regions such as the Lékié suggests a non-negligible role (Gockowski et al., 2004).

RESULTS

Plant Diversity in Cocoa Farms

Non-timber products

The farmer-guided inventory of non-timber products (NTPs) in the 46 CAFs enumerated 254 plant species belonging to 78 different plant families. Of these, 93 species were used as food, 186 species had medicinal value, and 103 species were used for other purposes such as food wrapping,

TABLE 1 Structural Characteristics of CAFs Across Intensification and Market Access Gradients in the Southern Cameroon Forest Benchmark

	High (Lékié) $n = 16$	Medium (Mefou) $n = 15$	Low (Mvila) $n = 15$	All $n = 46$	p
Shannon index	4.3	4.8	5.0	4.7	<.001
Cocoa yield (kg ha^{-1})	589.0	399.7	363.5	450.8	<.001
Cocoa tree density per ha	986	1025	936	969	.896
Tree density per ha	140	215	134	162	.009
NTP plant species per ha	44	72	57	57	.108
African plum *D. edulis* (individuals/ha)	15.1	22.9	5.4	14.5	<.001
Avocado *P. americana* (individuals/ha)	23.8	17.5	11.2	17.6	.103
Mango *M. indica* (individuals/ha)	19.4	10.9	3.2	11.4	<.001
Relative density of fruit trees (%)[a]	39	27	16	27	<.001
Community dominance index *CDI* (0–100)	31.4	24.1	21.4	25.8	.003
Basal area at breast height (m^2/ha)	12.5	17.2	13.0	14.2	.185
Basal area economic timber species (m^2/ha)	6.7	4.5	5.3	5.5	.219
Basal area non-commercial species (m^2/ha)	3.4	8.3	4.9	5.5	<.001

Note. [a]Combination of mangoes, avocados, and African plum densities.

poles for construction, etc. (Appendix A). The majority was trees but 13 woody shrubs, 30 vines, and 46 herbaceous plants were also utilized. The Euphorbiaceae was the most represented botanical family with 16 species, followed by Sterculiaceae with 12 species and Apocynaceae, Caesalpiniaceae, and Moraceae with 11 species, respectively (Appendix A).

The Shannon index of plant diversity (H) declined as expected along the Mvila-Mefou-Lékié market/intensification gradient (Table 1). H also declined as the density of the three most important fruit trees—African plum (*Dacryodes edulis*), mango, (*Mangifera indica*), and avocado (*Persea americana*) increased (Figure 2). Structurally, combining these results with the significantly higher relative densities of fruit trees and lower basal area in the Lékié indicates that CAFs here have lower biodiversity and biomass than the other sites but a higher relative density of commercially attractive fruit trees. The measure of community dominance (*CDI*) increased significantly with the gradient (Table 1) suggesting that CAFs tend to become less diverse as market institutions and intensification proceed. In the Lékié sites either African plum-mango, African plum-avocado, or mango-avocado comprised the two dominant species on two out of every three farms sampled, in contrast to the Mvila site, where only 1 out of 15 CAFs was dominated by avocados and African plum (Appendix B). Cocoa densities were statistically equivalent across sites at approximately 1,000 trees ha^{-1} which is significantly below the 1,300 to 1,600 trees ha^{-1} recommended by research.

Table 2 presents the 25 species with the highest frequency of occurrence and their uses. Heading the list is the African plum, *D. edulis* (G. Don)

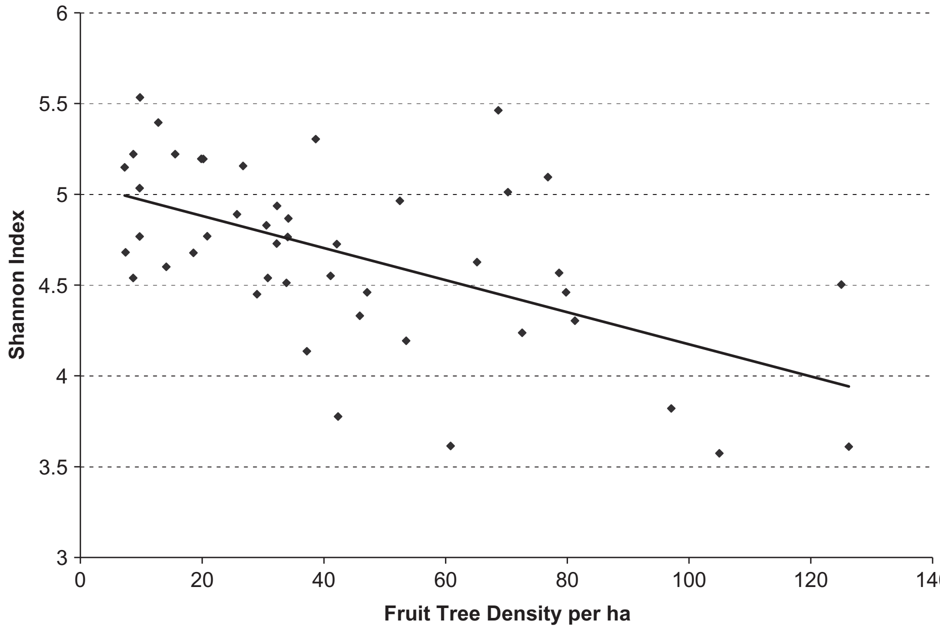

FIGURE 2 Shannon index of plant diversity and combined relative density of the African plum, avocado, and mango trees.

H. J. Lam. This is a semi-domesticated tree of the humid forest which produces an oleiferous fruit that is a mainstay in the diets of households in the forest zones of Cameroon and Nigeria. Its natural range is the Congo basin with a westward extension into Nigeria (Kengué, 2002). Avocado (*P. americana* Mill.) and mango trees (*M. indica* L.) were the next most frequently reported. Both of these introduced species as well as African plum have well-developed markets in the urban areas. Next on the list were the medicinal plants: spiral ginger, *Costus afer* Ker Gawl., and *A. boonei* De Wild., which are used mainly to treat amoebic dysentery and fever, respectively.

Commercialization, Revenues, and Revenue Distribution

Cocoa production

Cocoa yields were nearly twice as high in the Lékié as in the other two sites (603 kg ha^{-1} versus 354 kg ha^{-1}, Student's $t = 3.32$, $p = .0013$) due in part to the significantly higher use of fungicides to control cocoa blackpod disease, which were applied at more than double the rate of the other sites (50 sachets ha^{-1} versus 24 sachets ha^{-1}). The Cobb-Douglas cocoa production function confirms the importance of the quantity of fungicides applied in these shaded systems (Table 3).

