NORWEGIAN UNIVERSITY OF LIFE SCIENCES

DEPARTMENT OF PLANT AND ENVIRONMENTAL SCIENCES

CONTRIBUTION OF CACAO (*Theobroma cacao* L.) AGROFORESTRY SYSTEMS TO THE HOUSEHOLD ECONOMY OF SMALL-SCALE PRODUCERS IN THE CENTRAL AMERICAN ISTHMUS: THE CASE OF BOCAS DEL TORO, PANAMA

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Para Mamama,
hecho en su tierra natal

FOREWORD

Agroforestry has been defined as *"a holistic approach to land use, based on the combination of trees and shrubs with crops, pasture or animals on the same land unit, whether simultaneously or in sequence"*[1]. Agroforestry systems worldwide are reknowned for their multiple productive capacities. They embrace traditional knowledge as the social and ecological components coevolve and produce "*a variety of foods and fibers within locally available means*"[2]. And they "*can contribute substantially to advancing a sustainable agriculture through their influence on ecological and social processes"*[3]
These complex systems promote soil and water conservation, retain soil organic matter, nutrients and productivity over time and help maintain higher biodiversity than any other monocrop system in the tropics. They are a primordial source of food and cash crops for the households that manage them. But just how diverse and productive are these agroforestry systems and what is the economic value derived? What is the contribution of these different products to the smallholder's economy? What are the social and economic constraints and opportunities for these smallholders?
I wanted to explore in depth the economic performance of such systems in a one-year period, taking in consideration not only the classic cash income perspective, but also its importance as a family subsistence enterprise. I tried to integrate the biophysical, social and economic elements to formulate a research strategy that would lead to improved understanding of these particular systems. This required a complete and thorough inventory of each cacao agroforest, and consultation with people in each household about the productive capacity of all tree, fruit and tuber species present in their cacao plots. It was a complex topic, and would need an interdisciplinary approach with participatory research methods. I tried to work under four basic premises:

1. "*We should always remember that people are the key elements in agroforestry*" [4]
2. "*Tropical farmlands can be confusing places to study*"[5]
3. "*Interchange of information and ideas between all the groups involved (including the farmers) is essential*"[6]
4. "*Diverse and complex social and ecological systems demand more robust and flexible agroforestry sciences*"[7]

The study took place in seven indigenous communities in the province of Bocas del Toro, in Panama. Data were collected during a six month period between September, 2010 and March, 2011. A total of thirty-nine agroforestry systems were involved in the study. All household heads took an active part in the research process, and many family members

[1] Lundgren, 1987
[2] Buck et al. 1998. p. viii
[3] Buck et al. 1998. p. viii
[4] Huxley, 1999. p. ix
[5] Huxley, 1999. p. x
[6] Huxley, 1999. p. 7
[7] Buck et al. 1998. p. 193

provided their input and views to compile important information during surveys and crosschecking meetings. Preliminary and final results were handed back and discussed with each family to ensure a more equitable distribution of knowledge.

The study would not have been possible without the generous support of the *Central American Cocoa Project: competitiveness, environment and culture* (PCC). Part of CATIE´s Mesoamerican Agroenvironmental Program, this Project has been active since 2008 in six different countries throughout Central America. The PCC provided funding and materials for all field activities and its research team provided continuous guidance throughout the data compilation and analysis processes.

The present study constitutes an attempt to integrate social, economic and ecological sciences in the pursuit of an improved, interdisciplinary "hybrid agroforestry science" (Rocheleau in Buck et al. 1999). This study was designed as a template to be utilized in follow-up reseach projects in five other countries after Panama, so information can be compiled in a common database for the PCC. This would enhance the current database available for the Central American Isthmus and make comparisons between countries easier.

I would like to thank my supervisors: MSc. Rolando Cerda (CATIE): thank you for your attention to detail, valuable discussion points, your immense patience and all your help. MSc. Justine Kent (CATIE): thank you for unravelling the magic of subsistence economics for the non-economist -your advice made my project worthwhile!- thanks for your support through those hard times. PhD. Geir Lieblein (UMB): thank you for believing in me and giving me the strength to jump over all obstacles -including numerous country borders. And PhD. Charles Francis (UMB/UNL): thank you for inspiring my mind and spirit. supporting me through many conceptual and institutional challenges, and making me hang in there till the end. You make us see the utter need for an alternative research paradigm! Also, a special thanks to Sergio Vilchez and Eduardo Corrales, for without them the statistic analyses would just not have been possible.

Last and not least, a great big THANK YOU to the Bocatorean families that let me in to their homes and made me feel like part of the family. And to the community guides: Ventura, Mamerto, Max, Victoriano and Julio, and the dendrologist-multitasker-technician extraordinaire, Juan Abrego, thank you for creating the best working teams and for making the hard strenuous work so enjoyable and rewarding!

ABSTRACT

Cacao (*Theobroma cacao* L.) is the main cash crop of Ngöbe-Buglé indigenous communities in Bocas del Toro, Panama. Their traditional polycultures include many other food crops for family consumption, but there is no actual description of their diversity, productivity or contribution to household economy. This study was designed to determine the value and allocation of multiple products, depict floristic composition of cacao agroforestry systems (AFS), assess socio-economic performance, and propose scenarios for poverty alleviation. Mixed quantitative and qualitative research methods determined productivity of all species in thirty-nine cacao AFS. Annual Net Cash Flow (NCF) and Family Benefit (FB) were calculated. Bocatorean cacao AFS include 139 planted and naturally occuring species, among them considerable volumes of high-value timber. Functional markets for most products are missing. Smallholders generate most income (52%) from external sources. Cacao AFS bring in 19%; other farming activities account for the remaining 29%. Percent annual value from cacao AFS is mostly allocated to family consumption (45%) or to feed farmyard animals (12%); sales account for 43%. The ratio of annual FB/ha to NCF/ha is 3.8, which denotes much greater productivity than measured in conventional financial terms. Returns to labour are $13.6 for FB and $3 for NCF, further demonstrating the importance of cacao AFS for family food security. Alternatives to a one-crop approach are presented as income generation opportunities. Improved communal harvesting and forest management can foster timber and organic produce sales in nearby urban areas. High value fruits and spices can be introduced to diversify agrobiodiversity and markets. Better crop management and grafting of improved genetic material will increase cacao yields. Procuring payments for ecosystem services would benefit landowners. Sparking interest in the younger population would optimize the development of human capital, creativity, entrepreneurism, and trade in a province where lack of job opportunities keeps almost 70% of the population under the poverty line.

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Comentario [GL1]: What is the difference between a R and a potential R?

1. INTRODUCTION

Cacao (*Theobroma cacao* L.) is an economically important crop worldwide; production for 2011 surpassed 4.1 million tons (www.icco.org), reaching a current market value of over $5 billion (www.worldcacaofoundation.org). Small family farms make up the bulk of cacao producers, and approximate 5 to 6 million smallholders are responsible for 85% of the world's production. Up to 50 million people depend on this crop for their livelihoods (www.worldcacaofoundation.org) and most of this production occurs in areas of high biodiversity (Franzen & Borgenhoff, 2007), stretching 20º North and South of the Equator (www.icco.org). Though the market for organic cacao is fairly small (0.5% of total) it is growing at a promising rate, and 18 countries including those in the Central American Isthmus are responsible for the estimated 15,000 tonnes produced worldwide (ICCO, 2006).

Organic, shade-grown cacao has been described as one of the best examples of permanent agriculture that in some ways preserves a forest environment (Ruf and Schroth, 2004), supporting higher levels of biodiversity than most other tropical crops (Rice and Greenberg, 2000). This system has increasingly received attention as a sustainable agricultural land use that meets biological, ecological and economic objectives, as it also provides important crops to improve the livelihoods in local communities (Duguma et al, 2001; Parrish et al. 1998; Rice & Greenberg, 2000; Scroth et al. 2004).

In Central America and the Caribbean, cacao is traditionally grown under a canopy of different timber and fruit bearing trees (Somarriba, 2004), a good example of diversified and productive agroforestry systems (AFS). Canopies maintain agronomic stability by conserving soil moisture, providing high levels of soil organic matter, lessening erosion and maintaining a stratified structure that in turn creates niches to support biologically diverse plant and animal communities (Beer et al. 2003). Located along the Mesoamerican Biological Corridor, among nature reserves, protected forests, wetlands and national parks, the main services these AFS provide are buffering and connectivity, but also carbon sequestration and conservation of biodiversity, which have invaluable positive benefits at a global scale (PCC, 2007).

Cacao AFS around the world represent a continuum between densely treed, multi-strata, botanically complex agroforests to highly intensified, non-shade, commercial monocultures (Asare, 2006). Species richness, tree density and vertical structure of the shade tree component in cacao agroforests vary greatly among countries, among farms in the same agroecological zone (Somarriba et al., 1996), and even among areas within the same agroforest as trees show scattered or patchiness patterns (Somarriba & Beer, 2011). Floristic composition and biophysical make up of cacao AFS affect natural and agronomic diversity and in turn productivity, and careful characterization of these aspects helps enlighten interaction between these components.

Shade trees have environmental, social and economic value, and play an important role in reducing the vulnerability of households to climatic stress, falling prices and food insecurity (Tschartnke et al, 2011). Products obtained from shade trees include firewood, medicine, resins, honey, fibre and construction materials (Somarriba, 2007). Fruit and timber trees serve as an alternative source of income in the short and long term (Corven, 1993), lessening farm income variability throughout the year, and providing resiliency in case cacao prices should fall (Somarriba, 2007).

Though many goods obtained from cacao AFS are mentioned in the literature (Beer et al. 1998; Laird et al. 1996; Laird et al., 2007; Oladokun, 1990; Osei-Bonsu et al. 2002; Ramirez et al., 2001; Rice 2008; Gockowski & Sonwa, 2008; Tscharntke et al. 2011), few studies highlight the contribution these make to household incomes. Studies that focus on economics deal mostly with the main crop, and may not mention the other parts of the economy, so the tangible value of shade trees and other system components is usually left out for simplicity (Obiri et al. 2007), and their contribution towards household economy and wellbeing is unaccounted for, unclear or absent (Rice, 2008). But the net worth of a hectare of cacao AFS must amount to more than the value of cacao beans sold per hectare per year.

In Latin America and the Caribbean, there is a strong link between poverty, hunger and food insecurity (Espindola et al. 2005). Remote areas inhabited by indigenous peoples are the poorest, most sparsely populated, and are reported as the most affected by chronic hunger and acute malnutrition (FAO, 2010). Considering that cacao producers have incomes of under US$ 1.08 a day (PCC, 2007), access to “cost-free” products becomes utterly important; households must manage to produce enough to feed their families, a basic need which could not be afforded otherwise.

The study site was chosen to address a particular group of organic, small-scale producers; over 90% of cacao production in Panama is concentrated in the province of Bocas del Toro, in the hands of Ngöbe-Buglé and Naso-Teribe indigenous people (PCC, 2009). Along with Afro-Caribbean and *campesino* producer families, 1,500 smallholders manage a total of 4,500 ha where they grow organically certified, shade-grown cacao (Pineda, 2007). The importance of maintaining sustainable and productive agricultural systems becomes increasingly important in this particular area, which is endowed with very high biodiversity (WRI, 2006), but is also severely affected by extreme poverty and prevalence of chronic malnutrition in school children (INTA, 2009).

No studies to date describe in detail the financial dynamics of cacao growers of the Central American Isthmus. There is no background information on economic performance of cacao AFS except for dry cacao poundage, and a full assessment of how the diverse timber and fruit products coming from the cacao AFS are utilized has not been done previously. These are recognized as the most ecologically sustainable agricultural systems in the tropics, but how diverse are they? Does floristic complexity affect productivity and income generation? What is their actual output concerning family food security? Aside from the incalculable value of ecosystem services they provide, what would be a hard cash number generated per household or per hectare? What is the overall importance of cacao AFS within the small landholder’s economy? These are all questions that must be answered in order to plan effective hunger and poverty reduction strategies if the Millennium Development Goals are to be met (www.un.org/millenniumgoals).

Without knowing the intricate relationships between managerial, environmental and economic performance of these AFS, it is hard to assess which measures can be taken to improve their performance. It is also difficult to evaluate the effectiveness of any agricultural development project if there is no baseline of their floristic composition, productivity status and economic output from which to plan optimization processes.

A new paradigm for agricultural development research and action, especially necessary for rural small-scale producers must integrate increased productivity and income generation, but also ecosystem restoration, food security and climate regulation objectives encompassing a "win-win-win-win" approach (Scherr et al., 2010).

The present study integrates social, economic and ecological sciences in the pursuit of an improved, interdisciplinary "hybrid agroforestry science" (Rocheleau in Buck et al., 1999). The main objective is to investigate in detail what the products obtained from these cacao AFS are and how they contribute to the well being of grower families, specifically what their share is in terms of household income and other benefits in kind. In order to answer the previous research questions, achieve this main goal and explore the interrelations among components, operational limitations and possible improvements to the systems, four specific objectives were pursued:

1. To depict the floristic composition and the biophysical make up of cacao agroforestry systems
2. To assess the total production of goods from cacao agroforestry systems, their relative importance and their economic contributions to annual household net cash flow and family benefit
3. To examine the links and emergent correlations between biophysical aspects and socio-economic performance of cacao agroforestry systems
4. To envision changes in the management/operational aspect of these agroforestry systems that would improve the economic performance and overall household benefit of smallholders

2. MATERIALS AND METHODS

a. Site description

i. Locality

The study area is located in the province of Bocas del Toro, Panama; situated between 81º, 08' & 82º, 56' west and 08º, 00' & 09º, 37' north; and bounded by the Caribbean Sea to the North, by the provinces of Chiriquí to the South and Veraguas to the East (MIDA, 2009). It is divided into three civil districts: Bocas del Toro, Chiriquí Grande and Changuinola. The study area also included the district of Kankintú, which belongs to the Indigenous Territory of Comarca Ngäbe-Buglé; this is a separate political region, with its own General Congress and auto determination capacity. Formed in 1997 it spans across almost 7000km^2 and covers 8.8% of the country's territory, and is the home of the most numerous indigenous group in Panama (SINAMP, 2007).

The study took place across various communities in the province (Figure 1). To the south, Norteño, Santa Marta and Silico Creek belong to the District of Kankintú, part of the Ngöbe-Buglé Indigenous Comarca. La Gloria and Río Oeste Arriba belong to the District of Changuinola. Quebrada Pluma and Palo Seco belong to the township of Valle Risco, which is part of Palo Seco Protective Forest (BPPS). BPPS is a special buffer zone around the Biosphere Reserve of Parque Internacional La Amistad (between Panama and Costa

Rica), whose main objective is to protect the hydrology, soils and forest resources of the area while allowing for development of its local communities (ANAM-CBMAP, 2006).

Figure 1. Communities that comprise the PCC Network

The population under study was comprised of thirty-nine farms with organic cacao AFS whose owners are presently affiliated to COCABO (the Cacao Cooperative of Multiple Services of Bocas del Toro). These 39 farming systems were chosen because the network of permanent sample plots (PSP) of the Central American Cocoa Project (PCC) is located here. All these were chosen due to the different topographic features they display, and they represent the variability of conditions that can be found in AFS in the area. They are characterized by differences in elevation, slope, flooding patterns, as well as surrounding land use (forest, agricultural fields), and they tend towards either closed or open canopy. For these reasons, they have been used to study the different environmental services the systems provide, like carbon capture, conservation of biodiversity and soil quality (PCC, 2009). The sampling units were of variable size from 0.3 to 10ha, and were located in three main politico-geographic zones: Changuinola District, Palo Seco Protective Forest and Comarca Ngöbe-Buglé (see Annex 1).

ii. Climate, vegetation and soils

The region presents Tropical Wet Climate according to the Köppen classification system (MIDA-ANAM, 2007), where annual precipitation averages hover around 3600 to 3800mm

(DEC, 2001), but can reach up to 5000 mm (MIDA, 2009). There is not a well-defined dry season (MIDA-ANAM, 2007); while most abundant rains result from pressure systems and winds coming from the northern hemisphere between December and February, year-round precipitation is caused by more moderate Caribbean systems (MIDA-ANAM, 2007). Following the Holdridge life zones classification, the area presents three types of forest: Tropical Humid Forest, Pre-montane Wet Forest and Tropical Wet Forest (ANAM, 1999b). These life zones harbour the majority of marketable and potentially marketable timber species in Panama, and some areas maintain their original forest cover still today (FAO, 2003). Instead of swidden agriculture or extensive cattle operations, these areas are well suited for permanent arboreal crops (FAO, 2003), as is the case of cacao.

Soils in the province are classified as Ultisols, typical of warm humid climates (Brady & Weil, 2008). Characterized by mainly acid to very acid conditions, they have low phosphorous content, low organic matter content, and overall low to very low fertility (IDIAP, 2010).

Type I soils are located in the flood plains close to the shore; these are arable but need nutritional management to remain productive (ANAM, 1999a). The hilly and sloped areas where the indigenous communities are located are Types VI and VII, which are non-arable, with severe to very severe limitations for agrological use. If flat or slightly sloped, these show potential as pastures, but in any abrupt terrain, forest or forest reserves should be maintained (ANAM, 1999a).

iii. Socio-economic background

The province of Bocas del Toro is sparsely populated and basic services are scarce and deficient, particularly in rural areas (MIDA-ANAM, 2007). This is the second poorest province in the country with a population of about 90 000, where 63% is indigenous (IDB, 2002). General poverty was estimated at around 68.6% of the total inhabitants, where 37.8% are extremely poor (MEF, 2003). Compared to the rest of the province, the population within the Comarca shows even higher levels of general poverty at 98.4%. The situation is worse because 90% are under the extreme poverty line (MEF, 2006). Living in these geographically isolated areas, the population is excluded from markets and has little or no access to services, particularly health, education and infant nutrition (MEF, 2006).

The economic system within the Comarca Ngöbe-Buglé is limited to three activities: 1) agriculture, most of it for subsistence purposes; 2) handicrafts production, with difficult marketability, and 3) paid work as labourer (GRUDEM, 2010). A very high proportion of households generate no income because about 91% of the actively working population are dedicated to subsistence agriculture and have no actual sales. Those that manage to sell handicrafts make a very low income, calculated as $7.76 per household per year, and when there is a paid labourer in the family, the monthly income for the household is an estimated $247 (GRUDEM, 2010).

iv. Description of households: age groups, education level and access to services at the community level

The members of all 39 households comprised the population under study. The size of families ranged from 4 to 18 family members, with an average of 7 (±3). In each household, an average of 4 family members worked on-farm, and only 0.6 worked off-farm. Most of the population (70%) is under 30 years of age (Figure 2), of these, 37% are younger than 15. This last population subset attends school, and is usually spared from any involvement in farm activities. The average age of the head of the household was 53 years old (±15), and there were only five women as heads (13%), compared to 34 men.

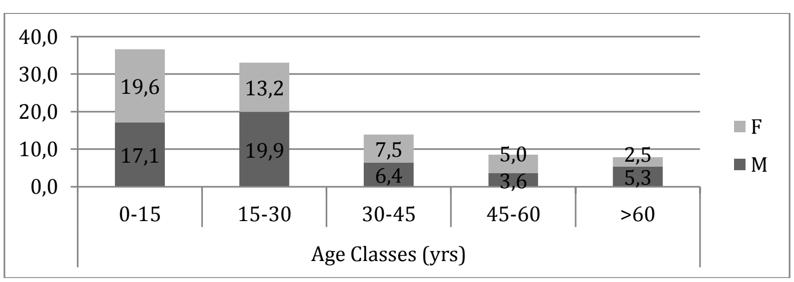


Figure 2. Percentage distribution of individuals by age class and gender in 39 households in Bocas del Toro.

There were differences in education across households, but on average, primary, secondary and superior schools were attended by 35.6%, 33.4% and 2.1% respectively, and only 28.8% had not received any formal education (Figure 3).

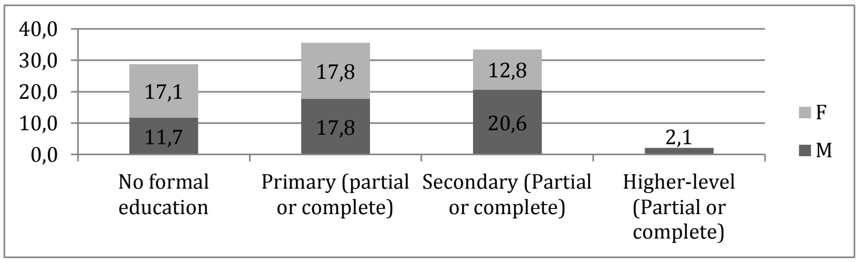


Figure 3. Percentage of educated family members according to gender and school level achieved in 39 households in Bocas del Toro.

In this study, cacao AFS were located in seven different communities. Each displayed distinct socio-economic development, and had different environmental surroundings, varying access to markets and transportation issues; therefore the availability of services was different for each community (Table 1). Four of the seven communities have access to most basic services except electricity, which is not widely available; only one community has had some lines installed. Two communities have no high school or health centre; they are smaller in size and are situated close to other bigger communities that do provide these services. Only one community has no access to any services: Quebrada Pluma. It is located about two hours walk from the nearest town, across two rivers with no bridge; its remoteness and steep terrain make it almost unreachable during the rainy months of the year where the trails become too muddy and the rivers grow.

Table 1. Accessibility to basic services in seven communities in Bocas del Toro.

Community	**Primary school**	**High school**	**Health centre**	**Running water**	**Transport**	**Telephone**	**Electricity**
La Gloria	X	X	X	X	X	X	
Rio Oeste Arriba	X			X	X	X	
Palo Seco	X	X	X	X	X	X	

Quebrada Pluma							
Silico Creek	X	X	X	X	X	X	X
Santa Marta	X			X	X		
El Norteño	X	X	X	X	X	X	

v. Description of markets

Access to market depends on the product and is different in each community. Tubers and all tree fruits, as well as maize and pineapples are sold within the community; animal products like eggs, chicken and pigs are sold fresh since there is no electricity for refrigeration. These goods can be traded with the neighbours for other goods, and all communities display an intricate and efficient but informal local market.

Peach palm is harvested by hand, not by household members, but usually by young tree climbers in each community; they get paid in cash or have the option of taking enough produce to sell it themselves. Peach palm buyers from the city show up every week during the harvest months; they visit every community (except those where there is no road) and buy enough racemes on the spot to fill up a load. Families do not assume the transport costs.

Most bananas are either consumed in the household or sold within the community. However, there is a small market for organic, high quality *Gros Michel* and *Primitivo* bananas through COCABO. Every two weeks, trucks visit La Gloria to pick up produce in boxes, but no other communities benefit from this service.

Cacao is harvested and is fermented in the field, on a hole on the ground covered with banana leaves, in a bag, or more frequently in a wood box, built for that purpose. Sun drying is very common; people use a tarp on the ground or a zinc-roofing sheet, though some have access to drying kilns made with plastic sheets. Cacao is sold in the form of dry beans, and there are three collection sites run by the COCABO Cooperative. One is in Almirante, one in Chiriquí Grande, and one in Valle del Riscó. The cost of a one-way taxi ride for one person with a 100 lbs bag to the town of Almirante from La Gloria and from

Río Oeste is $3 to $5. In the south, the same taxi ride but headed to Chiriquí Grande is about $4 from Silico Creek and Santa Marta, and about $2 from Norteño. Finally, producers that live in Palo Seco can take a taxi with their bags to Valle del Riscó for $0.50; while those living in Quebrada Pluma must carry their load all the way.

Women sell more specialty items like chocolate paste and ground peach palm paste in Changuinola, usually on weekends. A one-way bus ride from Norteño and Silico Creek costs about $4, about $1.50 from Río Oeste and $1.20 from La Gloria.

Handicrafts are sold through women artisan cooperatives; they have collective display of all items throughout the year in two little markets, one in Silico Creek and one in Norteño.

Timber harvest for the purpose of sale is prohibited within the Ngäbe-Buglé Comarca, so Silico Creek, Santa Marta and Norteño cannot have access to such market. Harvest for personal use and church donations is allowed, timber may also be "sold" to a neighbor within the Comarca; but this is often more of a gift, the amount received is nominal, usually under $20 per tree (F. Quiroz, pers.comm[8].).

Within Palo Seco Protective Forest, great efforts have been made to retain forested areas to safeguard the watersheds and protect endangered species. An active agroforestry association (ASAFRI) continues to educate people in the community about the importance of trees for watershed health and environmental quality (Mendez et al. 1999). Asides from this, timber sales are uncommon because finding transport is difficult and expensive, freight by truck for 1000 BDFT goes for an approximate $60 (R. Quintero, pers.comm.[9]). The permits for timber harvest cost around $8, and must be processed in person at the ANAM offices in Changuinola or elsewhere, which represents another transport cost. As by law, 10 seedlings must be bought and replanted for each tree felled, these go for $0.50 to $1.00 depending on the species. An oficial timber transport permit must also be included; they cost $2 but are only good for 72 hours (Gaceta Oficial, 1994 & 1998).

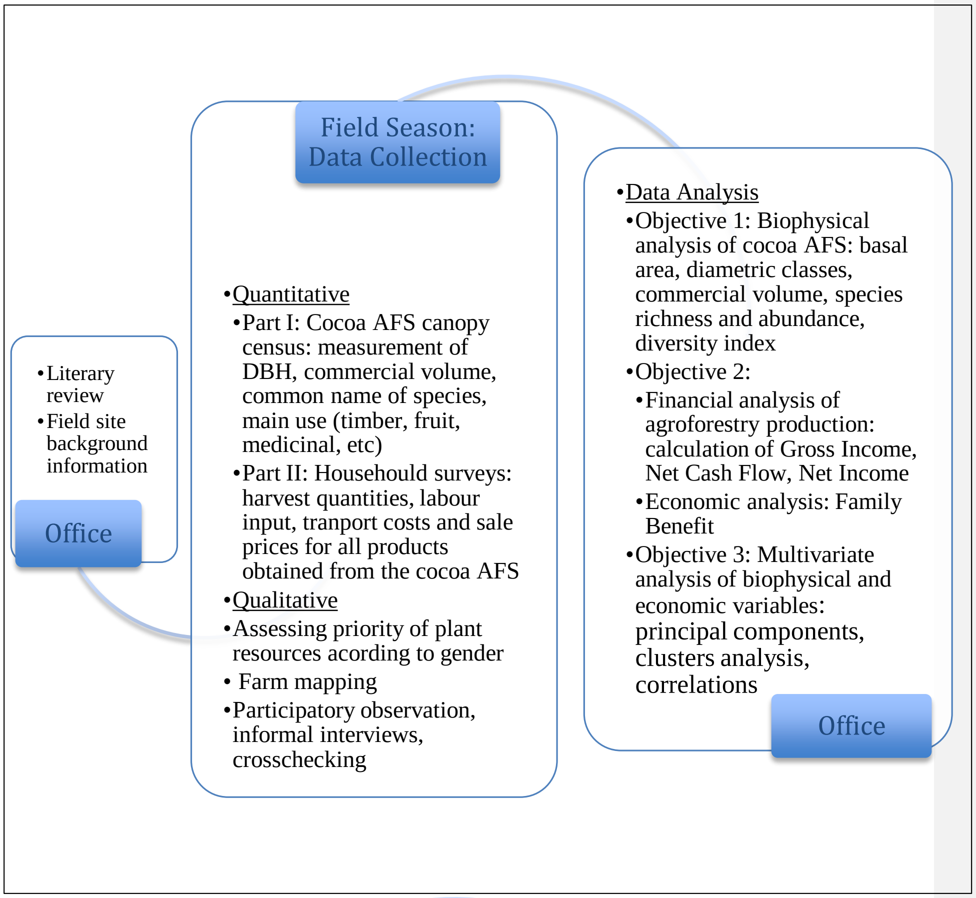
These 39 families represent a sample of 2.6% of the total population (1500) of small-scale, organic cacao growers associated to COCABO. The majority of members live in communities with the same assets and constraints. Some live right on their cacao AFS,

[8] Felipe Quiroz, personal communication, October 3, 2010
[9] Roberto Quintero, personal communication, September 20, 2010

while others have to walk for an hour to get to them. They have tended for these cacao AFS, on average, for 28 years (range 2 to 60 years), and identify themselves with this type of cropping system because of family tradition and other cultural reasons

b. Methodology

In this study, a mixed methods approach was used to address the research objectives more thoroughly. Research took part in two phases, generating qualitative and quantitative data in a sequential manner. Both kinds of data were collected and analysed throughout the study to broaden the understanding and complement the drawing of conclusions (Creswell, 2003). Figure 4 sums up the steps followed for data gathering and analysis and is useful as a guide to the rest of the thesis.


Field Season: Data Collection
•Literary review
•Field site background information
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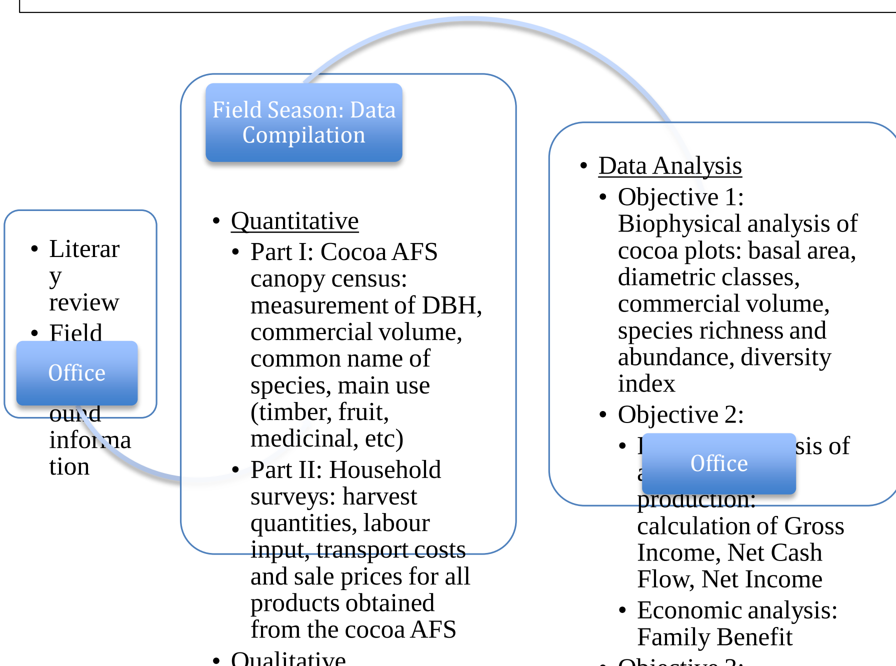
•Quantitative
•Part I: Cocoa AFS canopy census: measurement of DBH, commercial volume, common name of species, main use (timber, fruit, medicinal, etc)
•Part II: Household surveys: harvest quantities, labour input, tranport costs and sale prices for all products obtained from the cocoa AFS
•Qualitative
•Assessing priority of plant resources acording to gender
• Farm mapping
•Participatory observation, informal interviews, crosschecking
•Data Analysis
•Objective 1: Biophysical analysis of cocoa AFS: basal area, diametric classes, commercial volume, species richness and abundance, diversity index
•Objective 2:
•Financial analysis of agroforestry production: calculation of Gross Income, Net Cash Flow, Net Income
•Economic analysis: Family Benefit
•Objective 3: Multivariate analysis of biophysical and economic variables: principal components, clusters analysis, correlations
Office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• Qualitative
• Data Analysis
• Objective 1: Biophysical analysis of cocoa plots: basal area, diametric classes, commercial volume, species richness and abundance, diversity index
• Objective 2:
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production: calculation of Gross Income, Net Cash Flow, Net Income
• Economic analysis: Family Benefit
• Objective 3:

Figure 4. Summarized methodology: Steps for data collection and analysis

i. Data Collection

Part I

Complete Inventory of canopy

According to Kleinn & Morales (2001), shade cacao is an example of a conglomerate of trees outside the forest (TOF), and constitutes a very heterogeneous resource in terms of geometric arrangement and tree density. This makes sampling plots hard to locate to better represent the whole tree component, so plots were not established. The whole cacao AFS was inventoried including all trees on the perimeter (Somarriba et al. 2001).

A full level inventory (100% intensity) was carried out in all 39 AFS from September to November of 2010: all non-cacao trees with diameter at breast height (DBH) ≥10cm were identified by their common name and their diameter recorded. Fruit trees and palms were classified into immature, productive and over mature. *Musa* species were counted and identified by variety. Total standing volume was estimated for all timber species over 30cm DBH. Property owners were urged to participate in the inventory of stumps; where all tree stumps were tallied according to height, diameter, year of harvest, use given to the wood and sale price. (Full protocol in Annex 2, formularies in Annex 3).

Part II

Household Surveys

From mid December 2010 and until February 2011 all families were visited in order to complete the household surveys. A convenient time was decided on by household heads and all family members were invited to partake in the 2hr+ session. To start, results of the inventory were given back in print-form; they were discussed and crosschecked with the household heads and others present.

Following Geilfus (2008) and Orozco & Brúmer (2002), a short site description for each agrarian unit was defined. Family members were encouraged to create a map of their farming system (major crops and production systems); the following aspects were collected during the survey:

- Family description, ages and schooling level achieved, years of ownership
- Total production of fruits and other goods, with quantities consumed, fed to domestic animals or sold
- Variable costs including inputs, labour and transport
- Market prices for all products
- Management activities in each agroforestry system

Information gathered from these surveys was used as the prime data for various financial analyses. (Formularies in Annex 4)

ii. Data Analyses

Biophysical Data Analysis

To describe the canopies of each cacao AFS, parameters calculated included species richness, relative frequency and density per hectare of all individuals (including *Musa* sp.), Shannon´s and Simpson´s diversity indexes (Magurran, 1988). Basal area, diametric classes and commercial volume according to market value were calculated for all timber species (Orozco & Brumér, 2002). This analysis was done between November and December of 2010.