TABLE 2 Relative Frequency of 25 Most Common Plants With Food, Medicinal, Service, or Timber Values in the CAFs Across Intensification and Market Access Gradients in the Southern Cameroon Forest Benchmark

	Locality and level of intensification				Use value		% of farms	
Plant species	High (Lékié) $n = 16$	Medium (Mefou) $n = 15$	Low (Mvila) $n = 15$	All $n = 46$	Food	Med	Ser	Tim
D. edulis (G. Don) H. J. Lam	100	100	100	100	x	x	x	x
P. americana Mill.	100	100	87	96	x	x		
M. indica L.	100	93	87	93	x	x		
Costus afer Ker Gawl.	81	100	100	93	x	x	x	
A. boonei De Wild.	94	80	100	91		x	x	x
P. angolensis (Welw.) Warb.	69	100	93	87	x	x		x
Anchomanes difformis (Blume) Engl.	88	100	67	85		x		
Ficus exasperata Vahl	69	93	87	83	x	x	x	
Spathodea campanulata P. Beauv.	75	80	93	83		x	x	
T. superba Engl. & Diels	63	73	100	78	x	x		x
Myrianthus arboreus P. Beauv.	63	80	87	76	x	x		
Pterocarpus soyauxii Taub.	63	73	93	76		x	x	x
Albizia adianthifolia (Schumach.) W. Wight	31	100	93	74		x	x	x
Elaeis guineensis Jacq.	69	67	87	74	x	x	x	
Funtumia elastica (Preuss) Stapf	50	80	93	74		x	x	
Ricinodendron heudelotii (Baill.) Heckel	75	67	80	74	x	x	x	x
Carpolobia alba G. Don	75	87	53	72	x	x	x	
Crassocephalum biafrae (Oliv&Hiern) Moore	69	87	60	72	x	x		
Paullinia pinnata L.	63	67	87	72	x	x	x	
Rauvolfia vomitoria Afzel.	69	87	60	72		x		
C. sinensis (L.) Osbeck	69	73	67	70	x	x		
M. excelsa (Welw.) C.C. Berg	50	87	73	70		x	x	x
Morinda lucida Benth.	75	73	60	70		x		
Ceiba pentandra (L.) Gaertn.	63	87	53	67		x		x
Ficus mucuso Welw. ex Ficalho	50	87	53	63	x	x		

Overall, the level of biodiversity as measured by the Shannon index (H) was not a significant determinant of cocoa production in southern Cameroon, whereas fruit tree abundance had a significant negative impact (Table 3). The elasticity of cocoa output with respect to associated fruit

TABLE 3 OLS Regression Estimates of a Cobb-Douglas Function of Cocoa Production From Southern Cameroon ($n = 45$)

Variable	Coeff.	*SE*	*t* ratio	*p*
Intercept	4.536	1.437	3.157	.003
FAMLAB	−0.007	0.086	−0.087	.931
AGELAB	0.055	0.023	2.369	.023
$AGELAB^2$	−0.001	0.000	−2.130	.040
LAND	0.362	0.115	3.155	.003
FUNG	0.213	0.085	2.512	.017
H	0.155	0.790	0.196	.846
FRUIT	−0.242	0.097	−2.495	.017
LÉKIÉ	0.453	0.187	2.426	.020
Brusch-Pagan test ($\chi^2 = 11.98$, 8 *df*, $p = .15$); Adj. $R^2 = .519$				

trees is equal to −0.242. That is, a 10% increase in associated fruit trees (an increase of 5 trees at the mean) would lower cocoa output by 2.42% (a decrease of 12.5 kg). Land planted to cocoa was a positive determinant of cocoa output. *FAMLAB*, the proxy variable for labor input was not significant; however, *AGELAB*, the mean age of the labor force, had a significant, non-linear effect on output with the highest labor efficiency achieved at a mean age of 54 yr. The locational variable *LÉKIÉ* was also significant and indicates that the physical and infrastructural endowments of the division are more favorable to cocoa production than those of the other two sites.

Commercialization of non-cocoa products

Market participation for non-cocoa products from these systems varied across sites. In the intensified CAFs of the Lékié where market institutions are better developed, all of the producers indicated sales of non-cocoa products during the 12 months prior to the interviews while in the Mefou and Mvila sites, 23 and 47% of producers did not market any products other than cocoa from their agroforests. For most non-cocoa commodities, the wife of the producer was most frequently involved in their sale, with the exceptions of palm products and timber (Table 4). The dominant role of women in selling fruit from the cocoa system translates into a controlling role in managing the finances generated by those sales. Fifty-seven percent of the producers interviewed indicated their wives controlled these revenues, while 18% indicated that they were solely in control and 22% indicated that these finances were managed jointly. Where men were either exclusively or jointly in control of financial resources from non-cocoa sales, the mean revenue was about 20% higher than when only women controlled revenues although the difference was not statistically significant.

Avocado was the most widely commercialized commodity (Table 4) but was only 3rd in terms of total revenues (Figure 3). Household gross sales

TABLE 4 Frequency of Households' Selling, Mean Sales, and Household Status of Seller by Commodity in all Sites

Commodity	No. of house-holds report-ing sales	Mean sales[a] (000 fCFA ha^{-1})	Household status of seller		
			Husband	Wife	Children
P. americana (avocado)	51	16 ± 24	20%	76%	4%
M. indica (mango)	35	21 ± 39	26%	69%	6%
D. edulis (African plum)	33	31 ± 46	27%	67%	6%
Citrus sinensis (orange)	33	12 ± 13	12%	85%	3%
Musa spp. (dessert banana)	25	29 ± 40	8%	88%	4%
Citrus reticulata (mandarine)	21	29 ± 42	19%	81%	0%
E. guineensis (palm wine & oil)	17	76 ± 185	41%	47%	12%
Irvingia gabonensis (bush mango)	15	11 ± 20	40%	60%	0%
Musa spp. (plantain)	12	24 ± 23	17%	83%	0%
Cola acuminata (red cola)	11	4.3 ± 3.7	45%	55%	0%
Standing timber	10	9.1 ± 7.0	100%	0%	0%
Citrus grandis (grapefruit)	7	4.2 ± 4.4	29%	71%	0%
Spondias cytherea Sonn. (casse mangue)	6	5.5 ± 3.0	0%	100%	0%
Dacryodes macrophylla (tom)	5	13 ± 12	20%	80%	0%
Sawn planks	6	140 ± 140	100%	0%	0%
Citrus limon (lemon)	4	1.9 ± 1.1	25%	75%	0%
Ricinodendron heudelotii (ezezang)	4	17 ± 10	0%	100%	0%
Garcinia kola (bitter cola)	4	9.2 ± 12	25%	75%	0%
All sales	298	25 ± 66	26%	70%	4%

Note. [a]2004 exchange rate: US$1 = 528 fCFA.

of oil palm products (wine and oil) and African plum were the largest of the more than 20 products for which sales were reported. Both generated slightly more than 4 million fCFA (franc *Coopération Financière en Afrique centrale*, US$1 = 528 fCFA) in sales which was approximately double the sales values of avocados, dessert bananas, and timber.