Financial and Economic Analysis

From Ferbuary to May of 2011 all information collected in the surveys was tabulated and analysed accordingly. To determine the importance of the cacao AFS within the household economy, the following indicators were used:

Gross Income per Household Suprasystem = Dollar value of the total amount of products sold in the farm system plus the total amount of remittances, government pensions and salaries obtained (external sources of income).

$$GI\ HS = GI_{sold} + GI_{consumed} + GI_{external}$$

Gross Income per Farming System = Dollar value of the total amount of products sold in the farm system (no external sources).

$$GI\ FS = GI_{sold}+GI_{consumed}$$

Gross Income per Cacao Agroforestry System = Dollar value of the total amount of products sold coming from the cacao AFS only (no other farming system components).

$$GI\ AFS = GI_{sold}+GI_{consumed}$$

Percentages were calculated, and relationships among these three Gross Incomes were analysed to determine the relative importance of the cacao AFS in different economic contexts.

To calculate profitability of each cacao AFS in financial terms, two indicators were used: Net Cash Flow and Net Income. These two indicators are used to define the monetary value that goes into and comes out of cacao AFS. The first measures cash flow, and the second includes fixed as well as variable costs, from the perspective of a business (includes cash and non-cash inputs).

Net Cash Flow = Dollar value of the difference between Gross Income in cash minus Total Costs [fixed and variable] in cash

$$NCF = GI_{cash} - VC_{cash}$$

Net Income = the Dollar value calculated for the Net Cash Flow minus the dollar value of all the family labour invested (VFL= value of family labour)

$$NI = NCF - VFL$$

To calculate profitability of each cacao AFS in terms of competitiveness among subsistence systems, the economic indicator “Family Benefit” was used. The Family Benefit indicator was chosen specifically for its ability to quantify real value of subsistence-based systems, a value that is mostly unnoticed or unaccounted for in typical financial analyses (CATIE, 1987). The indicator sheds light on the importance of the added value of goods and services produced on the farm and consumed by the family.

> Family Benefit = Net Cash Flow plus the Dollar value of all the goods that the family consumes from the cacao AFS. (VFC=value of family consumption)

$$FB = NCF + VFC$$

To be able to compare among all the systems studied, given that they had different areas, and different social conditions in terms of availability of labour, or capacity of investment, all indicators were expressed in a "per farm" and a "per hectare" basis. This indicates how efficient cacao AFS are both per farming system and per unit of area (CATIE, 1987).

Competitiveness was also studied in terms of the return to family labour, dividing the numbers obtained for each indicator by the total days of work that went into the system. This value of return to family labour is more easily compared to the local wages for other kinds of farm work, this helps us understand if it is more profitable to stay in one's farm and work instead of trying to find another work opportunity given the local rates of unemployment.

The analysis followed the methodology proposed by Imbach (CATIE, 1987) but a few changes needed to be made to work with the obtained datasets. The original definitions for each financial and economic indicator are presented along with the amendments that needed to be done in every circumstance in Annex 5.

After the interpretation of results from each of the mentioned indicators, I focused on the actual system of diversified production inside the cacao AFS to see what specific products bring in the most cash or the most Family Benefit. This would determine which are more valuable than others, or why some of these specific combinations of products or product groups (tree fruits, timber, bananas, tubers, cacao) are so valuable for the small-scale grower. The indicators used for this part of the study are Family Benefit and Net Cash Flow; these were calculated separately for each of the products, or product groups in every cacao AFS.

Multivariate analysis

From June to August of 2011, data from previous analyses was compiled and the multivariate analysis was run, which used over 60 biophysical and socioeconomic variables to determine links and correlations, and mark differences between cacao AFS. These included variables such as total basal area and standing volume, number of male and female workers, floristic composition descriptors, labour input, costs and economic remuneration, all calculated for the whole area of the AFS and standardized to values per hectare (Annex 6, Table 1). The statistics programs InfoStat (InfoStat, 2011) and R (R Development Core Team, 2008) were used for different steps as needed.

Two farming systems, number 7 and 37 were kept out of the analysis due to atypical values; this reduced the number of farming households to 37. Following Bidogeza et al. (2007) and Milán et al. (2003) a Principal Components Analysis (PCA) was done first and followed by a Cluster Analysis (CA). The PCA was done using the 60 initial variables and the 37 farming systems. The first 10 components were kept since they explained 80% of variability. Correlations between the 10 components and the original variables were identified using the *envfit* function from the Vegan Package (Oksanen, 2006). The squared correlation coefficient r^2 was used as the goodness-of-fit statistic and significance was tested by 1000 permutations. A set of 38 variables was chosen as the most important in defining the components (See Annex 6, Table 2).

With these 38 variables, a Cluster Analysis was done to typify entities (agroforestry systems and their households) into clusters or groups according to particular attributes or variables (Bidogeza, 2007); using Ward's method and Euclidean distance three groups of cacao farming systems were obtained.

An analysis of principal coordinates was done using the *capscale* function form the Vegan Package (Oksanen, 2006) to validate differences between farming system groups according to their spatial ordination. A hypothesis test confirmed they were significantly different (Annex 6, Figure 1).

To determine which specific variables were significant in differentiating the farming systems into each of the three groups, the dataset was subjected to rank transformation, followed by ANOVA and the LSD Fisher test at 95% confidence. Of the 38 variables, 22 had statistical significance in group differentiation (See Annex 6, Table 3)

4. RESULTS

a. Floristic composition of cacao agroforestry systems

i. Woody perennial component: richness, diversity, abundance and density of species and use groups

A total of 139 species was identified as part of the canopy of cacao AFS, these belong to 46 different families (Annex 7). 131 trees and shrubs, 5 palm species, one bamboo and two bromeliads were found. The richest families were Fabaceae-Papilionidae (12 species), Moraceae (9) and Meliaceae (8).

Species richness in cacao AFS ranged from 12-55 species, and averaged 26 (±9). Diversity indexes were calculated; the mean for the Shannon Index was 1.94 (±0.51, range 0.72-3.05), and for Simpson's Inverse it was 0.70 (±0.15, range 0.26-0.92).

In terms of relative abundance (RA), eighteen species are the most prevalent, with values from 0.52 to 0.01 (Figure 5). The remaining species presented very low RA (less than 0.01 each) but when added altogether, they came up to 0.13.The most abundant overall was laurel (*Cordia alliodora*) at 0.52 RA, followed by peach palm (*Bactris gasipaes*) at 0.13 RA.

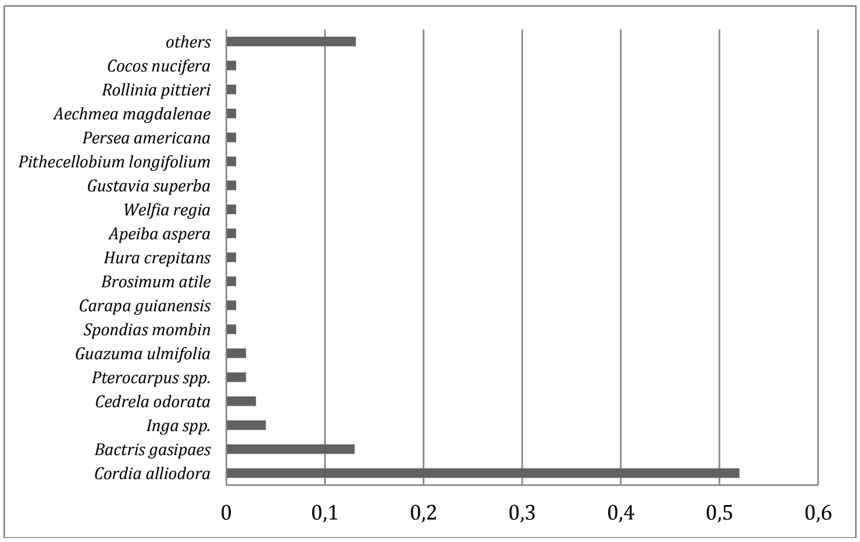


Figure 5. Relative abundance (0-1) of most abundant woody perennials within cacao agroforestry systems in Bocas del Toro

Managers of these cacao AFS maintain a variety of species for different purposes. Species were classified according to the use they have, from which nine groups resulted (Table 2). Most species belong in the timber group, followed by fruit trees and firewood species.

Table 2. Use group, number of species and average density of woody perennials in cacao agroforestry systems in Bocas del Toro

Symbol	Use Group	total # of species	# individuals ha^{-1}
T	Timber	67	118.1

F	Fruit tree	29	34.8
FW	Firewood source	10	11.1
C	Construction materials (non-wood)	4	3.8
H	Handcraft material	8	2.6
LF	Used as live fences	5	1.1
RP	Riparian protection species	1	0.9
M	Medicinal properties	6	0.2
N/A	No use identified	6	0.2
	Total	136 (+3*)	172.8

*Three species (2 ground bromeliads and 1 bamboo) not included because of non-specific density parameter

The most abundant fruit species were jobo (*Spondias mombin*), membrillo (*Gustavia superba*), avocado (*Persea americana*), coconut palm (*Cocos nucifera*), orange (*Citrus sinensis*), biribá (*Rollinia deliciosa*), lemon (*Citrus spp*), manzana de agua (*Syzygium malaccense*) and breadfruit (*Artocarpus altilis*). The juice of *R. deliciosa* and lemon is consumed in drink form, breadfruit and membrillo are usually cooked with meals and the other fruit are fairly popular with the children; except *S. mombin*, which is not consumed at all. Medicinal trees are also kept even if they are not used; these included *Vismia macrophylla, Protium costarricense, Trattinnickia spp, Stemmadenia spp*, *Morinda citrifolia*, and *Quassia amara*. Non-wood construction materials are bamboo and three palm species (*Welfia regia, Socratea exorrhiza* and *Exorrhiza durissima*). Handicraft materials are sourced from different plants, for example traditional fibers are taken from *Aechmea magdalenae*, colouring from *Bixa orellana*, and *Hura crepitans*, where the whole tree is taken down and a boat is then carved out of the trunk. Refer to Annex 7 for a complete listing of all species.

Aside from cacao trees and naturally occurring forest species managers of these AFS actively enrich their plots by planting 63 species of trees and shrubs (See Annex 7). The majority are fruit trees, 30 species, followed by timber trees, 20 species. Over 96% of farmers reported planting fruit trees and 75% of them planted timber trees, while two other species with medicinal properties are planted on 13% of the cacao farms. One species is used for riparian protection and three more are used as live fences on 9% of the farms.

Lastly, 6 species, 3 used for handicrafts and 3 for traditional home construction were planted on only 6% of the cacao-based farms.

Annual plantings of staple goods were common in all 39 farms; these are basically *primitivo* type banana, which are consumed by families on a daily basis. Other annual plantings included 4 species of tubers: yuca (*Manihot esculenta*) was planted on 2 cacao farms, ñame (*Dioscorea spp*.) on 7 and dachín (*Colocasia esculenta*) on 8. The most commonly planted tuber was ñampí (*Xanthosoma sagittifolium*), on a total of 14 cacao-based agroforests.

More shade trees are favoured by some growers than others; total densities were recorded from 56 to 463 non-crop trees ha^{-1} At an average density of 173 trees ha^{-1} (±104), timber species came up to 118 trees ha^{-1}(±71) making this group the most numerous, most dense and therefore most important overall.

ii. Timber tree component: diametric classes, basal area and wood volumes

A total of 7585 timber trees was recorded in 39 cacao AFS, which covered an area of 78.27 ha. According to their distribution by diametric class in Figure 6, the majority (70%) is less than 30cm DBH, and with commercial diameter stipulated at 40cm and up[10], only about 10% are apt for harvest.

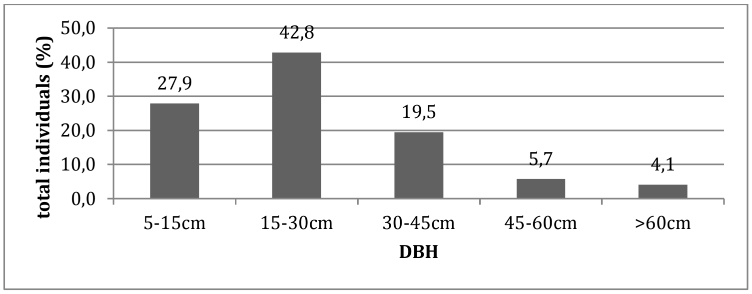


Figure 6. Distribution by diametric class of timber trees in cacao agroforestry systems in Bocas del Toro.

[10] Lisbeth Carreiro, ANAM, personal communication May 13th, 2011

Older and bigger trees were much less numerous than younger ones, but these represent most of the basal area and contribute to larger volume. Of the total basal area in all cacao AFS, most of it (73%) is held in trees over 30cm DBH (Figure 7).

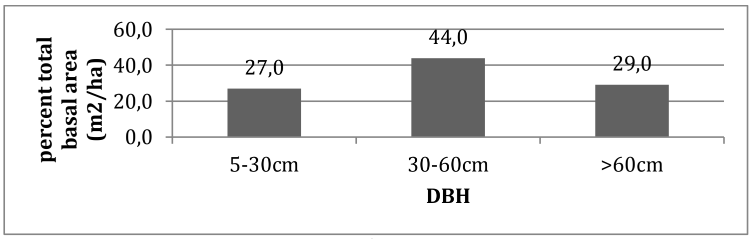


Figure 7. Distribution of basal area (m2 ha^{-1}) by diametric class for timber trees in cacao agroforestry systems in Bocas del Toro.

The actual minimum diameter for harvest was identified as 30 cm after the stump inventory. Within trees of harvestable size, three diametric classes were identified: 30-45cm dbh, 45-60 cm dbh and over 60 cm dbh. Volume was calculated for all timber trees according to their marketability potential (full list in Annex 8) and the results are presented in these three classes (Table 3). Over half of the standing volume is held in trees that are in the 30-45 cm diameter class, the remaining volume is divided almost equally between the two larger diameter classes. High value timber makes up the bulk of the volume in the first two diametric classes (84% and 81%) but is considerably lower in the >60cm class (at 35%).

Table 3. Total volume (m^3) according to diametric class and marketability in 39 agroforestry systems in Bocas del Toro.

	Diametric Class (DBH)					
Group	30-45cm		45-60cm		>60cm	
	m^3 total	m^3 ha^{-1}	m^3 total	m^3 ha^{-1}	m^3 total	m^3 ha^{-1}
Non Marketable	37.6	0.5	22.9	0.3	55.5	0.7
Potentially Marketable	93.7	1.2	50.2	0.6	195.9	2.5
High Value/Marketable	710.4	9.1	293.5	3.8	135.6	1.7
Total	841.6	10.8	366.7	4.7	387.0	4.9
Percentage of total	52.8%		23.0%		24.3%	

The average annual harvest rate of timber per household was calculated at 1.16 m^3 $ha^{-1}yr^{-1}$. Despite the abundance of timber trees present (67 species total), only 7 species are actually harvested, listed in Table 4. Timber was mainly used for home building (70% of al trees): only 26% of trees were sold, 4% were donated to the local church. From a total of 213 stumps inventoried, 193 (91%) were *C. alliodora*, denoting a marked preference for this type of wood.

Table 4. Timber species harvested in 39 agroforestry systems in Bocas del Toro.

Species	Total trees harvested
Cordia alliodora	193
Cedrela odorata	7
Virola spp.	4
Cordia megalantha	3
Hyeronima alchorneoides	3
Minquartia guianensis	2
Terminalia oblonga	1

iii. Musaceae component: distribution and densities

The only banana variety found in 100% of farms is *primitivo* (Table 5), for a total of 5622 individuals in all cacao AFS. The *gros michel* variety of bananas was found in 36 out of 39 farms (92%), for a total of 1700 individuals in all cacao AFS. The next most important variety is *manzana*; found on 17% of the farms. The common plantain variety was found on 56% of the farms inventoried. It has a relatively high sale price, and it is mostly sold and not consumed by the families. The second most important plantain was the *cuadrado* variety, found on 38% of farms (Table 5). Overall density for all banana plants was quite high at 100 plants per hectare, whereas for all plantains it was only over 7 plants per hectare (Table 4).

Table 5. Overall abundance of different varieties of banana and plantain within 39 cacao agroforestry systems in Bocas del Toro.

Type	**Variety**	**n***	**total abundance****	**density (total/ha)**
	congo	11	437	5.6
	gros michel	36	1700	21.7
banana	lacatán	4	47	0.6

	manzana	7	134	1.7
	primitivo	39	5622	71.8
	sabá	1	9	0.1
total			**7949**	**101.5**
	cuadrado	17	258	3.2
plantain	morado	8	154	1.9
	morado blanco	1	5	0.1
	plátano	22	165	2.1
total			**574**	**7.3**

*n=number of farms where varieties were found
**total=total number of plants counted in all farms

b. Economic performance of cacao agroforestry systems

i. Income generation in three system levels

Different levels of the household economy were considered and studied as separate systems of income generation (Figure 8). Families derive economic benefits in cash or in kind from every component in each system.

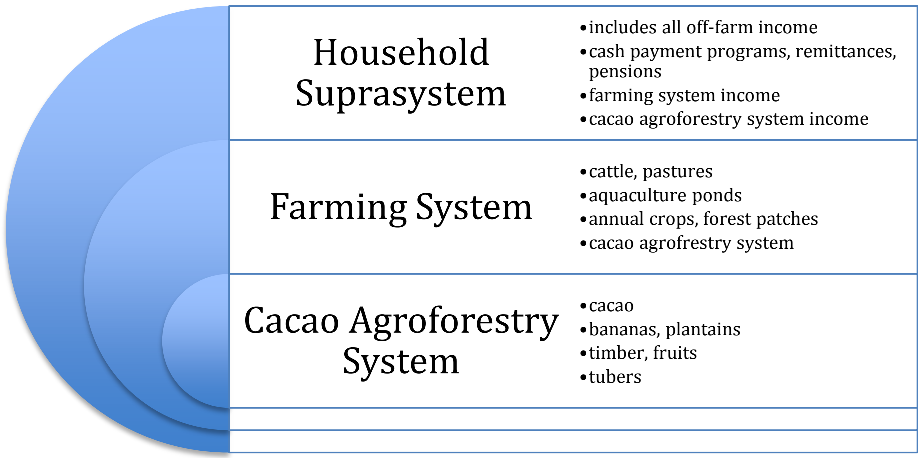


Figure 8. Income generation of small-scale growers in Bocas del Toro: hierarchy of systems and their components.

Results for the calculated Gross Income in Cash (GIC) were highly variable, where GIC for the Household Suprasystem varied from $128 up to $18000[11], with an average of $5046 in a one-year period (Table 6).

Farming Systems generated a GIC of $2,400 on average (Table 6), or almost half of the total household income. However, there were also extremes, from $128 to just about $14,600[12]. Within the Farming Systems, the Cacao Agroforestry System component generated an average GIC of $667, which is about a quarter of the overall farm production (Table 6). Income generation from this sole farming component was also very variable, and ranged from a mere $76 to over $4,800 per year[13].

Table 6. Average Gross Cash Income ($) derived from cacao and its three related economic systems for 39 households in Bocas del Toro.

	mean ± st dev	range
Total Gross income per household (Household Suprasystem)	5,046 ± 4,757	128 - 18,010
Gross income from farm production (Farming System)	2,407 ± 3,592	128 - 14,580
Gross income from cacao agroforestry system (Component of Farming System)	667 ± 836	76 - 4,811
Gross income from cacao alone (Subcomponent of agroforestry system)	311 ± 246	0 - 1,260

[11] The lowest number ($128) corresponded to a smallholder whose only sales activity was cacao and had no external income; the highest number depicted a household that had prime peach palm production, dairy and beef cattle operations, as well as cacao production, and a coffee AFS, from which they roasted and sold ground coffee.

[12] The lowest and highest numbers represent the two households described beforehand. One had no other farming activity than cacao production; the other ran a highly diversified farming operation with multiple production streams.

[13] The lowest number obtained ($76) represents a special case where there had been a recent death in the family, and the household head had fallen ill and couldn’t work, so there was very little harvesting done in the cacao plot. The highest number ($4,811) represents a keen, well-educated grower that made big money out of premium organic banana and plantain sales, as well as cacao.

Based on average numbers, small growers in Bocas del Toro generated 52% of their Total Gross Income from external sources (Figure 9); this means government pensions and off-farm work were a very important part of their economic well-being for 2010, where 60% of the households received pensions and 44% had family members working off-farm, 13% ran a small store and only 8% got remittances from family members.

Farming Systems, which include all cropland, banana, coffee and cacao AFS, forested areas, swidden agriculture plots and cattle assets generate 48% or the other half of their total Gross Income (Figure 9). From all components present in these Farming Systems, the Cacao Agroforestry System only contributes 19% to total income, where other crops and cattle play a bigger role and generate almost 30% when pooled together.

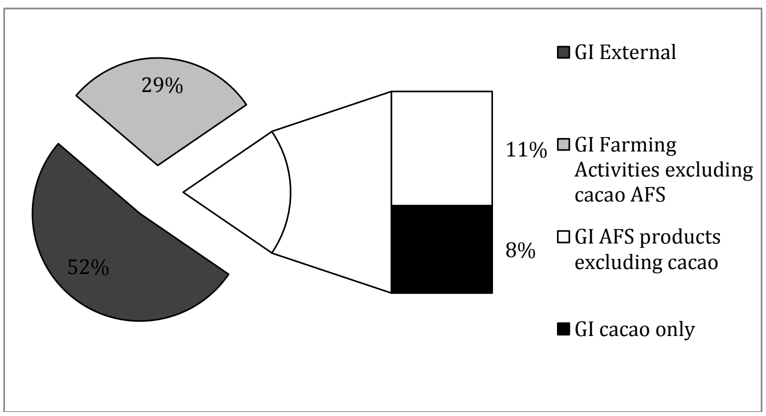


Figure 9. Average economic importance of cacao AFS in terms of Gross Income in Cash for 39 households in Bocas del Toro.

Of the 19% generated by cacao AFS for families in Bocas del Toro, only 8% of the total gross income is directly attributed to cacao (Figure 9). The rest (11%) comes from diverse subcomponents or products, which include peach palm, bananas, plantains and other fruits, as well as timber and tubers.

From the whole group under study, there were ten households (26% of the total) where the cacao AFS is the sole component of their farming system and for which the total gross income tends to be lower than the average at $3138 compared to $5046 (Table 6). In these circumstances the picture is a bit different; since they have no alternate farm production the economic importance of external sources of income comes up to 87%, making this group of small scale farmers almost completely dependent on outside sources. Of the remaining 13%, cacao alone accounts for 9% of gross income, and other subcomponents make up the other 4%.

ii. Economic analysis of cacao agroforestry systems: financial and subsistence indicators of profitability

After finding out the general economic workings of household income generation as a whole, focus turned to the key farm component, the system of interest in this study: the cacao agroforestry system. In general terms, produce from the AFS has three main purposes: some is sold, some is used for family consumption and some is used as feed for farmyard animals. The value of production for 2010 divided among these three areas is represented in Figure 10. This denotes higher home consumption than sales, almost at a 60:40 ratio, pointing more to family subsistence agriculture than a market-based type.

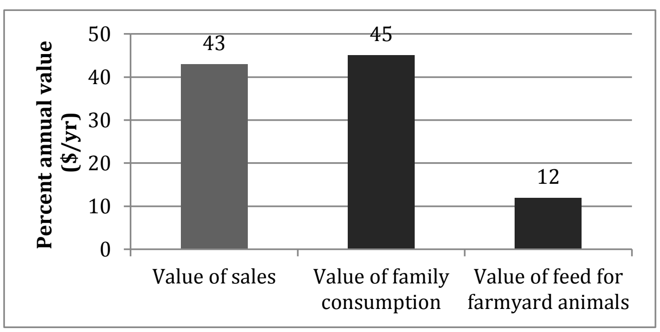


Figure 10. Proportion of total annual value allocated to three main purposes: sales, family consumption and animal feeding. Calculated from total goods produced in 2010 in 39 agroforestry systems in Bocas del Toro.

In addition to gross income (without any deductions like above), an analysis of the cacao agroforestry system component considered the costs of production for all goods in 2010. These included planting, maintenance, processing and transport costs as described by each producer surveyed. Financial and subsistence indicators were evaluated on a "per hectare" basis to eliminate bias due to different farm sizes (Table 7).

Table 7. Financial Indicators per unit area of 39 cacao AFS in Bocas del Toro for the year 2010 ($/ha)

	mean ± st dev	range[14]
Gross Cash Income/ha	376 ± 343	57--1809[15]
Net Cash Flow/ha	267 ± 380	-739--1645[16]
Net Income/ha	-451 ± 597	-1907--1260[17]
Family Benefit/ha	1005 ± 778	-247--3087[18]

Gross Cash Income (GCI) per hectare was $376 in average, while the Net Cash Flow (NCF) was only $267, as shown on Table 7. This reflects the importance of cash costs of production, which reduce total earnings by almost one third (29%). The management costs of the AFS are mostly comprised of cacao maintenance activities, which include general pruning, shade management and disease control, harvesting, fermenting and drying of the

[14] The substantial difference between families and farming systems is well depicted by the ranges obtained for every economic indicator, especially since these were calculated on a per hectare basis, and the agroforestry system size affects different production factors like maintenance cost and labour intensity.

[15] The lowest value obtained for Gross Cash Income ($57/ha) was associated to a household that only sold cacao beans and no other product, where the highest value was associated to a household that managed and sold multiple products from the cacao AFS including chocolate bars, roasted coffee, freshwater fish (tilapia) and even ran agroecotourism activities in their plot.

[16] Net Cash Flow was highly dependant on maintenance costs and on output, the lowest value (-$739/ha) represented a farming system that had undergone intensive shade removal, rehabilitation and grafting of cacao trees, so their harvest output was null. The highest number ($1645/ha) was associated to the household described above, which runs a very diversified enterprise, and has four capable, strong brothers running all maintenance and sale operations, so the cash costs are kept very low.

[17] Net Income values were negative for most households, but the highest value obtained ($1260/ha) was attributed to a smart and very organized young smallholder that sold high quality organic bananas, plantains and cacao; he receives premiums for all produce and runs a small plot that he can maintain and harvest mostly by himself, so his costs are low compared to his considerable earnings.

[18] Family Benefit values were mostly high, but there was a very low value (-$247/ha), which represents a household that relied on remittances, family members did not participate in any activities, and they did not harvest any produce for the household. The highest value ($3087/ha) represents a household whose cacao plot is located right on the main road, an excellent sales point; they sell considerably large quantities of peach palm when in harvest because buyers can easily reach them, and daily sales of banana and other fruit are a main part of their routine.

beans, which can take up to 8 days in the tropical rainy, humid climate. Within the total cost structure, management of cacao alone represents 74% of total costs in cash (±33%), and 87% (±11%) of non-cash costs, or unpaid family labour. Aside from planting and harvesting, little pruning or maintenance is given to the other products intercropped.

The average cash costs of maintenance were very variable, and depended on the willingness or capability of the household head to do work. In case of sickness, all labour had to be hired, the maximum amount spent on labour per hectare in one year ranged from $700 up to $900; but if the property was small enough and the head of the family was healthy, then this value was reduced to $0 as was the case on two of the farms. On average, the cost of hired labour per hectare was $109 (±$190), and it was mostly attributed to contracts for clearing the undergrowth. This is done by machete, a tiring task when farm size is over one hectare, so owners will usually hire younger guys from the community. In some instances, farmers engage in communal work, and help out with undergrowth clearing in exchange for meals.

The average family labour input was 90 days of work, or man-days per hectare (±65 days) for a one-year period. Family labour is used to take care of most activities, and all women and children come out to help during cacao harvest time. This amount is not paid for, but is accounted for in the Net Income per hectare: 90 man-days at $8/day -according to local wages- gives the value of family labour, an approximate $720, or almost seven times the cost of hired labour. This cost is the reason why Net Income was negative for all but four cacao AFS; the vast majority (90%) show negative values, with an average of -$451 (Table 7), so the real value of invested family labour becomes apparent.

From a strict financial perspective, judging by the Net Income value (Table 7), cacao AFS as an enterprise do not return investment on the factors of production and therefore are not economically viable. However, from a subsistence perspective (and supported by results in Figure 9), aside from cash generation, the real value that households derive from these complex systems is represented by Family Benefit (FB), which takes family consumption in consideration. FB is stated at over $1000 per hectare (Table 7). The ratio of value of FB to NCF per hectare is 3.8, denoting a much greater productivity than what can be measured via financial terms.

Given this positive outcome in terms of subsistence, profitability was studied in terms of returns to family labour. Numbers varied greatly and ranged from -\$14 to \$56 for each workday invested; the mean was \$13.6 (±13.1). Compared to the local wages, where the value of a day's work is \$8; only 13 cacao AFS are under this mark, representing 33% of the total, whereas another 30% are well above \$15 per workday invested. This indicates that even though labour input is low, averaging 90 man-days in one whole year, benefits are considerable, and working on their own cacao agroforests pays almost double than a one-day wage working elsewhere.

NCF per workday was much smaller in comparison; ranging from -\$42 to \$34, the average was \$3 per day (±9.6). Four AFS (10%) presented negative values due to particular reasons of family illness and the need for hired labourers. However, the majority of households (72%) generated less than \$5 per workday invested, this is \$3 less than what they could be paid if they were hired for work.

Regardless of the particular labour input capacities of small-scale growers, cacao agroforestry plots generate much more benefit in one day than what can be accounted for in cash terms. This higher value can be attributed to the diversified production strategies of the family, where consumption of bananas, tubers, fruits and timber products make the difference almost fivefold, from \$3 to \$13.6 per day.

c. Links among biophysical and socio-economic aspects of cacao agroforestry systems

i. Significant correlations

The set of 39 cacao agroforests and households studied was highly heterogeneous, but a few important and significant correlations ($p<0.05$) that came out of the Pearson test are described next. The age of the household head is negatively correlated both to level of education (-0.63) and to the gross income from total farm production (-0.33); but the number of family members per household is strongly associated to the number of educated family members (0.89), which is a positive demographic figure.

At the bigger scale, the number of educated family members is not correlated to the number of family members working off the farm, which is strongly associated to the total gross income at the household level (0.63); this may point to a lack of job opportunities in the area.

However, the number of educated family members shows a positive correlation to the number of family members working on the cacao plots (0.4), which is in turn, positively associated to family benefit (FB) per hectare at 0.34, and to FB per hectare attributed to bananas and peach palm as well (0.34 & 0.34). So given the lack of other employment opportunities, it can be beneficial for households to have a larger, on-site labourer pool.

In terms of floristic composition and economics, there is no correlation between the abundance or density of cacao plants and any cash or in kind benefits derived from cacao; nor among timber trees, banana or plantain density and benefits derived from any of these. The only exception is that higher fruit tree density is associated to higher FB ha^{-1} and NCF ha^{-1} (0.5 and 0.35); this suggests that fruit trees do play an important role in cacao AFS production.

Cacao plant density does not decrease with the inclusion of more shade trees; instead, density of all plants builds up collectively. Cacao plant density is positively correlated to density of timber trees (0.52), fruit trees (0.58), total trees (0.59) and also banana plants (0.6).

The family benefit per hectare (FB/ha) derived from cacao is not negatively affected either; it is positively correlated to FB/ha from banana (0.52), plantain (0.5), fruit (0.41), and less so peach palm (0.33). Net Cash Flow (NCF) per hectare from cacao is also positively correlated to FB/ha of plantain, banana and peach palm (0.51, 0.49 and 0.32), so benefit derived from other crops is not decreasing the cash or in kind benefits from cacao, there is no clear detrimental market competition.

In more general terms, FB/ha is very strongly correlated to FB from bananas/ha (0.89), and less so to peach palm/ha (0.44); the two most important consumption crops in the area.

On the other hand, NCF/ha is very strongly correlated to NCF cacao/ha at 0.86, to NCF plantain/ha at 0.63, and thirdly to NCF banana/ha at 0.5; this helps to confirm the importance of these crops in cash generating strategies.

The correlation between area and FB per hectare has moderate strength and is negative (-0.55), which is interpreted as those who have less area tend to derive more benefits per unit and increase their efficiency; especially noticed in FB attributed to cacao and banana (-0.37 and -0.53).

Data indicates that people with smaller land area strive to or decide to keep the most trees possible as compared to larger plots. Correlation between size of AFS and total basal area (-0.41), standing timber volume (-0.48), total tree density (-0.44) and densities of fruit and timber trees is negative and significant (-0.46 and -0.38); this tendency is even displayed in terms of harvest rate (-0.36), in $m^3ha^{-1}year^{-1}$.

Management activity can be speculated from the amount of days of work invested in a year (man days yr^{-1}). There is a positive correlation between total cacao plant density and the total amount of man-days (0.37), and also with the total workers in the cacao AFS (0.37), this is expected since the majority of management effort is dedicated to cacao.

ii. Affinity and divergence: grouping of farming systems

A set of multi-phase statistical analyses resulted in three main groups of cacao AFS through cluster analysis; from the final selection of 37 cacao AFS, 14 went into Group 1, 16 to Group 2, and 7 to Group 3. These display affinity between those AFS belonging to each group, but also display many differences between groups (Figure 11).

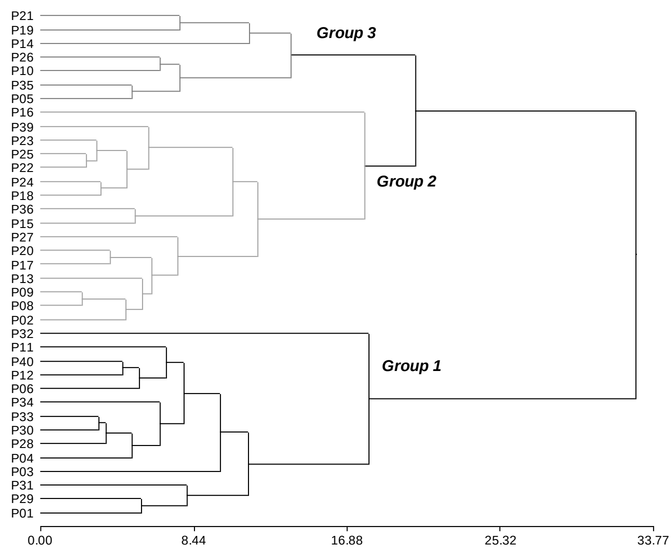


Figure 11. Dendrogram of distribution of 37 cacao agroforestry systems in Bocas del Toro into three main groups according to their biophysical and socio-economical attributes.