CAF gross revenues

Table 5 presents the gross revenues generated from cocoa production systems across the Mvila-Mefou-Lékié intensification gradient. The difference in cocoa revenues per ha between the Lékié and the other sites is accentuated by the higher cocoa prices received by farmers in the Lékié which is attributable to better road and communications infrastructure and a higher

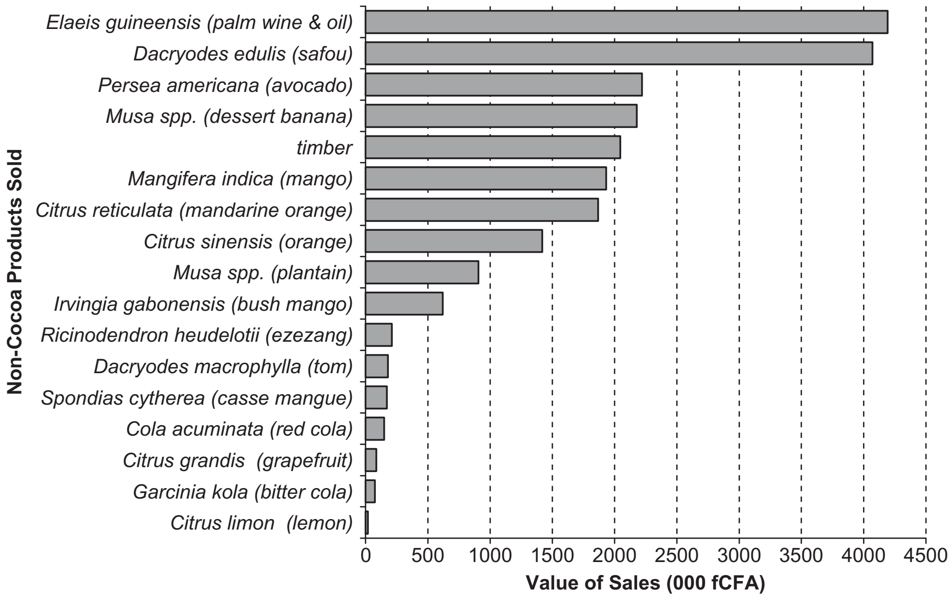

FIGURE 3 Value of total sales (US$1 = 528 fCFA) of non-cocoa products from CAFs ($n = 90$) in 2003–2004.

TABLE 5 Estimated Annual Gross Revenues From Cocoa and Non-Cocoa Products in 2003–2004 Season Across Intensification and Market Access Gradients in Southern Cameroon

	US$				
	Lékié	Mefou	Mvila	All sites	*P*
Cocoa gross revenues per ha	741	425	397	521	.000
Cocoa gross revenues per household	2,036	1,053	1,012	1,367	.004
Non-cocoa revenues per ha	201	217	51	156	.024
Non-cocoa revenues per household	610	643	153	469	.074
Total cocoa system revenues	2,646	1,696	1,165	1,836	.013
Per capita cocoa system revenues	506	294	241	347	.000

Source: 2004 IITA survey of cocoa and non-cocoa products in southern Cameroon.

frequency of collective sales (Wilcox, 2006). The higher land productivity of cocoa systems in the Lékié combined with slightly larger farm sizes translates into mean cocoa revenue that is double that of the less intensified sites. There was no statistical difference in the mean level of non-cocoa revenue between the Lékié and Mefou sites which are both equally endowed in terms of market access, while the mean level of non-cocoa gross revenues was substantially lower for the Mvila sites. Overall, non-cocoa CAF revenues accounted for 26% of total system revenues but were only 13% of Mvila CAF revenues. The combined mean level of cocoa and non-cocoa revenues increased along Mvila-Mefou-Lékié intensification gradient.

Revenue distributions across the intensification gradient

The mean per capita income from the CAF was greatest in the Lékié and exceeded the US$1 a day poverty line whereas the means for the other two sites fell short of this threshold. It should be noted that almost all households produce a diversity of crops for both consumption and sale and that cocoa generates only a portion of household cash income which was estimated at 53%, 45%, and 47% by farmers in the Lékié, Mefou, and Mvila sites, respectively. Dividing CAF revenues by number of household members, we find that the average per capita CAF revenue was less than US$1 per day for 71% of individuals living on farms with CAFs. By site, per capita CAF revenues were in excess of the poverty line for 46%, 25%, and 15% of individuals living on cocoa farms in the Lékié, Mefou, and Mvila sites, respectively (Figure 4). The distribution is positively skewed with the highest quintile of the per capita revenue distribution accounting for 70% of total income

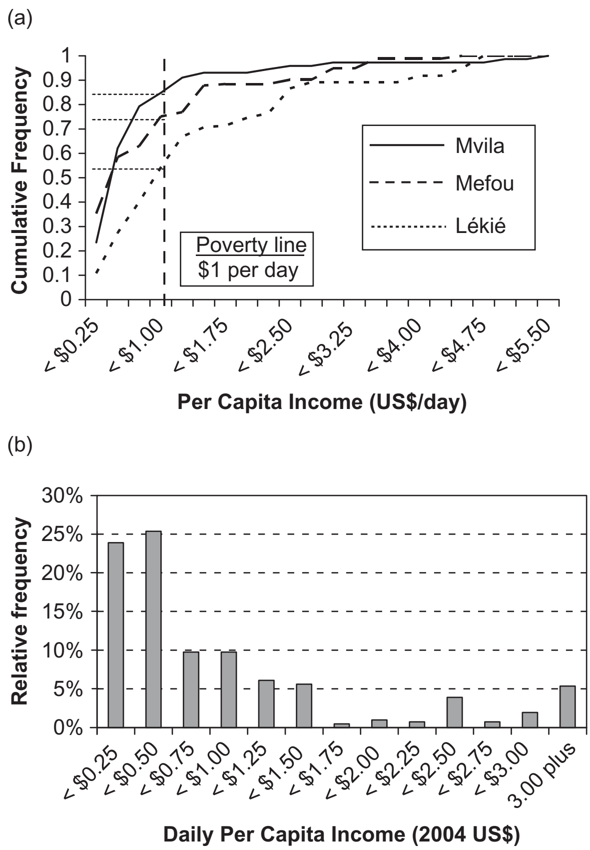

FIGURE 4 Distribution of 2003–2004 income from cocoa production systems in southern Cameroon.