In terms of their biophysical make up, the most important differences in typology were used to name the groups (refer to Table 8):

- Group 1: large, scattered, many cacao trees
- Group 2: small, scattered, few cacao trees
- Group 3: small, very complex, crowded

Group 1 is characterized by having the largest area and consequently, the highest species richness; however, it displays a lower density of woody perennials compared to Group 3. Group 1 also has the lowest density of both fruit trees and banana plants; therefore the basal area is almost as low as in Group 2. In Group 1, companion trees have given way to the highest density of cacao plants of all (Table 9).

Group 2 is distinguished by having a smaller area and the lowest density of woody perennials, timber trees and cacao plants of all groups. It also displays a small basal area, similar to Group 1, but a higher fruit tree and banana plant density.

Group 3 presents the smallest area but the highest density for woody perennials overall. It is also identified by the highest fruit tree, timber tree and banana plant density; with a medium value for density of cacao plants, Group 3 also has the highest basal area of all groups (Table 8). These features set Group 3 apart as the most complex in vegetative spatial arrangement.

Table 8. Biophysical attributes in three main groups of cacao agroforestry systems in Bocas del Toro. (mean ± standard deviation, letters across represent group difference, *non-significant)

	Group 1 Large, scattered, many cacao trees n= 14	**Group 2** Small, scattered, few cacao trees n=16	**Group 3** Small, complex, crowded n=7	p value
Area	2.97 ±1.0 b	1.06 ±0.5 a	1.04 ±0.9 a	<0.0001
Species richness	27 ±7.6 a	22 ±8.7 a	24 ±6.3 a	0.3614*
Woody perennials ha^{-1}	157 ±102.7 a	147 ±52.2 a	274 ±153.2 b	0.0173
Basal area m^2 ha^{-1}	10 ±2.9 a	11 ±5.8 a	12 ±7.4 a	0.7152*
Timber trees ha^{-1}	117 ±85.7 a	102 ±41.7 a	166 ±94.6 a	0.1539*
Fruit trees ha^{-1}	22 ±14.5 a	28 ±15.1 a	76 ±40.4 b	<0.0001
Banana plants ha^{-1}	123 ±94.1 a	141 ±123 a	149 ±111.3 a	0.8564*
Cacao plants ha^{-1}	687 ±56.9 a	506 ±53.2 a	590 ±80.4 a	0.0819*

In socio-economic terms as seen in Table 9, Group 1 makes the smallest investment in labour at 65 days/ha. Because of their larger area, their total production of cacao is much higher than the other two groups, even if at the hectare level there is much less production. Hiring labour is necessary for larger plots of land; the cost of maintenance and harvest activities lowers the Net Cash Flow, Group 1 displays a lower NCF per workday and per hectare then Group 3. Other aspect is that having a larger area, these farming systems are ensured larger quantity and volume of produce than smaller counterparts; this makes it unnecessary to produce intensively in every hectare owned. Therefore, Group 1 shows the lowest Family Benefit (FB) per hectare and also the lowest FB per workday of all.

Table 9. Socio-economic attributes: labour input, productivity and profitability in three main groups of cacao agroforestry systems in Bocas del Toro (mean ± standard deviation, letters across represent group difference, *non-significant)

	Group 1 Large, scattered, many cacao trees n= 14	**Group 2** Small, scattered, few cacao trees n=16	**Group 3** Small, complex, crowded n=7	p value
workdays ha^{-1}	66 ±35.8 a	120 ±90.5 a	93 ±47.6 a	0.1030*
cacao kgs total	261 ±128.8 b	128 ±64.5 a	180 ±118.5 a	0.0048
cacao kgs/ha	92 ±53.0 a	152 ±127.4 a	238 ±145.2 b	0.0227
FB $workday^{-1}$	8 ±4.5 a	10 ±9.4 a	26 ±15.1 b	0.0006
NCF $workday^{-1}$	4 ±2.6 b	-2 ±10.9 a	8 ±5.7 b	0.0037
FB ha^{-1}	443 ±213.9 a	1029 ±693.1 b	1886 ±616.8 c	<0.0001
NCF ha^{-1}	210 ±114.0 a	99 ±291.5 a	586 ±389.8 b	0.0011
FB total	1389 ±926.3 a	884 ±580.5 a	1845 ±1423.3 a	0.0667*
NCF total	619 ±441.7 b	52 ±362.1 a	510 ±438.0 b	0.0016

Group 2 makes the biggest investment in workdays per hectare; in these small-size plots this results in added cacao kg per ha, a higher FB/workday, and a much higher FB per hectare than Group 1 (Table 9). The drawback of investing so much in labour and recurring to paid contracts instead of family labour results in Group 2 having the lowest NCF values of all. Group 2's total NCF is one tenth or less of groups 1 and 3; NCF per workday fares the worst, with a negative number; and NCF/ha is less than half of Group 1 and one sixth of Group 3 (Table 9).

Group 3 instead, has a medium value for labour input; yet given their small size, they still manage to attain the highest values for FB and NCF per hectare, and the highest FB and NCF per workday as well. Even if Group 1 surpasses them by total kg of cacao, and total NCF, this group of complex, smaller farms, crowded with trees, boasts the highest total FB of all. This is the group that makes the most out of their land, they harvest the greater cacao poundage per hectare; they have the biggest returns per hectare of all 3 groups making them remarkably efficient (Table 9).

iii. Cacao agroforestry system subcomponents: differences in cash and in-kind benefits generated through diversified production

Cocoa growers derive benefits from other species within the cacao agroforests that were not accounted for through the previous inventories, which include a variety of fruits and tubers that grow in vines or low to the ground. The farming system groups differed on cash totals and particular products that they derive cash benefits from. The miscellany of answers was simplified from the total range of species mentioned to seven fundamental products, a list of species included in each product is found in Annex 9.

Table 10 clearly shows cacao as the most important product overall; contributing from $75, to $100 and over $300 to groups 1, 2 and 3; each time making up about 50% of total cash flow (Table 10). Banana was the second most important in all groups comprising from 15% (in Group 3) to 30% (in Group 2) of total earnings, though it generated much less cash, from $45 in groups 1 and 2, to $90 for Group 3. Peach palm was a very important sale item for Group 3 at 16% of earnings, but less so for Group 1 and 2 (10% of earnings). Fruit and tubers only generated some cash in groups 1 and 3, but a very minimal value of under $20 in one full year. Group 2 had no sales of plantain or tubers whatsoever, and even shows a negative cash flow for the wood harvested; for these reasons Group 2 was not very efficient in terms of generating cash for the year of 2010.

Table 10. Net Cash Flow generated by each product ($ per hectare) of 37 cacao agroforestry systems in Bocas del Toro (mean ± standard deviation, letters across represent group difference, *non-significant)

	Group 1 Large, scattered, many cacao trees n= 14	**Group 2** Small, scattered, few cacao trees n=16	**Group 3** Small, complex, crowded n=7	p value
NCF/ha cacao	100 ±43.7 b	79 ±40.9 b	323 ±61.9 a	0.0063

NCF/ha banana	44.26 ±30.5 a	46.77 ±28.5 a	90 ±43.1 a	0.6505*
NCF/ha peachpalm	23 ±14.6 b	13 ±13.7 b	95 ±20.7 a	0.0072
NCF/ha plantain	10 ±6.5 a	2 ±6.1 a	19 ±9.2 a	0.2836*
NCF/ha fruit	19 ±11.8 a	15 ±16.7 a	5 ±11.1 a	0.6798*
NCF/ha tubers	9 ±5.0 ab	0 ±4.7 b	20 ±7.1 a	0.0778*
NCF/ha timber	4 ±17.4 a	-51 ±16.3 b	24 ±24.6 a	0.0219

In Table 11 it becomes clear that in terms of Family Benefit, all groups derive some utility from all seven products and total profits per hectare increase considerably. Compared to Net Cash Flow, Group 1 derived twice as much profit in terms of Family Benefit ($200 to $440); Group 3 shows a threefold increase from $580 (NCF) to $1880 (FB); and Group 2 is the most impressive, accruing ten times as much benefit as total cash flow (from $100 to $1000). This clearly indicates that Group 2 farms are very capable managers too, but that they simply allocate most of their produce for at-home consumption and not for the market.
Table 11 also shows that even if utility is low for items such as plantain and tubers (under $20) there are no negative values, even for timber; because benefits outweigh the high costs of harvest when utilized for home consumption.
Instead of cacao and its importance to cash flow discussed above, the single most important product for all three groups in terms of subsistence is banana. It amasses 45%, 70% and 50% of total benefit derived for groups 1, 2 and 3 respectively. Groups 2 and 3 display very similar benefit values for banana, at over $700 and $900 per hectare; whereas in Group 1 it only amounts to $200.

Table 11. Family Benefit generated by each product ($ per hectare) of 37 cacao agroforestry systems in Bocas del Toro (mean ± standard deviation, letters across represent group difference, *non-significant).

	Group 1 Large, scattered, many cacao trees n= 14	**Group 2** Small, scattered, few cacao trees n=16	**Group 3** Small, complex, crowded n=7	p value
FB/ha banana	196 ±123.61 b	715 ±115.63 a	925 ±174.81 a	0.0021
FB/ha cacao	106 ±43.35 b	108 ±40.55 b	340 ±61.31 a	0.0066
FB/ha peach palm	47 ±23.54 b	66 ±22.02 b	281 ±33.3 a	<0.0001
FB/ha fruit	38 ±32.86 b	38 ±30.74 b	179 ±46.48 a	0.0348
FB/ha plantain	19 ±8.88 ab	8 ±8.3 b	49 ±12.56 a	0.0315

FB/ha tubers	16 ±15.35 a	21 ±14.35 a	67 ±21.7 a	0.1499*
FB/ha timber	22 ±17.86 b	75 ±16.71 a	41 ±25.26 ab	0.1079*

Cacao is second in importance, with a lesser contribution of about 23%, 10% and 18% to total benefits for groups 1 to 3. Peach palm is the third most important product for family subsistence overall, at a similar contribution to that of cacao (10%, 6% and 15% for groups 1 to 3).

On a product per product base, peach palm is especially important for Group 3 where it reaches a FB value of almost $300 per hectare (very similar to that of cacao). At just about $180 per hectare, fruit plays an important role for Group 3, but less so for the other two groups, where values only reach about $40. Plantain and tubers are somewhat important and generate up to $115 when added up, but only for Group 3; in groups 1 and 2 this sum only comes up to $35 and $30. Finally, benefits from timber are $22 and 40 for groups 1 and 3, and are only really noticeable for Group 2, going from -$50 in net cash (Table 10) and reaching up to $80 per hectare in one year.

On a per hectare basis, Group 3, which comprises the smallest farms with the most complex canopies, derives the largest total benefit from all products. At a total value of over $1800 in one year, this is close to double the sum of all benefits for Group 2, and an almost fivefold difference with respect to Group 1. These are by far the most efficient farmers in the lot, given their smaller farming units; they excel at making the most out of their land and manage to produce important quantities of an array of fruits and tubers to help sustain their families.

5. DISCUSSION AND IMPLICATIONS

a. Biophysical Aspects

In terms of floristic composition, a total of 139 species were identified in 39 Bocatorean cacao AFS; a slightly higher number than in Ghana (Osei-Bonsu et al. 2003) where 116 species were identified in 60 cacao agroforests, but less than in Southern Cameroon, at 201 species in 60 agroforests (Sonwa, 2004). Compared to very similar systems and equivalent topographic conditions, overall diversity as per Shannon-Wiener Index was 1.94 in Bocas del Toro, but only 1.71 in Talamanca (Deheuvels et al. 2011). So Bocatorean agroforests show higher diversity, an important and valuable attribute for ecosystem sustainability because it positively influences functional diversity, and increases the system's resistance and resilience properties (Tschartnke et al, 2011).

Timber trees were by far the most abundant, and while there is a lot of quality timber stored in these AFS annual harvest rates are very low. This is due to many factors, including by-law sale restrictions, cost and validity timeframe of legal permits, and other sawing and transportation costs. Also, trees are viewed as "stored capital" that can provide a lump sum of cash when the necessity arises, like sending kids off to school or a medical expense. These unexpected requirements are covered by timber sales; so ensuring valuable timber development is like putting money in the "tree bank" for a later purpose (Tscharntke et al. 2011).

Local smallholders value *C. alliodora* wood over most others, and assist this one species to regenerate and conform 50% of their total canopies; this is the single most utilized species for home construction purposes and wood sales, making up over 90% of the total volume harvested in Bocas del Toro. So in actuality, very few other species are harvested for their timber value.

This is not necessarily negative, since many of these other timber species are part of the UICN Red List for Panama (Gaceta Oficial Digital, 2008), and now we have an indication that these endangered species are conserved in productive agricultural systems outside of protected areas. Also noted to happen in Ghana (Asare, 2006), this fact asserts the potential conservation value of cacao AFS (Perfecto et al., 2007). Furthermore, maintaining these native forest species in buffer zones outside of protected areas may in turn increase the gene pool and contribute to the conservation of these very species (Beer et al. 1998).

b. Socio-economic Aspects

Total annual value of goods consumed surpass the value of goods sold from cacao agroforests in a ratio of almost 60:40. Aside from cacao staple food crops like banana, peach palm and tubers are grown in large enough quantities to provide household daily needs and to feed farmyard animals, Cacao AFS have a diferent relative importance according to the economic system studied. Within the whole farming system, cacao AFS make up 40% of total Gross Cash Income. For the average smallholder, cacao sales represent only 17% of all farming activities output. Though there is an important exception to this average, and 10 of the households studied (26% of the total) depend exclusively on their cacao AFS and have no other farming activities. This group derives 70% of their total farming sales from cacao, and only 30% from other products, very close to the findings by Jagoret et al. (2009). This indicates that when smallholders have no other farming options, they are much more limited in their income generation and depend mostly on cacao production

When encompassing the whole household economy system, small-scale cacao growers derive only about 8% of their gross family income from cacao, and an array of products (including timber, peach palm, banana, plantain, tubers and tree fruits) coming from the cacao AFS makes up another 11% for a total of 19%. In the special case of the 10 households that only maintain a cacao AFS and no other farming activity, these numbers are even worse, where cacao brings in only 9% of total income, and other products account for 4% for a total of 13%. So those smallholders that can only base their economy on cacao fare the worst economically, and are much more dependent on external income generation and government help.

The economic contribution of cacao AFS to the families net cash flow and family benefit is very different. In general, smallholders generate little cash income from the whole production obtained from these AFS. This is so because of various important findings:

1) within the total household economy, 52% of gross income comes from sources external to farming and cacao AFS productive activities, like government pensions and off-farm work

2) within the cacao AFS, managers direct only 43% of production to sales, while the rest is kept for use at home (either for family use or for raising farmyard animals)

3) the net cash income generated through the sale of products that make up this 43% is relatively low (average was $267 per hectare per year)

4) from the net cash value of sales, cacao accounts for only 42% of the total, with consistent low yields (average 188 kg/ha) amounting to only $112 per hectare

The significance of these findings could be interpreted negatively, since cacao AFS are not a main part of the family's economy, and that the income they generate is of little importance. However, this study has shown that the real value of cacao AFS lies in the benefit that households generate from their plots by harvesting for at-home consumption purposes, calculated as Family Benefit, for which the total value is almost four times higher than Net Cash Flow.

Cacao is undoubtedly a cash crop, and families do not keep more than 5-7 kg a year for home use. Whereas most fruits (avocadoes, mandarins, breadfruit, etc) and banana are harvested for consumption (6:1 ratio of banana consumed to sold); other food crops like peach palm and tubers are equally sold or kept for household use. These crops are quite versatile, they can be easily stored and cooked in various forms; they are also used to feed pigs and chickens, which entails an additional saving to the household. Food security is the first and foremost purpose of intercropping in cacao-based agroforests in Bocas del Toro.

Net returns to land and labour that consider secondary products of cacao agroforests in Bocas del Toro are low in terms of Net Cash Flow ($267/ha and $3/man-day), but are much greater when evaluating them in terms of Family Benefit: $1005/ha and $13.6/man-day. This clearly demonstrates how the Net Cash Flow underestimates the real profitability of cacao AFS, where Family Benefit presents a more reliable number.

In strict financial terms, cacao AFS are not profitable as an enterprise; when all labour input costs are accounted for, Net Income is negative (average annual loss of $450/ha). But considering the many other intervening factors, like the lack of job opportunities, the isolated location, and marketing difficulties, these smallholders are doing as best as they can. By the values obtained for the Family Benefit generated, and because of its intrinsic relation to household food security, these are systems that present a different type of profitability, as they seem to play a big part in providing for the family's need of staple foods.

c. Biophysical and Socioeconomic Links

Key findings from this study explictly link biophysical complexity and diversity to superior economic and productive capacity. A group of 7 small farms (Group 3), which are very densely treed and hold the largest basal area, and also incorporate the largest abundance of banana plants and fruit trees (which results in a very complex structure), are, of all farms, the ones with the best economic performance in terms of return to land and returns to labour. Smallholders of these particular small farms in can manage them in a highly efficient way, to produce and harvest more cacao, bananas, peach palm and fruits per hectare than the other small farms with a less diverse, less dense canopy; they even surpass larger farms, where labour input is less extensive, but also much less productive. These 7 AFS are extremely successful in deriving monetary and in kind benefits from a small area, while maintaining a densely treed, species-rich agroforest, and without having to recur to an exceeding amount of labour to accomplish this. Their management strategy and tactics should be studied in more detail, learned from, and proposed as a tentative, viable production alternative for small-scale growers in the area.

Efficiency of small to medium farms has been noted before; according to Rice and Greenberg (2000), smaller farms present higher productivity in pods per hectare and are also more efficient in "pods per dollar input" than larger operations. Small farms in suboptimal agrological sites have shown very high complexity in their shade structure (Beer et al. 1998). And a study of the fruit tree component in cacao farms in Cameroon and Nigeria found that smallest farms had the greatest fruit tree densities (Degrande et al., 2006) same as in Bocas del Toro. All these studies give positive overviews of cacao AFS, but they do not explicitly determine that small farms with complex canopies are in fact the most productive and also the ones that fare better economically.

Though tere is however room for inaccuracy and the numbers obtained may be a bit askew because many AFS were not even one hectare in size, so extrapolation may affect total results, these findings are an interesting example of synergistic systems and may be studied with greater attention to detaill in order to obtain more accurate farm management profiles.

d. Implications

Overall, Family Benefit showed much higher numbers than Net Cash Flow, boasting the subsistence value of these agroforests. However, the reduction of poverty would entail focusing on the less promising economic indicator, Net Cash Flow, in order to secure more income per hectare from these systems. This should not threaten or impair the provision of family consumed goods, but rather be targeted to adding more economic value to the existing system. The results point to an open opportunity to increase agrobiodiversity in an agriculturally marginal area, where productive and environmental sustainability can both be enhanced at once (Pimbert, 1999).

In the past, the one crop approach has resulted in halting of farmer innovation, and general loss of local knowledge (Asare, 2006), and the economic gain from improving this single component may not have the desired overall effect in improving smallholders income. This is not to say that cacao production should not be improved. By all means, any aspect that improves production in one of the system's components may also improve the overall system performance. What it warns against is the specialization into one single crop, be it fruit, timber or bananas; since this would work against the projected diversification of family income, and increase the economic risk level for small-scale farmers. People may benefit more from diversified and attainable polyculture options if there are receptive market possibilities, and if management costs do not increase greatly.

The most interesting findings overall helped highlight plausible courses of action and more efficient management scenarios that can potentially improve income generation. The proposed operational changes will contribute to enhance the overall wellbeing of smallholders and are discussed on a one by one basis:

1. Firstly, there was no significant correlation between the density of timber and fruit trees and shrubs or banana plants and the total harvest derived from them. During the interviews it was evident that not all produce is harvested for consumption and plenty is left in the fields, and economically speaking, this is considered lost value. The first income recuperation strategy is perhaps the simplest one: if harvesting was carefully carried out with a market possibility in mind, a lot more produce could be harvested and sold from the

AFS. This could be done in a communal labour form, or "junta", as it is commonly done in the harvest of cacao.

Of course market possibilities should be promoted either by community members, or by COCABO. Opening streams for additionally harvested produce even if done within the community could have a positive impact on the already existing informal market. A roadside stand run by the community would also be beneficial depending on the location, but opening a simple communal transport of goods to the nearby urban areas would be even more beneficial in terms of reducing this lost value. COCABO could be interested in providing a stand for these products, since they are all organically produced, or developing a more formal trade with the raging tourism industry in Bocas del Toro's Colon Island. Organic fruit and produce would surely be welcome by visitors instead of the unhealthy options available, and prices paid would of course have an associated premium, but market demand in the Island should be studied more carefully and is beyond the scope of this study.

2. Cacao agroforests were found to be around 30 and up to 60 years old, that is, they are old, less productive and highly exposed to present low yields, which are mainly due to the prevalence of monilia (*Moniliophthora roreri*) in the area (Villalobos & Borge, 1998). Trees may lose vigor and productive potential, due to a lack of nutrients in the soils, and recurring fungal infections can prompt harvest losses of up to 80% or higher (Galindo, 1987).

Throughout the interview and informal conversations held, there was no mention of application of locally made organic compost and compost teas. In such high shade systems, even a minimal application of fertilizer could benefit older cacao plants, and intercropped trees, as well (Ahenkorah et al. 1974). Composts are now available in the community of Norteño; made by smallholders themselves, they are starting to use them in their own farms and also to sell small batches to different producers in the area (M. Aguilar, pers. comm[19]). These efforts could be replicated in all communities, which could then provide their own compost and organic fertilizers.

19 Máximo Aguilar, personal communication, October 3rd, 2010.

Yield levels should also gradually rise with the adoption of better management practices and techniques for cacao yield. The PCC is imparting Farming Field Schools on many communities, and part of the goals is reaching a total of 6,000 families with practical, hands-on extension services (PCC, 2007). By means of an agreement with the Agrarian Development Institute (IDIAP), different aspects of cacao management are explained and practiced on-site, tools and grafting material are handed out along with extension bibliography that is easy to read and can be consulted as needed.

Clonal gardens with improved germplasm material are already planted in the area, and this material will be available for free (PCC, 2007). However, because cacao takes from one to five years to bear fruit after grafting, this could be considered a long-term economic gain.

3. Another highly interesting finding is that cacao plant density did not decrease with the inclusion of more shade trees in the plots; instead, density of all plants seemed to build up collectively. Cacao plant density was positively correlated to density of timber trees, fruit trees, total trees and also banana plants. In contrast, cacao trees are initially planted with some fruit trees in Cameroon, but because fruit may sell at better prices than cacao, farmers replace cacao trees with more fruit-bearing trees. In the village of Ntsan, for example, oranges have taken over 50% of the cacao plantations, which have now become mixed orchards (Sonwa & Weise, 2008). This is not the case in Bocas del Toro.

Furthermore, the Family Benefit and Net Cash Flow derived from cacao was not negatively affected either, so benefit derived from other crops is not decreasing the monetary or in kind benefits from cacao. An increase in complexity and related higher agrobiodiversity in cacao AFS does not show a clear association to lessened productive capacity or detrimental market competition from other crops.

In a recent study by Deheuvels et al. (2011), four typologies of agroforests in Talamanca differed in their quantitative and qualitative attributes in respect to floristic composition and structure, but showed no statistical difference in cacao yield. This may suggest that yield is ultimately not affected by the structure of the AFS, in fact Deheuvels et al. (2011) found that cacao yield per tree increased when banana plant density accounted for 15% of the canopy or higher.

Intercropping a mix of species that can provide more economic benefits to farmers and maximize biodiversity would be a win-win situation (Leakey & Tchondjeu, 2001). This could be achieved by planting vulnerable or endangered forest species along with some alternative crops that can complement cacao production (Franzen and Borgehoff Mulder, 2007).

Worldwide, numerous crops have been successfully grown with cacao, among them coconut (*Cocos nucifera*) as an overstorey (Liyanage et al., 1985; Ramadasan et al., 1978), examples of polycultures with coffee (*Coffea arabica/robusta*), chilies (*Capsicum sp*), ginger (Zin*giber officinalis*), turmeric (*Curcuma longa*) and black pepper (*Piper nigrum*) are also common (Liyanage et al., 1985). Others mention economic tree species like oil palm (*Elaeis guineensis*) (Amoah et al., 1995), and rubber (*Hevea brasiliensis*) (Egbe and Adenikinju, 1990), and even other spices such as cinammon (*Cinnamomum zeylanicum*), cloves (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*) (Liyanage et al., 1985).

Rambutan (*Nephelium lappaceum*) and passion fruit (*Passiflora edulis*), when combined with quality hardwood plantings, were reported to increase incomes up to $2,500/ha per year (Sanchez et al., 2002; Sanchez et al., 2009). Vanilla (*Vanilla planifolia*) has been noted to have premiums of up to 100% when grown organically (Gibbon et al., 2009). As they have been grown in the humid zones of Honduras, and in the wet and intermediate wet zones of Indonesia, all these alternative crops may be adaptable to the climate in Bocas del Toro.

Without hampering the food security base that these polycultures provide, planting of additional trees, shrubs and other crops of economic value could promote more stable incomes and help families achieve an improved "food-and-cash-crop" diversified production and livelihood strategy (Tscharntke et al., 2011). Smallholders could undertake an adaptive growth strategy to increase their productive potential (Coelli & Fleming, 2003), combining more cash and subsistence cropping in a gradual manner, while maintaining the use of household labour so as not to raise costs.

4. Other studies that focused on farming households that run mixed food and cash crop production systems have highlighted the importance of literacy and education level of the household head to farm management efficiency (Amos, 2007) and that higher education

levels can also mean more opportunities for off-farm employment (Fleming & Lummani, 2001; Coelli & Fleming, 2003). They have also emphasized the benefits of having large families to increase efficiency of harvest (Amos, 2007).

This study found that in Bocas del Toro families are fairly large, averaging 7 members, that may represent a stable labour pool; also that over 70% of the population is literate and has done some schooling. These combined features are a good starting point and open the possibility to spark new interest in young cacao growers, especially those who already attend technical high schools in the area (one is located near Changuinola, and one in Chiriquí Grande) and are specializing in cacao and agricultural production.

Since the vast majority of population (70%) under study was younger than 30, and these will become the new heads in their own time, learning about successful enterprises of local cacao smallholders could draw them to take over the challenge, to get back out in the cacao plots and actively direct the future of income generation through diversified production strategies. Learning from and adapting these locally successful projects like aquaculture, agroecotourism, and quality finished product sales to their own conditions would necessarily trigger the creative, entrepreneurial and trade skills of this younger, educated crowd, and finally help develop the valuable human capital in a province where the lack of job opportunities keeps over 50% of the total population under the poverty line.

5. It is clear that cacao AFS are complex and densely forested agricultural systems. This high quality timber resource presents two main opportunities to improve income generation at the household level or even at the community level. One would be the recognition of the importance of this resource as a biodiversity and watershed conservation mechanism in an era where climate change has become inevitable and reduction of emissions has then become ultimately important and necessary. A communal plan to request participation in the United Nations REDD+ Programme (http://www.un-redd.org) or in FAO's Payment for Ecosystem Services from Agricultural Landscapes (http://www.fao.org/es/esa/pesal/index.html) would definitely improve the net worth of the massive areas under this kind of land use, and help ensure that livelihoods are positively impacted by the protection of a naturally biodiverse and yet highly productive buffer zone.

Another possibility would be to carry out a communal forest management plan so as to lower the individual costs of tree harvesting and transportation, this should of course be overseen by experienced local forestry technicians that can ensure sustainable harvesting rates. An organized group of experienced sawyers could set up their portable mills and assist in creating a market of finished boards to be sold locally or to urban interested parties. This sustainable timber market should be based on the exploitation of a rapid growth, uncompromised timber species such as *C. alliodora*, and overseen by the National Environmental Authority (ANAM). A simply built multipurpose office could serve as the community forestry headquarters and as a warehouse to keep sustainable timber boards for sale. Of course this initiative cannot be carried in those areas under the Ngöbe-Buglé Comarca law, in which timber exploitation and sales are forbidden.

5. CONCLUSION

Throughout this study the environmental, social and economic aspects of cacao AFS were studied in as much detail as possible in an effort to create a holistic understanding of the agricultural systems managed by small-scale cacao producers in Bocas del Toro.

Cacao AFS are floristically complex and diverse, they boast a Shannon's Index of 1.94 and present a total of 139 species in the canopy. Average stocking of non-crop trees is 173 ha^{-1} of which the vast majority is timber trees (68%). Cacao AFS hold high quality timber volumes of $14.6m^3\ ha^{-1}$, where the overall dominant species is *Cordia alliodora*.

The economic importance of cacao AFS is difficult to determine because the majority of production goes towards household consumption (57%) and not sales (43%). Also, the biggest share of incomes (52%) in the area comes from government pensions and off-farm work, secondly (39%) from alternate farming activities, and thirdly (19%) from cacao AFS. This study confirms that the first and foremost purpose of these traditional polyculture systems is ensuring family food security and not cash generation; cacao is the only exclusive cash crop while other important products like banana, peach palm and tubers are consumed on a daily basis and are harvested in much greater volumes. Because of this, Family Benefit per hectare is 3.8 times larger than Net Cash Flow per hectare.

Assessment of biophysical and socio-economic variables links highest biodiversity and complexity of AFS canopies to highest productivity and profitability. Management techniques of these highly successful, synergistic small farms should be studied in more detail.

Operational changes to the current cacao AFS are proposed to improve the overall economic well being of smallholders. Cacao AFS have a much higher value per area in terms of food provision than cash generation, and are therefore tightly linked to Food Security; but in order to reduce the poverty levels of the population of concern, the general income levels must be improved. Six recommendations for further consideration and revision with the smallholders for further action and research are:

- Communal harvesting and marketing efforts
- Improved management and fertilization of cacao plantations
- Intercropping of cacao SAF with more valuable fruits and spices
- Empowering the young workforce to improve the technical efficiency of current agroforests
- Obtaining monetary recognition through REDD+ or PESLA programmes
- Creating Community Forestry initiatives to market sustainably harvested timber

Even though cacao AFS may not be the most important generator of income among the smallholder's full portfolio, they still make up a very important part of the culture and tradition of Bocatorean cacao grower families. They provide cash and food for indigenous families living below the extreme poverty line, in an area where acidic, nutrient deficient soils and harsh topography do not allow for most types of agricultural production; they support forest-dependent biodiversity by helping conserve a variety of endangered trees and allow for the integration of biodiversity conservation and livelihoods improvement.

ANNEX 1
The PCC Network: Permanent Sample Plots

Farming System Number	Community	Geographic/Political Zone	Area (ha)
P01	La Gloria	Changuinola District	3.8
P02	La Gloria	Changuinola District	0.9
P03	La Gloria	Changuinola District	2.1
P04	La Gloria	Changuinola District	2.7
P05	La Gloria	Changuinola District	0.3
P06	La Gloria	Changuinola District	3.9
P07	La Gloria	Changuinola District	2.7
P08	La Gloria	Changuinola District	1.5
P09	Rio Oeste Arriba	Changuinola District	0.8
P10	Rio Oeste Arriba	Changuinola District	0.3
P11	Rio Oeste Arriba	Changuinola District	2.9
P12	Rio Oeste Arriba	Changuinola District	3.5
P13	Rio Oeste Arriba	Changuinola District	2.0
P14	Palo Seco	Bosque Protector Palo Seco	1.1
P15	Palo Seco	Bosque Protector Palo Seco	0.4

P16	Palo Seco	Bosque Protector Palo Seco	1.5
P17	Palo Seco	Bosque Protector Palo Seco	1.9
P18	Palo Seco	Bosque Protector Palo Seco	1.0
P19	Palo Seco	Bosque Protector Palo Seco	2.6
P20	Palo Seco	Bosque Protector Palo Seco	1.3
P21	Palo Seco	Bosque Protector Palo Seco	1.9
P22	Quebrada Pluma	Bosque Protector Palo Seco	0.6
P23	Quebrada Pluma	Bosque Protector Palo Seco	0.5
P24	Quebrada Pluma	Bosque Protector Palo Seco	1.3
P25	Quebrada Pluma	Bosque Protector Palo Seco	0.3
P26	Quebrada Pluma	Bosque Protector Palo Seco	0.5
P27	Cilico Creek	Comarca Ngäbe-Buglé	1.3
P28	Cilico Creek	Comarca Ngäbe-Buglé	1.6
P29	Cilico Creek	Comarca Ngäbe-Buglé	4.7
P30	Cilico Creek	Comarca Ngäbe-Buglé	2.0
P31	Cilico Creek	Comarca Ngäbe-Buglé	3.6
P32	Cilico Creek	Comarca Ngäbe-Buglé	4.5
P33	Cilico Creek	Comarca Ngäbe-Buglé	1.8
P34	Cilico Creek	Comarca Ngäbe-Buglé	2.1
P35	Norteño	Comarca Ngäbe-Buglé	0.6
P36	Norteño	Comarca Ngäbe-Buglé	0.7
P37	Norteño	Comarca Ngäbe-Buglé	9.8
P39	Santa Marta	Comarca Ngäbe-Buglé	1.0
P40	Santa Marta	Comarca Ngäbe-Buglé	2.4

ANNEX 2

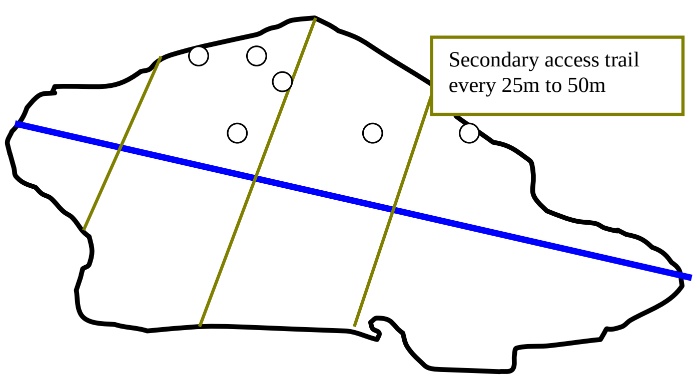
Protocol for Field Inventory

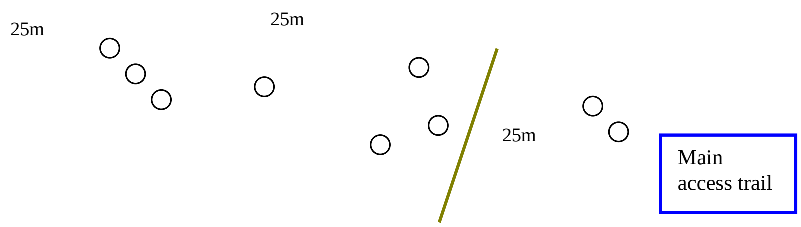
1. All households were noticed in advance so that the manager or the owner could accompany the inventory team in the field, and whoever else would like to join.