TABLE 6 Differences in Selected Parameters Between Cocoa Producing Households Constituting the Lower and Upper Quintiles of Per Capita Income Distribution

	Households		
	Lower 20%	Upper 20%	$p(T \leq t)$ 2-tail
Cocoa yield (kg/ha)	254	688	.000
Fungicide (sachets/ha)	23	42	.096
Non-cocoa revenues (US$/ha)	53	266	.011
Size of cocoa farm (ha)	1.63	3.95	.001
Mean no. of non-cocoa products sold	2	4	.019
Travel time to farms (min)	29	17	.131
Non-cultivated area in forest (ha)	28	18	.152
Fallow period	8	6	.263
Family size	8	4	.000
Dependency ratio	2.2	1.3	.026
Proportion in class from Lékié	14%	48%	χ^2 test of
Proportion in class from Mefou	57%	28%	independence
Proportion in class from Mvila	29%	24%	.086

(versus 2.3% for the lowest quintile). Overall, CAF revenues increased and poverty decreased as agricultural intensification and market access increased along the Mvila-Mefou-Lékié gradient.

A means comparison of production and demographic parameters for the households comprising the lower and upper quintiles of the per capita gross revenue distribution reveals several significant differences (Table 6). Not unexpectedly, high-income producers had significantly larger yields and tended to use more fungicides indicating an intensification of the cocoa cropping component of the system. High-income producers also participated more in the markets for non-cocoa commodities. Somewhat surprisingly, the low-income producers tended to have more land in forest and maintained longer fallow periods than the high-income producers although the difference was not statistically significant. It would appear that the availability of suitable land for creating new tree stock assets is not a constraint for low-income producers. High-income producers had significantly smaller families and fewer dependents. Nearly half of the high-income households are found in the Lékié site whereas nearly 60% of low-income households are found in the Mefou.

Consumption Values

Nutritional values to the household

The fruits, medicinal plants, and timber from CAFs also contribute to household consumption. As noted above, 23% of the cocoa producers interviewed were not selling any non-cocoa products. Only a small portion of the fruit actually produced is marketed—21% of estimated mango production, 16% of

African plum production, 17% of avocado production, and 26% of citrus production, respectively. The remaining proportions were either not harvested or were consumed by the household.

Pharmacopoeia

Medicinal plants are another aspect of these production systems. Overall, 57% of the producers interviewed had utilized a medicinal plant from their cocoa agroforest within the last 12 months. The proportion by site was highest in the Mefou at 70% and lowest in the Lékié at 47%. Malaria accounted for almost two thirds of the reported illnesses treated with plants from the cocoa farm. Ten medicinal plants from CAFs were used to treat malaria, with *Alstonia boonei* De Wild. and *Rauvolfia vomitoria* Afzel. the most common (used in 38% and 34% of the cases treated). The value of this consumptive use may be imputed from the average treatment cost of US$27 per bout of malaria cited by producers using pharmaceutically produced medicines and clinic visits.

Construction

Finally, timber (Appendix C) from CAFs had been felled for the purposes of home construction by over 1 in 5 cocoa farmers. When asked to give a free listing of the reasons why trees were associated with cocoa, 63% of the producers in the Lékié site included construction needs on their list versus only 30% in the Mefou and 27% in the Mvila sites (χ^2_5, $p = .005$).

DISCUSSION

Production Cycle

The typical CAF was established in the mid-1960s, has been in continuous production for nearly 40 yr, and is the most ubiquitous land-use system in southern Cameroon (Gockowski et al., 2005). Similar systems have been observed in southwest Nigeria. In the aggregate, CAFs account for a significant portion of existing secondary forest in this region. Millington, Critchley, Douglas, and Ryan (1994)—using satellite imagery—estimated that about 43,000 km^2 of wet forests in Cameroon had been converted to a “cultivation-forest mosaic” by the end of the 1980s. Included in this mosaic are approximately 3,750 km^2 of cocoa production systems (Food and Agriculture Organization of the United Nations [FAO], 2005). At the landscape level, the extent of shaded cocoa exceeds 40% of total land cover in some localities of the Lékié (Santoir, 1995). The permanent nature of this land-use system is in contrast to the slash-and-burn annual crop-fallow rotation systems which are the other mainstay of smallholder agriculture along the forest margins of southern Cameroon. This permanency provides the farmer a refuge from fire for maintaining stocks of fruit, medicinal, and timber species in addition to its function as a cocoa cropping system.

Shade, Pest, Disease, and Market Failures

Shade levels in CAFs affect the two most serious biotic constraints of cocoa production (capsid insects and blackpod disease) with opposite effects. The more humid conditions of shaded systems are favorable to the development of cocoa blackpod disease, which is caused by *Phytophthora megakarya*. Shaded cocoa production systems in southern Cameroon would not exist were fungicides not effective. If left untreated, losses from *P. megakarya* can range from 50 to 100% (Flood et al., 2004; Norgrove, 2005). From the Cobb-Douglas production function results, the value generated by the use of an additional unit of fungicide is equal to US$3 while the cost of an additional unit of fungicide was only US$1. This suggests that farmers are constrained in their use of fungicides. This is most likely due to market failure in rural credit and, to a lesser extent, input supply markets.

Improving farmer access to fungicides and the efficiency with which they are applied through rational pesticide application regimes would considerably increase their earnings and help to ensure the continued viability of shaded systems. Formal lending institutions have almost no involvement with the smallholder sector and the input supply markets have yet to develop in the less accessible regions following market liberalization in 1994. When the free distribution of government fungicides ended, farmers were left to their own devices. Private sector involvement in the input markets has been mixed. Although upward of two dozen retail suppliers operate in Yaoundé, only the Lékié has seen the development of local agrochemical supply stores in response to its booming intensified horticultural industry (Gockowski & Ndoumbé, 1999). In part, the lower use of fungicides in the other two sites relates to accessibility. Another factor explaining the underallocation of fungicides relative to the profit maximizing level of use is credit constraints.

Credit institutions both formal and informal in the three sites are very underdeveloped and the possibility that credit constraints are contributing to an underutilization of agrochemicals requires further investigation. In Southwest Cameroon and in Nigeria, interlinked credit institutions between cocoa buyers and farmers have evolved since liberalization and are now providing loans to a majority of cocoa producers in these regions (Gockowski, Mva, Oduwole, & Nyemeck, 2008). Efforts to develop similar credit institutions in the Center and South Provinces may be warranted. Some cultural control of the disease incidence can be achieved by regular farm sanitation practices and the reduction of shade.