2. Field crew consisted of the student, a local guide and a forestry technician.

3. Cacao AFS were identified and delimited with the help of maps and the local guide.

4. A main access trail was established across the longest part of the plot, secondary trails were established perpendicularly from the main trail to the perimeter of the plot at a distance of 25-50m. Flagging tape was used as necessary to mark these subplots. All trees within these subplots and those in the perimeter were inventoried.





5. Species identification: All trees tallied were identified with their common name by the local guide, then OFI/CATIE (2003) and Gentry (1993) were consulted for scientfic names. Any specimen found that could not be identified on site was photographed and taken to botany experts. Main uses and products from each species were annotated as well.

6. Total Census: All trees with diameter >5cm were inventoried, DBH at 1.3m was registered. For timber trees with diameter >30cm, commercial volume was calculated in the field by the technician.

7. Tree stumps: for all tree stumps found, diameter and height were measured, approximate year of felling, species and end use were determined with the help of the property owner/manager or another family member.

8. Fruit trees: any fruit bearing trees, palms and *Musa spp*. encountered were tallied.

9. Service trees: all other trees encountered for which local people have a particular and/or well-known use (i.e. as lumber, construction material, source of resins, medicinal properties, etc) were tallied.

ANNEX 3

Field Inventory Formularies

FORMULARY 1: Most Important Plant Resources

Farming System #:
Date:
Use*: T=timber, F=fruit, M=medicinal, H=handicrafts, etc

Women participating:

Men participating:

WOMEN			MEN		
Species	Use*	Priority	Species	Use*	Priority

FORMULARY 2: Agroforestry Inventory

Farming System #: Date:				Use*: T=timber, F=fruit, M=medicinal, H=handicrafts, etc			
Tree no.	Common name	circ (cm)	Use *	Tree no.	Common name	circ (cm)	Use *

FORMULARY 3: Volume of timber trees >30cm dbh

Farming System #:					Date:				
Tree no.	Common name	Circ (cm)	Hc (m)	Vol . (bdft)	Tree no.	Common name	Circ (cm)	Hc (m)	Vol . (bdft)

FORMULARY 4: Stump Inventory

Farming System #:					Date:		
Stump no.	Common name	Circ (cm)	Ht (cm)	Year cut	Volume (bdft)	Sold or kept?	Sale price ($)

FORMULARY 5: Musaceae Inventory

Farming System #: Date:		*Type: B=banana, P=plantain **Variety: GM=gros michel, Pr=primitivo
Type*	Variety**	No. Individuals

FORMULARY 6: Planted Species

Farming System #:	Date:	
Common name	Year planted	Quantity

ANNEX 4
Household Survey Formulary

Farming System #: ____
Date: ________

1. FAMILY INFORMATION
1.1 Interviewee:____

1.2 Family make-up and schedules

Name	Relation ship	Age	Gender	School Level	On farm Workng hours per week	Off farm working weeks per year	Off farm working hours per week	$ per man-day

School level Few 0, Primary 1, Secondary. 2, University/College. 3

1.3 Hours worked per day: _____

2. FARM SYSTEM INFORMATION
2.1 Farm map: drawn with all land uses, crops, area, etc
2.2 Total farm size (ha):__________ Years of ownership: __________
2.3 What crops are grown and how much do you harvest?

Crop/ Land Use	Area (ha)	Products	Harvest months	Harvest frequency (days/weeks)	Annual harvest (note units)	Sale price

2.4 Name any other income sources

Income source	Quantity/year	Unit price
Handcrafts		
Remittances from family		
Pension		
Food sales		
Other:		

3. CACAO SAF PRODUCTION: QUANTITIES AND COSTS

3.1 Production of fruits and non-timber

Product	Harvest months	Frequency (days or weeks)	Annual production (note units)	Quantity consumed by family	Quantity used for animal feed	Cantidad para venta por año

3.2 Sale prices and costs per product

Product	Cantidad para venta por año	Precio de venta por unidad	Dónde vende?	Medio de transporte pagado utilizado	Costo transporte utilizado por unidad

3.3 How far a walk is the cacao agroforestry system from your home?

4. MAINTENANCE ACTIVITIES AND HARVEST COSTS

4.1 Labour investment and maintenance costs of cacao agroforestry system (cacao, fruits, timber, others)

		Timing and labour input			Labour pool type		Gender of labourers		Costos por contratos	
CROP	**Activity**	Month	Repetitions per year	Man-days per activity	Family labour	Hired labour	M	F	Costo por jornal	Costo por contrato
CACAO	Maintenance pruning/ shoot removal									
	Brush clearing									
	Pruning for disease									
	Trail maintenance/ drainage									
	Harvest									
	Fermenting									
	Drying									
OTHERS										

4.2 Input use and associated costs

Input type	Price per unit	Quantity used per year

5. TIMBER COMMERCIALIZATION COSTS

5.1 How many boards (12 feet length x 1 foot wide X 1 inch deep) can be carried in one day from the cacao AFS to the house by one person? _________

5.2 Where have you sold timber? ____ On farm _____ Off farm
Transport cost to location per unit of volume ___________

Note:

- Wood volume output and prices according to species have been annotated during stump inventory
- All smallholders hire local fellers and sawyers. The cost of hire plus use of equipment is $0.10 per board foot

6. COMMUNITY SERVICES AVAILABLE

Service	
Primary School	
Health Centre	
Input Market	
Produce Market	
Running water	
Electricity	
Payphone	

ANNEX 5
Economic Analysis

DEFINITIONS AND SPECIAL CONSIDERATIONS

The analysis followed the methodology proposed by Imbach (CATIE, 1987) but a few changes in definitions and formulae needed to be made to work with the obtained datasets:

Total Gross Income was calculated at current market prices reported in each community. Because prices vary according to difficulty of production of a particular product or closeness to a given market, these subtle differences give a better estimate for each household situation.

Total Costs by definition these include Fixed Costs and Variable Costs (CATIE, 1987).

Fixed Costs are those that must be paid for whether the farm is productive or not. An example can be the cost of renting land or machinery to produce a specific good. Cacao production is rudimentary in Bocas del Toro: there is no use of electricity, no roads, no real permanent infrastructure to ferment or dry cacao beans. Some producers have kilns made of wood and plastic, which were donated by the government, but in this case, donations are not counted as fixed costs (CATIE 1987) because the producers didn't pay for them, so their initial value (from which depreciation would derive) is considered to be zero. Other inputs like machetes are not used exclusively in the cacao AFS, so they were not counted as Fixed Costs. These are considered relatively small investments when compared to the total costs, and the outcome of the analysis will not vary greatly if they are not included. For the purpose of this study, the total value of Fixed Costs is deemed as zero.

Variable Costs correspond to Direct Costs (CATIE, 1987), those costs or investments that are clearly related to production in one of the farm's components. In this study, our component of interest is the Cacao AFS. These Direct Costs are the amount of dollars spent in the production of goods and may consist of seeds, seedlings, fertilizer, pesticides or other agricultural inputs and labour. In this study, Direct Costs in Cash mainly consist of contracted labour since there is no use of chemicals, fertilizers or other inputs. The cost of labour depends on the community or the area where the farm is, on the area covered by the Cacao AFS, on the difficulty of the job if the area hasn't been well maintained, on the number of workers needed to do the job. For these reasons I used the value in Dollars of each particular contract as reported by each producer to calculate direct production/maintenance costs.

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Original Equations:

a. Net Income = the Dollar value calculated for the Net Cash Flow plus the Dollar value of quantifiable changes in Inventory (I) minus all

Depreciations (D), minus the payment of interest on credits (IC) and minus the dollar value of all the family labour invested (VFL)

NI = NCF + I – (D+IC+VFL)

b. Family Benefit = Net Cash Flow plus the Dollar value of any changes in Inventory plus the Dollar value of all the goods that the family consumes from the cacao AFS. (VFC=value of family consumption)

FB= NCF+ I + VFC

I = Changes in the Inventory: This refers to the increase or decrease of products that can be kept in stock (grains, forage, etc) to the investments in repairing or maintaining machinery or buildings, buying new land, or to the change in number of heads of cattle, pigs or poultry (CATIE, 1987). However, because animals are not exclusively kept in the cacao AFS, these weren't counted in. Also because of high humidity conditions, it is customary to sell or consume all products from the cacao plots as soon as they are ready, so there are no big stockpiles of tubers or fruit. All improvements coming from subsidies cannot be counted in (i.e. the plastic kilns), so the value for I will therefore be zero.

D= Depreciations: this measures loss of value on permanent buildings, machinery, and equipment used in the cacao AFS. There is no use of machinery or buildings, the only tool used is the machete, but these are not used exclusively in the cacao AFS, so I didn't take any depreciations on these. This D value will also be zero.

IC= payment of Interest on Credits: my study deals with a group of people that don't have access to or have very little access to Credit. The families in this study didn't report having to pay back any lines of credit. So the value for IC will also be zero.

VFL= value of Family Labour: all the work invested by the different family members in the cacao AFS was considered equivalent. Following Brown (1981), I didn't use any conversion factors to estimate productivity in terms of man-workday vs. woman-workday (Yang, 1965). The accepted dollar value per workday was reported by and crosschecked with all surveyed producers; it has a value of $8 per day. All work hours for men, women and young family members was recorded for all the different activities that take place in the cacao AFS. However, I didn't count in the labour of children less than 14 years of age.

Value of Family Consumption: takes into account all the timber, fruit and tubers harvested from the cacao AFS to be utilized at home, eaten at home or fed to farmyard animals. These are converted to dollar value according to the sale price given by each person interviewed.

A note on Value of land and Land tenure

There are different regulations for land tenure inside and outside the Ngäbe-Bugle Indigenous Comarca. Inside their territory, land is owned by families but is not really sold in the market, no outsiders can have access to this land no matter what price they offer; and it was not sold to begin with, but granted by the government. Also there are restrictions as

to renting land to others to work on, one can offer or “lend” the land during a specific period of time, but will not receive any cash for this action (Pers. comm. Aguilar, 2011).
Outside the Comarca, land was granted, not sold, to families that needed to settle in new territories in the 1960s and 1970s. It is socially inacceptable to sell your land to others simply because land is your most important possession. As families grow, this resource is split and granted to the sons and daughters, it becomes scarce. It is not considered wise to sell your land because it is the means of survival for your family, your children, your grandchildren and all future generations and it would be unwise to put all that in jeopardy (Pers. Comm. Abrego, 2010).

ANNEX 6
Multivariate Statistical Analysis

Table 1. List of selected 63 socio-economic and biophysical variables for initial Principal Components Analysis of 37 cacao agroforestry systems in Bocas del Toro

area (m2)	# working males
species richness	# working females
Shannon's Index (H')	# total family workers
Simpson's Inverse Index (1/D)	
	workdays invested per year
Annual Timber Harvest Rate (m3/ha)	FB/workday ($/day)
	NCF/workday ($/day)
Basal Area Total (m2/AFS)	Basal Area Total (m2/ha)
Basal Area >30cm dbh (m2/AFS)	Basal Area >30cm dbh (m2/ha)
Timber Volume >30cm dbh (m3/AFS)	Timber Volume >30cm dbh (m3/ha)
cacao kgs/AFS (dry beans)	cacao kgs/ha (dry beans)
# cacao trees/AFS	# cacao trees/ha
# woody perennials/AFS	# woody perennials/ha
# fruit trees/AFS	# fruit trees/ha
# timber trees/AFS	# timber trees/ha
# banana plants/AFS	# banana plants/ha
# plantain plants/AFS	# plantain plants/ha
Net Cash Flow ($/AFS)	Net Cash Flow ($/ha)
NCF cacao ($/AFS)	NCF cacao ($/ha)
NCF banana ($/AFS)	NCF banana ($/ha)
NCF peach palm ($/AFS)	NCF peach palm ($/ha)
NCF plantain ($/AFS)	NCF plantain ($/ha)

NCF timber ($/AFS)	NCF timber ($/ha)
NCF tuber ($/AFS)	NCF tuber ($/ha)
NCF fruit ($/AFS)	NCF fruit ($/ha)
Family Benefit ($/AFS)	Family Benefit ($/ha)
FB cacao ($/AFS)	FB cacao ($/ha)
FB banana ($/AFS)	FB banana ($/ha)
FB peach palm ($/AFS)	FB peach palm ($/ha)
FB plantain ($/AFS)	FB plantain ($/ha)
FB timber ($/AFS)	FB timber ($/ha)
FB tuber ($/AFS)	FB tuber ($/ha)
FB fruit ($/AFS)	FB fruit ($/ha)

Table 2. Seleted 38 variables having maximum correlation with 10 first Principal Components of PCA for 37 cacao agroforestry systems in Bocas del Toro.

Variable	r^2	p value	Variable	r^2	p value
Area (ha)	0.918	0.0010	NCF cacao ha^{-1} ($)	0.712	0.0010
Basal area >30cm dbh (m^2)	0.572	0.0010	NCF fruit ($)	0.283	0.0360
B. area >30cm dbh (m^2 ha^{-1})	0.249	0.0140	NCF fruit ha^{-1}($)	0.262	0.0360
Basal area (m^2)	0.689	0.0010	NCF ha^{-1} ($)	0.848	0.0010
Basal area (m^2 ha^{-1})	0.232	0.0080	NCF peach palm ($)	0.207	0.0130
Family Benefit ($)	0.599	0.0010	NCF timber($)	0.467	0.0020
FB banana ($)	0.226	0.0130	NCF timber ha^{-1} ($)	0.552	0.0010
FB banana ha^{-1}($)	0.477	0.0010	NCF $workday^{-1}$ ($)	0.741	0.0010
FB cacao ($)	0.670	0.0010	Net Cash Flow ($)	0.915	0.0010
FB cacao ha^{-1}($)	0.756	0.0010	Total banana plants	0.351	0.0010
FB fruit ($)	0.283	0.0310	Total cacao plants	0.815	0.0010
FB fruit ha^{-1}($)	0.194	0.0400	Total fruit trees	0.381	0.0020
FB ha^{-1}($)	0.743	0.0010	Total timber trees	0.414	0.0010
FB peach palm ha^{-1} ($)	0.212	0.0320	Total trees	0.466	0.0010
FB plantain ha^{-1}($)	0.318	0.0060	Total trees ha^{-1}	0.168	0.0380
FB $workday^{-1}$ ($)	0.469	0.0010	Volume >30cm dbh(m^3)	0.617	0.0010
Fruit trees ha^{-1}	0.308	0.0040	Vol >30cm dbh (m^3 ha^{-1})	0.384	0.0020
NCF banana ($)	0.230	0.0220	Workdays yr^{-1}	0.432	0.0010
NCF cacao ($)	0.631	0.0010	Working males	0.312	0.0040

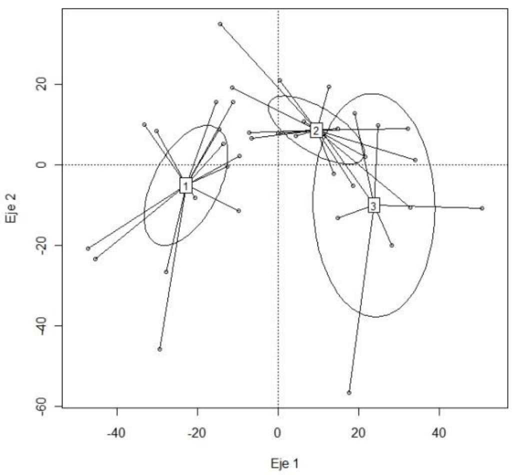

Figure 1. Ordination of cacao agroforestry systems into three main groups based on 38 variables (biophysical and socioeconomic). The ellipses represent the confidence interval at 95% for each group (r^2= 0.616, p=0.0009).

Table 3. ANOVA results: Significant variables in differentiation of Farming System Groups 1, 2 and 3. (Rank transformation values: mean ± standard error, capital letters note difference between groups).