However, reducing shade levels may considerably increase the instability of these production systems. Cocoa grown in full sun or limited shade is more subject to attack by capsid bugs than shaded cocoa (Padi & Owusu, 1998; PAN, 2001). Extensive feeding by capsids on fan branches results in the degradation of the cocoa canopy and can destroy or at least seriously reduce the future productivity of the tree if left untreated (Padi & Owusu). Another market failure explaining the prevalence of shaded systems in Cameroon is the absence of upper Amazonian hybrids which have been widely adopted by Ivorian and Ghanaian cocoa farmers and are more suited to full sun production systems.

Shade and Risk

Flexibility in managing price risk is an important facet of CAF systems. With a shaded system, when prices fall or illness strikes, the farmer can reduce labor input and fungicides accordingly without seriously affecting the future productive potential of the tree stock. Producers with full sun systems facing pressure from capsids and mistletoe do not have this option. If they do not spray their tree stock, investment will be lost. In effect, the shade farmer is able to temporarily abandon his cocoa farm. When cocoa farmers in the 1990s were facing historically low cocoa prices, many adopted a "wait and see" attitude while reducing significantly the quantity of labor employed to the point of farm abandonment. The feasibility of rehabilitating shaded cocoa in southern Cameroon was demonstrated by a participatory research trial on an abandoned farm where following proper pruning and application of class III fungicides, yields were restored to 300 kg in the 1st yr and over 500 kg by the 3rd yr (Norgrove, 2005).

The Importance of Local Knowledge

One of the important factors explaining the prevalence of shaded systems in southern Cameroon are the stocks of botanical knowledge possessed by producers that have been used to successfully integrate cocoa production with a wide variety of forest species (Nomo, 2005). In total, 254 plant species in these systems were being utilized by farmers for 392 different purposes. In other cocoa-growing areas of West Africa, such as southwest Cote d'Ivoire, recently arrived migrant farmers from savanna regions lack this botanical knowledge and are less predisposed to maintaining shade in their production systems.

The Consumptive Values of CAFs

The consumption values generated by CAFs included food, medicines, and timber for household construction needs. The food value generated by CAFs—especially the contribution of African plum to the household diet—is particularly notable. Considering that the average fruit yield of an African plum tree is approximately 50 kg $tree^{-1}$ yr^{-1} under farmer conditions (Kengué, 2002), and that for the representative cocoa farm the average density is 15 trees ha^{-1}; the total annual production of fruits per household is estimated at nearly 2 t of which approximately 300 kg is marketed leaving 1,700 kg for household consumption. The caloric value of the African plum produced on the typical cocoa farm exceeded the annual needs of more than two adults. The edible mesocarp of the fruit is a rich source of lipids (49–59%) and protein (26%) including essential amino acids such as leucine, threonine, and lysine (Omoti & Okiy, 1987; Obasi & Okolie, 1993; Mbofung, Silou, & Mouragadja, 2002). During the peak of the harvest from July through October this protein- and oil-rich food becomes a staple in rural diets.

Medicinal plants included in the CAF were also important for a majority of the households, particularly for the treatment of malaria. The mean medical cost of treating malaria with modern medicine was reported at nearly US$30 per episode which is prohibitively costly for most rural households.

The abundance of avocado, African plum, and mango was significantly higher in the sites with market access. However, from the cocoa regression there was a significant negative effect of fruit tree density on output. Assume that we reduce the number of African plum trees by 5 causing a decline in African plum output on an annual basis of 250 kgs. Further let us assume that this household markets 16% of its African plum production and that the producer price for African plum is equal to 200 fCFA kg^{-1} which was the modal price at the time of the survey. Under these assumptions the household would forego African plum revenues of 8,000 fCFA. At the same time cocoa production increases by 12.5 kg which increases cocoa revenues by approximately 8,200 fCFA. At the margin the monetary benefits of associating African plum are in essence equal to the monetary loss of foregone cocoa revenues, but if the consumptive value of these fruits is considered, farmers enjoy net gains in welfare.

Distributional Outcomes

The income distributional outcomes of CAFs were shown to be dependent on both market access and agricultural intensification. In the Lékié, the combination of intensified cocoa and fruit production systems and more developed market institutions resulted in significant poverty reduction. Intra-household distributional outcomes depended on the product; in most cases men controlled cocoa, timber, and palm wine revenues while women exerted control over revenues from fruits. The differential expenditure habits of women versus men—especially regarding children's schooling—make this an important finding.

The comparison of households in the lowest and highest quintiles of the revenue distribution (Table 6) suggests that poverty among cocoa producers in southern Cameroon is associated with the scale of, and intensity of cocoa production, and limited commercialization of non-cocoa products. Land availability was not a constraint, but the overall extent of tree stock assets was significantly lower in the lowest quintile of the revenue distribution.

CONCLUSION

To help households out of chronic poverty at least three issues need to be addressed:

- the intensification of the cocoa component of these systems by increasing farmer exposure to integrated pest management practices and rational fungicide use including consideration of production credit facilities to relieve credit constraints;
- improving the efficiency of non-cocoa commodity marketing. Improving the commercial trade in these products will in turn drive the process of their intensification and household specialization (Ruiz-Pérez, 2004). Innovations should be targeted to the needs of women who are predominantly involved in marketing activities;
- expanding CAF assets among the poor. At least in southern Cameroon suitable land is not a constraint among households in the lower tail of the income distribution. Other constraining factors preventing the growth of tree stock assets among poor households such as labor, input, or credit market failures may need to be addressed as well.

Farmers in the Lékié and Mefou sites were modifying their production systems in response to market opportunities by reducing biodiversity and increasing the densities of African plum, avocado, and mango. On 21 of the 46 farms inventoried, both the African plum and avocado were either the most abundant or second most abundant non-cocoa tree species (Appendix B). In line with this tendency and given their relative economic importance (Figure 3), it is recommended that research should focus on optimizing simplified associations of (a) cocoa and African plum, (b) cocoa and avocado, and (c) cocoa and *T. superba*. Much could likely be achieved by relatively minor system modifications. For instance, Kengué (2002) notes that African plum yields can be doubled by increasing the ratio of female to male trees. Increased productivity needs to be accompanied by improved marketing institutions focused on the mobilization and training of women and farmer organizations.