Variable	Group 1		Group 2		Group 3		F	p value
Workdays yr^{-1}	27.21 ±2.33	B	15.53 ±2.18	A	10.50 ±3.29	A	10.85	0.0002
Area (ha)	29.61 ±1.87	B	12.88 ±1.75	A	11.79 ±2.65	A	25.84	<0.0001
Basal area m^2	30.00 ±1.76	B	12.97 ±1.64	A	10.79 ±2.48	A	31.83	<0.0001
Basal area >30cm dbh m^2	28.64 ±2.08	B	14.16 ±1.95	A	10.79 ±2.95	A	17.67	<0.0001
Volume >30cm dbh m3	28.07 ±2.22	B	14.19 ±2.07	A	11.86 ±3.13	A	13.67	<0.0001
Total cacao plants	29.64 ±1.87	B	12.63 ±1.75	A	12.29 ±2.65	A	26.03	<0.0001
Total trees	29.86 ±1.76	A	11.09 ±1.65	A	15.36 ±2.49	B	31.66	<0.0001
Total fruit trees	25.07 ±2.4	B	11.78 ±2.24	A	23.36 ±3.39	B	9.27	0.0006
Total timber trees	28.25 ±2.18	B	12.75 ±2.04	A	14.79 ±3.09	A	14.59	<0.0001
Total banana plants	27.93 ±2.22	B	14.75 ±2.08	A	10.86 ±3.14	A	13.53	<0.0001
Net Cash Flow	25.57 ±2.29	B	11.25 ±2.15	A	23.57 ±3.24	B	11.61	0.0001
FB cacao	25.43 ±2.44	B	12.19 ±2.29	A	21.71 ±3.46	B	8.2	0.0012
NCF cacao	25.21 ±2.45	B	12.16 ±2.29	A	22.21 ±3.46	B	8.11	0.0013
FB $workday^{-1}$	14.82 ±2.51	A	17.56 ±2.34	A	30.64 ±3.54	B	6.98	0.0029
NCF $workday^{-1}$	21.64 ±2.27	B	11.88 ±2.13	A	30.00 ±3.21	C	12.16	0.0001
Fruit trees ha^{-1}	14.00 ±2.45	A	18.13 ±2.29	A	31.00 ±3.46	B	8.18	0.0013
NCF ha^{-1}	18.50 ±2.52	A	14.56 ±2.36	A	30.14 ±3.57	B	6.66	0.0036
FB ha^{-1}	10.79 ±2.14	A	20.88 ±2	B	31.14 ±3.03	C	15.82	<0.0001
FB cacao ha^{-1}	17.07 ±2.77	A	17.19 ±2.6	A	27.00 ±3.92	B	2.56	0.0919
FB banana ha^{-1}	10.93 ±2.35	A	22.38 ±2.2	B	27.43 ±3.32	B	10.3	0.0003
FB peach palm ha^{-1}	13.79 ±2.35	A	17.88 ±2.2	A	32.00 ±3.33	B	10.22	0.0003
FB fruit ha^{-1}	16.64 ±2.67	A	17.06 ±2.49	A	28.14 ±3.77	B	3.63	0.0372
NCF timber ha^{-1}	22.57 ±2.57	B	14.13 ±2.4	A	23.00 ±3.63	B	3.63	0.0372

ANNEX 7

Species found in 39 cacao agroforestry systems in Bocas del Toro. (Use Type refers to H= Handcraft material, C= Construction materials (non-wood), LF= Used as live fences, F= Fruit tree, FW= Firewood source, T= Timber, M= Medicinal properties, RP= Riparian protection species, N/A= No use identified).

Common name	Use Type	Latin name	Family	Planted by managers
Achiote	H	Bixa orellana	Bixaceae	X
Ackee	F	Blighia sapida	Sapindaceae	X
Achiotillo	M	Vismia macrophylla	Clusiaceae	
Aguacate	F	Persea americana	Lauraceae	X
Aguacate de montaña	FW	Persea schiedeana	Lauraceae	
Alcanfor	M	Protium costarricense	Burseraceae	
Alcarreto	T	Aspidosperma spp.	Apocynaceae	
Alfajía	T	Trichilia pleeana	Meliaceae	
Almendro	T	Dipterix panamensis	Fabaceae-Pap.	X
Amarillo	T	Terminalia amazonia	Combretaceae	
Anón	F	Guatteria aeruginosa	Annonaceae	X
Anonillo	T	Rollinia pittieri	Annonaceae	
Arazá	F	Eugenia stipitata	Myrtaceae	X
Arenillo	T	Andira inermis	Fabaceae-Pap.	
Arraiján	T	Weinmannia pinnata	Cunoniaceae	
Balso	T	Ochroma pyramidale	Malvaceae	
Bambito	T	Ocotea glaucosericea	Lauraceae	
Bambú	C	Bambusa vulgaris	Poaceae	
Bateo	T	Carapa guianensis	Meliaceae	X
Berbá	T	Brosimum alicastrum	Moraceae	
Berbá macho	T	Brosimum guianense	Moraceae	
Biribá	F	Rollinia deliciosa	Annonaceae	X
Bongo	H	Ceiba pentandra	Bombacaceae	
Borojó	F	Borojoa patinoi	Rubiaceae	X
Cacho de venado	FW	Xylosima panamensis	Salicaceae	
Cacique	T	?	Moraceae	X
Cacique blanco	T	?	Moraceae	X
Caimito	F	Chrysophyllum cainito	Sapotaceae	
Calabacito	H	Amphitecna latifolia	Bignoniaceae	
Café	F	Coffea arabica	Rubiaceae	X
Cañafístula	T	Cassia moschata	Fabaceae-Caes.	X
Caoba	T	Swietenia macrophylla	Meliaceae	X
Caraña	M	Trattinnickia aspera	Burseraceae	
Carambola	F	Averrhoa carambola	Oxalidaceae	X
Caucho	T	Castilla elastica	Moraceae	
Cedro	T	Cedrela odorata	Meliaceae	X
Cedro macho	T	Guarea guidonia	Meliaceae	
Cedro maría	T	Callophylum brasiliense	Clusiaceae	X
Ceibo	H	Hura crepitans	Euphorbiaceae	
Cerillo	T	Simphonia globulifera	Clusiaceae	X
Chonta	C	Exorrhiza durissima	Arecaceae	X
Chuchupate	T	Guarea grandifolia	Meliaceae	

Cigarrillo	T	Schizolobium parahyba	Fabaceae-Caes.	
Coco	F	Cocos nucifera	Arecaceae	X
Cocobolo	T	Dalbergia retusa	Fabaceae-Pap.	
Cola de pava	FW	Trichilia martiana	Meliaceae	
Colpachí	LF	Croton schiedeanus	Euphorbiaceae	
Cortezo	T	Apeiba aspera	Tiliaceae	
Criollo	T	Minquartia guianensis	Olacaceae	X
Cuajá	T	Vitex cooperi	Verbenaceae	
Espabel	T	Anacardium excelsum	Anacardiaceae	X
Ficus estrangulador	N/A	Ficus spp.	Moraceae	
Frijolillo	FW	Lonchocarpus heptaphyllus	Fabaceae-Pap.	
Fruta de pan	F	Artocarpus altilis	Moraceae	X
Gallote	T	Hernandia stenura	Hernandiaceae	
Gavilán	T	Pseudosamanea guachapele	Fabaceae-Mim.	
Golondrino	T	Aspidosperma megalocarpum	Apocynaceae	
Goma	LF	Cordia dentata	Boraginaceae	
Guaba de la montaña	FW	Inga spp.	Fabaceae-Mim.	
Guaba machete	F	Inga jinicuil	Fabaceae-Mim.	X
Guaba rabo de mono	FW	Inga edulis	Fabaceae-Mim.	X
Guácimo	FW	Guazuma ulmifolia	Malvaceae	
Guácimo blanco	FW	Guazuma spp.	Malvaceae	
Guanábana	F	Annona muricata	Annonaceae	X
Guanacaste	T	Enterolobium cyclocarpum	Fabaceae-Mim.	X
Guarumo	FW	Cecropia spp.	Cecropiaceae	
Guarumo de montaña	T	?	?	
Guayaba	F	Psidium guajava	Myrtaceae	X
Guayabón	T	Terminalia oblonga	Combretaceae	
Guayacán	T	Guaiacum sanctum	Zygophyllaceae	X
Higuerón	T	Ficus spp.	Moraceae	
Hombre grande	M	Quassia amara	Simaroubaceae	X
Huevos de caballo	M	Stemmadenia grandiflora	Apocynaceae	
Huevos de chumico	T	Macoubea spp.	Apocynaceae	
Indio desnudo	T	Bursera simaruba	Burseraceae	
Jaboncillo	LF	Sapindus saponaria	Sapindaceae	
Jackfruit	F	Artocarpus heterophyllus	Moraceae	X
Jagua	T	Genipa americana	Rubiaceae	
Jagua de montaña	T	?	?	
Jícaro	H	Crescentia cujete	Bignoniaceae	X
Jira	C	Socratea exorrhiza	Arecaceae	X
Jobo	F	Spondias mombin	Anacardiaceae	
Laurel	T	Cordia alliodora	Boraginaceae	X
Laurel negro	T	Cordia megalantha	Boraginaceae	
Limón	F	Citrus limonum	Rutaceae	X
Limón mandarina	F	Citrus spp.	Rutaceae	X
Limón ácido	F	Citrus spp.	Rutaceae	X
Madroño	F	Garcinia madruno	Clusiaceae	
Majagua	T	Poulsenia armata	Moraceae	
Majaguillo	N/A	Heliocarpus americanus	Malvaceae	
Mameicillo	T	?	Sapotaceae	
Mamey	F	Mammea gigantean	Clusiaceae	

Mamey de montaña	T	Chrysophyllum colombianum	Sapotaceae	
Mamón chino	F	Nephelium lappaceum	Sapindaceae	X
Mandarina	F	Citrus reticulata	Rutaceae	X
Mango	F	Mangifera indica	Anacardiaceae	X
Marañón	F	Syzygium malaccense	Myrtaceae	X
Matarratón	LF	Gliricidia sepium	Fabaceae-Pap.	X
Mayo blanco	T	Vochysia guatemalensis	Vochysiaceae	X
Mayo colorado	T	Vochysia ferruginea	Vochysiaceae	
Membrillo	F	Gustavia superba	Lecythidaceae	X
Membrillo de montaña	T	Cespedesia spathulata	Ochnaceae	
Miguelario	T	Virola spp.	Myristicaceae	X
Miguelario de hoja fina	T	Virola spp.	Myristicaceae	
Molenillo	T	Quararibea astrolepis	Bombacaceae	
Nance	F	Byrsonima crassifolia	Malpighiaceae	X
Naranja	F	Citrus sinensis	Rutaceae	X
Naranjita	T	Swartzia simplex	Fabaceae-Pap.	
Nigüito	T	?	Boraginaceae	
Níspero	T	Manilkara chicle	Sapotaceae	X
Noni	M	Morinda citrifolia	Rubiaceae	X
Nuez moscada	F	Myristica spp.	Myristicaceae	X
Olivo	T	Simarouba amara	Simaroubaceae	
Oreja de mula	FW	Miconia argentea	Melastomataceae	
Palo de agua	FW	?	?	
Palo de pataste	F	Theobroma bicolor	Sterculiaceae	
Palo santo	LF	Erythrina berteroana	Fabaceae-Pap.	X
Panamá	T	Sterculia apetala	Malvaceae	
Penca	C	Welfia regia	Arecaceae	X
Piña	F	Ananas comosus	Bromeliaceae	X
Pita	H	Aechmea magdalenae	Bromeliaceae	
Pixbae	F	Bactris gasipaes	Arecaceae	X
Quira	T	Platymischium polystachium	Fabaceae-Pap.	
Roble	T	Tabebuia rosea	Bignoniaceae	X
Sangrillo	T	Pterocarpus spp.	Fabaceae-Pap.	
Sangrillo con hoja de Alfajía	N/A	?	Fabaceae-Pap.	
Sigua	T	Guarea glabra	Meliaceae	
Sotacaballo	RP	Pithecellobium longifolium	Fabaceae-Pap.	X
Tachuelo	T	Zantoxylum spp.	Rutaceae	
Tapacarga o Escoba	H	Carludovica palmata	Cyclanthaceae	X
Teca	T	Tectona grandis	Lamiaceae	X
Toronja	F	Citrus paradisi	Rutaceae	
Tulipán africano	N/A	Spathodea campanulata	Bignoniaceae	
Tunú	N/A	?	?	
Yaya	T	Unonopsis spp.	Annonaceae	
Yuplón	F	Spondias cytherea	Anacardiaceae	X
Zapatero	T	Hyeronima alchorneoides	Euphorbaceae	X
Zapote	F	Pouteria sapota	Sapotaceae	X
Zorro	T	Astronium graveolens	Anacardiaceae	

ANNEX 8

Classification of Timber Species and their Marketability Status

HIGHLY VALUABLE

Common name	Latin name
Amargo amargo	*Vatairea sp*
Caoba	*Swietenia macrophylla*
Cedro amargo	*Cedrela odorata*
Cedro cebolla	*Cederla tonduzii*
Cedro espino	*Bombacopsis quinata*
Cocobolo	*Dalbergia retusa*
Guayacán	*Tabebuia guayacan*
Laurel	*Cordia alliodora*
María	*Calophyllum brasilensis*
Nazareno	*Peltogyne purpurea*
Pino amarillo	*Pithecelobium manguense*
Quira	*Platymiscium pinnatum*
Roble	*Tabebuia pen*
Cedro bateo	*Carapa sp*

POTENTIALLY COMMERCIAL

Common name	Latin name
Amarillo	*Terminalia amazonica*
Amarillo guayaquil	*Centrolobium yavizanum*
Amarillo pepita	*Lafoensia punicifolia*
Ajo	*Cassipourea sp*
Alacarreto	*Aspicosperma megalocarpon*
Alcornoque	*Nora oleifera*
Algarrobo	*Hymenaea courbaril*
Almendro	*Dipteryx panamensis*
Baco	*Magnolia sororum*
Balsa	*Ochroma lagopus*
Bálsamo	*Miroxylon balsamun*
Bambito amarillo	*Ocotea sp*
Bambito rosado	*Ocotea austinli*
Berbá	*Brosimum utile*
Bongo	*Ceiba pentandra*
Cabimo	*Copaifera aromatica*
Cañafístula	*Cassia fistula*
Cativo	*Prioria copaifera*
Cerillo, Cero	*Symphonía globulifera*
Coco	*Lecythis tuyrana*
Corotú	*Enterolobium cyclocarpum*
Cortezo	*Apeaba aspera*
Cuajao	*Vitex cooperi*
Cutarro	*Swartzia panamensis*
Espavé	*Anacardium excelsum*
Frijolillo	*Poeppigia procera*
Guayabillo	*Terminalia lucia*

Guayabo de montaña	*Eugenia sp*
Jobo	*Spondia mombís*
Madroño	*Calycophyllum candissium*
Mamecillo colorado	*Sloanea sp*
Mango	*Manguifera indica*
Mata hombro	*Cornus disciflora*
Mayo blanco, Corozo	*Vochysia hondurensis*
Mayo negro	*Vochysia ferruginea*
Membrillo	*Gustabia sp*
Miguelario	*Virola sp*
Nance	*Byrsoniama crassifolia*
Níspero	*Manilkara achras*
Nuno, Ceibo	*Hura crepitans*
Olivo, Ñipa	*Sapium sp*
Orey	*Camprosperma panamensis*
Panama	*Sterculia apetala*
Pava, Gargorán, Pavo	*Didymopanax morototoni*
Punula	*Quararibea sp*
Sandé	*Brosimum sp*
Sangre	*Pterocarpus officinalis*
Sangrillo negro	*Paramachaerium gruberí*
Sigua	*Nectandra sp*
Tachuelo, Alcabú	*Zanthoxylum sp*
Yaya	*Unonopsis sp*
Zapatero, Plátano, Pilón	*Hieronyma alchorneoides*
Zorro	*Astronium graveolens*

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ANNEX 9

Selected species included in each Product Group

Banana	Only actively harvested banana varieties::
	congo
	cuadrado
	gros michel
	lacatán
	manzana
	primitivo
	sabá
Cacao	All varieties of *Theobroma cacao*
Fruit	Only actively harvested/consumed fruit:
	Ananas comosus
	Annona muricata
	Artocarpus altilis
	Citrus spp. (lemon, orange, tangerine)
	Cocos nucifera
	Eugenia stipitata
	Gustavia superba
	Inga spp.
	Mangifera indica
	Morinda citrifolia
	Persea americana
	Syzygium malaccense
Peach palm	All varieties of *Bactris gasipaes*
Plantain	Only actively harvested plantain varieties:
	cuadrado
	morado
	plátano
Timber	Only actively harvested timber species:
	Cedrela odorata
	Cordia alliodora
	Cordia megalantha
	Hyeronima alchorneoides
	Minquartia guianensis
	Terminalia oblonga
	Virola spp.
Tubers	Only actively harvested tuber species:
	Colocasia esculenta
	Dioscorea spp.
	Manihot esculenta
	Xanthosoma sagittifolium