There has been much debate in recent years about the relationships between technology change, agricultural intensification, and deforestation along the forest margins (Angelsen & Kaimowitz, 2001; Gockowski, Nkamleu, & Wendt, 2001; Vosti et al., 2005; Tomich et al., 2005; Green et al., 2005). The debate hinges upon a host of factors including the nature of the technology employed. In this study, the intensification of shaded cocoa agroforests led to a noticeable decline in plant diversity. At the same time, intensification of both the fruit and cocoa components of these systems appears to have significantly reduced poverty while still retaining most of the biodiversity of the CAFs. Still at issue is the trade-off between biodiversity and income surrounding the most intensified cocoa technology systems which entail monocultures of cocoa hybrids, fertilizers, agrochemicals, and no shade. While Green et al. (2005) find evidence that more biodiversity is conserved in the landscape when higher yielding systems are pursued, the issue can only be resolved by further empirical study of extant no-shade cocoa systems which do not exist in the study site but are widespread in the Bas-Sassassandra and western regions of Côte d'Ivoire and Ghana (Gockowski & Sonwa, 2008).

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APPENDIX A Plant Species Enumerated by Type of Use on Farmer-Guided NTFP Species Inventories

Family	Latin name	Plant use		
		Food	Medicine	Service
Acanthaceae	*Acanthus montanus*		x	x
	Pseuderanthemum macrophylla			
	Pseuderauthum tunicatum		x	
	Thomandersia hensii			
Agavaceae	*Dracaena arborea*			x
Amaranthaceae	*Achyranthes aspira*		x	
	Cepatula prostrata		x	x
Anacardiaceae	*Antrocaryon klaineanum*	x	x	
	Lannea welwitschii	x	x	
	M. indica	x	x	
	Pseudospondias microcarpa	x		
	Spondias cytherea	x		
	Trichoscypha acuminata	x	x	
	Trichoscypha arborea	x		
Annonaceae	*Annona muricata*	x		
	Cleistopholis patens		x	x
	Enantia chlorantha		x	
	Greenwaydendron suaveolens		x	
	Hexalobus crispiflorus	x		
	Monodora myristica	x	x	
	Pachypodanthium staudtii		x	x
	Polyalthia suaveolens			
	Xylopiaauranthiodora	x	x	x
	Xylopia quintasii			x
Apocynaceae	*Alafia multiflora*		x	
	A. boonei		x	x
	F. elastica		x	x
	Hevea brasiliensis			x
	Picralima nitida		x	
	Rauvolfia macrophylla		x	
	Rauvolfia mannii			x
	Rauvolfia vomitoria		x	
	Tabernaemontana crassa		x	
	Tabernanthe iboga			x
	Voacanga africana		x	
Araceae	*Anchomanes difformis*		x	
	Rhektophyllum mirabile			
Araliaceae	*Polyscia fulva*		x	
Arecaceae	*E. guineensis*	x	x	x
Asclepiadaceae	*Cryptolepis sanguinolenta*	x	x	
Aspidiaceae	*Tectaria camerooniana*		x	

(*Continued*)

APPENDIX A (Continued)

Family	Latin name	Plant use: Food	Medicine	Service
Asteraceae	*Ageratum conyzoides*		x	
	Aspilia africana		x	
	Chromolaena odorata		x	
	Crassocephalum biafrae	x	x	
	Elephantopus mollis		x	x
	Emilia coccinea		x	
	Melanthera scandens		x	
	Tithonia diversifolia		x	
	Vernonia amygdalina	x	x	
	Vernonia conferta		x	x
Bignoniaceae	*Kigelia africana*			x
	Markhamia lutea		x	x
	Newbouldia laevis		x	x
	S. campanulata		x	x
Bombacaceae	*Bombax buenopozense*	x	x	x
	Ceiba pentandra		x	
Boraginaceae	*Cordia aurantiaca*			x
	Cordia platythyrsa		x	x
Bromeliaceae	*Ananas comosus*	x		
Burseraceae	*Canarium schweinfurthii*	x	x	x
	D. edulis	x	x	x
	Dacryodes macrophylla	x	x	
	Santiria trimera	x		
Caesalpiniaceae	*Afzelia bipindensis*		x	
	Afzelia pachyloba			x
	Berlinia bracteosa			
	Berlinia confusa			
	Brachystegia mildraedii			
	D. benthamianus		x	x
	Erythrophleum ivorense	x	x	x
	Hylodendron gabunense	x	x	x
	Mildbraediodendron excelsum			
	Pachyelasma tessmannii		x	x
	Strephonema pseudocola			
Capparaceae	*Buchholzia coreacea*	x	x	
Caricaceae	*Carica papaya*	x	x	
Cecropiaceae	*Musanda cecropioides*	x	x	x
	Myrianthus arboreus	x	x	
Clusiaceae	*Allanblackia floribunda*	x	x	
	Garcinia cola	x	x	x
	Garcinia lucida		x	x
	Garcinia ovalifolia	x	x	
	Harungana madagascariensis		x	x
	Mammea africana	x	x	

(*Continued*)

APPENDIX A (Continued)

		Plant use		
Family	Latin name	Food	Medicine	Service
Combretaceae	*Combretum smeathmannii*		x	
	Pteleopsis hylodendron		x	
	T. superba	x	x	
Commelinaceae	*Palisota ambigua*		x	x
	Palisota hirsuta		x	x
Convuvulaceae	*Ipomea batatas*	x	x	
	Ipomea pes-caprae		x	
Coryphyllaceae	*Drymaria cordata*		x	
Cucurbitaceae	*Cognauxia podolaena*		x	x
	Dimorphochlamys mannii		x	
	memordia Cabraei		x	
	Memordica friesorum	x	x	x
Dioscoreaceae	*Dioscorea bulbifera*		x	
Ebenaceae	*Diospyros barteri*	x		x
	Diospyros crassiflora			x
Erythroxylaceae	*Erythroxylum mannii*			x
Euphorbiaceae	*Alchornea cordifolia*		x	x
	Alchornea floribunda			x
	Bridelia micrantha	x	x	x
	Croton aligandrus		x	
	Discoglypremna caloneura	x		
	Elaeophorbia drupifera		x	
	Macaranga hurifolia	x	x	
	Mallotus oppositifolius		x	
	Manihot utilissima		x	x
	Phyllanthus amarus		x	x
	Phyllanthus discoideus			x
	Phyllanthus muellerianus			x
	Ricinodendron heudelotii	x	x	x
	Tetrorchidium didymostemon		x	x
	Tragia benthamii		x	
	Uapaca guineensis	x	x	x
Fabaceae	*Millettia sanagana*		x	x
Flacourtaceae	*Caloncoba gilgiana*			x
	Caloncoba sp.			x
	Dovialis zenkeri			
Gnetaceae	*Gnetum africanum*	x		
Icacinaceae	*Icacina mannii*		x	
Icanaceae	*Desmosatachys tznuifolius*		x	
	Lasianthera africana			x
Irvingiaceae	*Desbordia glaucescens*	x	x	
	Irvingia gabonensis	x	x	
	Klainedoxa gabonensis	x		

(*Continued*)

APPENDIX A (Continued)

Family	Latin name	Plant use		
		Food	Medicine	Service
Lauraceae	*Hypodaphnis zenkeri*	x	x	
	P. americana	x	x	
Lecythidaceae	*P. macrocarpus*	x	x	
Leeaceae	*Leea guineensis*		x	x
Liliaceae	*Asparagus racemosus*		x	
	Gloriosa superba		x	
Loganaceae	*Anthocleista schweinfurthii*		x	
Malvaceae	*Sida acuta*		x	x
	Sida veronicifolia		x	
Maranthaceae	*Haumania danckelmaniana*			x
	Megaphrinium macrostachyum			x
Melastomataceae	*Dinophora splenneroides*	x		
	Dissotis retundifolia		x	
	Tristemma mauritianum	x		
Meliaceae	*Carapa procera*		x	
	Entandrophragma angolensis		x	x
	Entandrophragma candolei			x
	Entandrophragma cylindricum	x	x	x
	L trichilioides		x	x
Mimosaceae	*Acacia pennata*		x	x
	Albizia adianthifolia		x	x
	Albizia ferruginea		x	x
	Albizia zygia		x	x
	Calpocalyx dinklagei			
	Cylicodiscus gabunensis		x	
	Inga edulis	x		
	Pentaclethra macrophylla	x	x	x
	Piptadeniastrum africanum		x	
	Tetrapleura tetraptera	x	x	x
Moraceae	*Antiaris africana*		x	x
	Antiaris welwitschii			x
	Artocarpus altilis	x	x	
	Bosqueia angolensis		x	x
	Ficus conraui		x	x
	Ficus exasperata	x	x	x
	Ficus mucuso	x	x	
	Ficus sur			x
	M. excelsa		x	x
	Morus mesozygia		x	
	Treculia africana		x	
Myristicaceae	*Coelocaryon preussii*		x	x
	P. angolensis	x	x	
	Staudtia kamerunensis		x	x
Myrtaceae	*Eugenia jambos*	x		

(*Continued*)

APPENDIX A (Continued)

Family	Latin name	Plant use		
		Food	Medicine	Service
	Psydium guajava	x	x	
	Sygygium guineensis		x	
Ochnaceae	*Lophira alata*		x	x
Olacaceae	*Coula edulis*	x	x	x
	Olax latifolia			x
	Ongokea gore			x
	Schrebera arborea			
Oxalidaceae	*Oxalis barrelieri*		x	
Palmae	*Raphia monbuttorum*	x		
Pandaceae	*Microdesmis puberula*			x
Papilionaceae	*Amphimas ferrugineus*	x	x	
	Desmodium adscendens		x	
	L. sericeus		x	x
	P. soyauxii		x	x
Passifloraceae	*Adenia gracilis*		x	
	Adenia lobata		x	
Periplocaceae	*Mondia whitee*	x	x	
Phytolaccaceae	*Hilleria latifolia*	x	x	
Piperaceae	*Piper guineense*	x	x	
	Piper umbellatum	x	x	
Poaceae	*Olyra latifolia*		x	
	Setaria barbata		x	
	Setaria megaphylla		x	x
Polygalaceae	*Carpolobia alba*	x	x	x
Pteridophytae	*Alsophyla camerunensis*	x		
Rhamnaceae	*Maesopsis eminii*		x	x
Rhizophoraceae	*Poga oleosa*	x		
Rubiaceae	*Borreria intricans*		x	
	Canthium arnoldianum		x	
	Geophila lancistipella	x	x	
	Hellea stipulosa			
	Massularia acuminata			x
	Mitragyna stipulosa			
	Morinda lucida		x	
	Nauclea diderrichii	x	x	
	Pausinystalia johimbe		x	
	Schumanniophyton magnificum		x	
Rutaceae	*Citropsis articulata*			x
	Citrus grandis	x	x	
	C. reticulata	x	x	
	Citrus sinensis	x	x	

(*Continued*)

APPENDIX A (Continued)

Family	Latin name	Plant use		
		Food	Medicine	Service
	Zanthoxylum heitzii		x	x
	Zanthoxylum gilletii		x	x
Sapindaceae	*Eriocoelum macrocarpum*		x	x
	Paulinia pinnata	x	x	x
Sapotaceae	*Baillonella toxisperma*	x	x	
	Gambeya lacourtiana	x	x	
	Omphalocarpum lecomteanum			
	T. africana		x	
Simaroubaceae	*Hannoa klaineana*			x
Solanaceae	*Solanum torvum*		x	
Sterculiaceae	*Cola acuminata*	x	x	
	Cola ballayi		x	
	Cola ficifolia	x		
	Cola lateritia	x	x	
	Cola lepidota	x		
	Cola nitida	x	x	
	Cola pachycarpa	x		
	Eribroma oblonga		x	x
	Mansonia altissima		x	x
	Sterculia rhinopetala			x
	Theobroma cacao	x	x	
	T. scleroxylon	x	x	
Tiliaceae	*Duboscia macrocarpa*	x		x
	Glyphea brevis		x	x
	Triumfetta cordifolia			x
Ulmaceae	*Celtis tessmannii*	x	x	
	Holoptelea grandis		x	
	Trema orientalis	x		
Urticaceae	*Fleurya ovalifolia*		x	
	Laportea ovalifolia		x	
	Pouzolzia denutata		x	
Verbenaceae	*Clerodendron buchholzianum*		x	
	Clerodendron splendens		x	
	Vitex grandifolia	x	x	
Vitaceae	*Cayratia cf debilis*	x		x
	Cissus barbeyana		x	
Zingiberaceae	*Aframomum citratum*	x	x	
	Aframomum melegueta	x	x	
	Costus afer	x	x	x

APPENDIX B Tree Associations and Dominance Index of the FIVE MOST ABUNDANT SPECIES BY SITE

Site	Five most abundant species by sample sites					Five species index
	1st	2nd	3rd	4th	5th	
Lékié	*P. americana*	*M. indica*	*D. edulis*	*T. superba*	*L. trichilioides*	52
	M. indica	*D. edulis*	*P. americana*	*C. reticulata*	*L trichilioides*	70
	P. americana	*D. edulis*	*M. indica*	*C. reticulata*	*T. africana*	47
	E. guineensis	*T. scleroxylon*	*T. superba*	*P. americana*	*M. excelsa*	45
	M. indica	*D. edulis*	*P. americana*	*E. guineensis*	*T. africana*	56
	P. americana	*E. guineensis*	*D. edulis*	*M. indica*	*M. excelsa*	67
	P. americana	*D. edulis*	*M. indica*	*E. guineensis*	*C. reticulata*	52
	M. indica	*D. edulis*	*P. americana*	*F. exasperata*	*M. excelsa*	61
	M. indica	*E. guineensis*	*P. americana*	*D. edulis*	*Phyllanthus discoideus*	54
	P. americana	*M. indica*	*D. edulis*	*M. mesozygia*	*P. angolensis*	62
	M. excelsa	*P. americana*	*M. indica*	*D. edulis*	*E. mannii*	50
	T. superba	*M. indica*	*D. edulis*	*P. americana*	*F. exasperata*	45
	D. edulis	*M. indica*	*Mansonia altissima*	*Ficus mucuso*	*A. boonei*	42
	P. americana	*M. indica*	*D. edulis*	*C. reticulata*	*F. exasperata*	63
	D. edulis	*P. americana*	*F. exasperata*	*M. indica*	*M. excelsa*	48
	D. edulis	*Albizia adianthifolia*	*M. indica*	*P. americana*	*F. exasperata*	57
Mefou	*P. americana*	*A. adianthifolia*	*D. edulis*	*Ficus mucuso*	*M. indica*	40
	P. americana	*D. edulis*	*F. elastica*	*M. lutea*	*P. discoideus*	43
	D. edulis	*A. adianthifolia*	*M. excelsa*	*Albizia zygia*	*Ficus mucuso*	31
	D. edulis	*M. indica*	*P. americana*	*F. elastica*	*T. superba*	50
	P. americana	*C. sinensis*	*F. elastica*	*T. superba*	*M. mesozygia*	37
	D. edulis	*P. americana*	*Discoglypremna caloneura*	*Albizia zygia*	*E. guineensis*	48
	P. americana	*D. edulis*	*Albizia zygia*	*C. sinensis*	*M. indica*	62
	Bridelia micrantha	*D. edulis*	*Ficus mucuso*	*A. adianthifolia*	*Albizia zygia*	42
	D. edulis	*M. indica*	*P. americana*	*A. adianthifolia*	*P. discoideus*	35
	Rauvolfia vomitoria	*Xylopia aurantiodora*	*Discoglypremna caloneura*	*F. exasperata*	*M. excelsa*	31
	D. edulis	*M. indica*	*E. guineensis*	*Rauvolfia vomitoria*	*Markhamia lutea*	47

	D. edulis	*M. indica*	*P. americana*	*A. adianthifolia*	*C. sinensis*	56
	P. americana	*D. edulis*	*P. soyauxii*	*Coelocaryon preussii*	*A. adianthifolia*	26
	Rauvolfia vomitoria	*D. edulis*	*M. indica*	*Markhamia lutea*	*P. angolensis*	42
	D. edulis	*M. indica*	*A. adianthifolia*	*Rauvolfia vomitoria*	*D. benthamianus*	45
Mvila	*D. edulis*	*F. elastica*	*A. vogelii*	*M. indica*	*Albizia zygia*	28
	A. vogelii	*P. americana*	*F. elastica*	*M. cecropioides*	*P. macrocarpus*	29
	P. americana	*E. guineensis*	*F. elastica*	*P. angolensis*	*A. adianthifolia*	31
	E. guineensis	*M. indica*	*P. americana*	*A. adianthifolia*	*Bridelia micrantha*	52
	A. boonei	*D. benthamianus*	*E. guineensis*	*S. campanulata*	*P. angolensis*	28
	E. guineensis	*P. macrocarpus*	*Markhamia lutea*	*Eribroma oblonga*	*T. superba*	36
	E. guineensis	*P. americana*	*D. edulis*	*A. vogelii*	*Cola acuminata*	53
	P. americana	*E. guineensis*	*D. edulis*	*A. adianthifolia*	*M. indica*	42
	A. vogelii	*P. americana*	*F. elastica*	*H. zenkeri*	*P. angolensis*	38
	F. elastica	*T. superba*	*P. discoideus*	*A. adianthifolia*	*Albizia glaberrima*	26
	P. americana	*T. superba*	*P. discoideus*	*P. macrocarpus*	*P. soyauxii*	30
	A. vogelii	*L. sericeus*	*P. discoideus*	*X. quintasii*	*E. guineensis*	44
	E. guineensis	*A. vogelii*	*Bosqueia sp.*	*F. exasperata*	*L. sericeus*	41
	P. americana	*P. angolensis*	*T. superba*	*F. elastica*	*D. edulis*	41
	P. americana	*M. indica*	*M. hurifolia*	*N. laevis*	*F. elastica*	46

APPENDIX C Coefficients for Allometric Estimation of Timber Volumes

Trade name	Species name	Min. exploit. dia. (cm)	Eq. no.	Coeff. A	Coeff. B	Coeff. C
Ayous	*T. scleroxylon*	80	2	−1.44681	0.023058	0.000991
Azobé	*Lophira alata*	60	1	−0.22233	0.000863	
Bété	*Mansonia altissima*	60	3	0.000531	2.105197	
Dibétou	*Lovea trichilioides*	80	2	−1.8992	0.050237	0.000668
Fraké	*T. superba*	60	1	−0.00676	0.000858	
Red doussié	*Afzelia bipindensis*	80	1	−0.94247	0.00108	
Ebène	*Diospyros crassiflora*	60	3	0.00135	1.831998	
Iroko	*M. excelsa*	100	1	−0.32917	0.000979	
Kossipo	*Entandrophragma candollei*	80	1	0.282233	0.000926	
Makoré	*T. africana*	60	2	−0.36943	0.008671	0.000736
Moabi	*Baillonnella toxisperma*	100	2	−0.88878	0.014004	0.000922
Sapelli	*Entandrophragma cylindricum*	100	2	−0.97627	0.028795	0.000831
Tiama	*Entandrophragma angolense*	80	3	0.000168	2.346741	
Bongo	*Zanthoxylum gilletii*	60	3	0.001051	1.967873	
Eyong	*Eribroma oblonga*	50	3	0.001461	1.926072	
Lotofa	*Sterculia rhinopetala*	50	3	0.000302	2.272659	
Movingui	*D. benthamianus*	60	3	0.001772	1.856575	
Other species		60	1	−0.00676	0.000858	