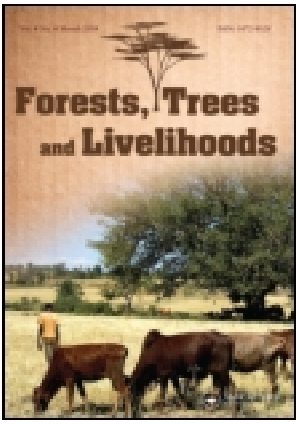

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Successional cocoa agroforests of the Amazon–Orinoco–Guiana shield

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Cocoa was used as a fruit in its native range. Cocoa fruits were harvested from "wild" cocoa stands embedded into the forests growing on the high terraces of the Amazon and Orinoco river systems and in the Guiana shield. "Wild" cocoa stands resulting from human intervention and disturbance of the local forest ecosystem are called sub-spontaneous cocoa stands. We propose that these sub-spontaneous cocoa forests are a new type of cocoa production system that we propose to call "successional cocoa agroforest." This article (1) describes the history of extractive cocoa in the Amazon basin, (2) outlines the possible historic path of domestication and use of cocoa sub-spontaneous stands, (3) specifies the biophysical and cultural processes that determine the creation–destruction–regeneration of the successional cocoa agroforest, (4) proposes a model for the functioning of this cocoa production system, and (5) documents the scarce information available on the changes in both the forest vegetation and biomass, and cocoa population numbers along the course of forest succession. This study shows the need to broaden the popular five classes classification of coffee and cocoa production systems (open sun cultivation, specialized shade, commercial shade, mixed shade, and rustic systems) to include a sixth type, the "successional cocoa agroforest."

Keywords: forest succession; population dynamics; domestication; wild cocoa; human settlements; abandoned cocoa plantations; sub-spontaneous cocoa

Introduction

When Spaniards arrived in America in 1492, cocoa was cultivated (that is to say, planted and tended) from southern Mexico to Venezuela and Colombia (Motamayor et al. 2002, 2008), but it was in Mesoamerica (southern Mexico – Costa Rica) where domestication of the crop and the manufacture and consumption of chocolate peaked. In its native South American region of origin (Amazonian Ecuador, Peru, Colombia, Brazil, Bolivia, Venezuela, and Guyana shield) (Motamayor et al. 2008), stands of cocoa trees (i.e., groups of trees) were found embedded in the forest matrix of the high terraces of the upper and middle tributaries of the Amazon, upper tributaries of the Orinoco, and along some river systems in the Guyana shield (Patiño 2002). Amazonia dwellers collected mature cocoa fruits from these wild stands and transported them to their settlements and cultivation sites (Patiño 2002; Clement et al. 2010). The Spaniards who first explored and then colonized the Amazon called these wild cocoa-forest stands, *cacaguales* (cocoa stands), a Mesoamerican term widely used at that time. In today Bolivia, these cocoa-forest stands are called *chocolatales* (chocolate stands; Bazoberry-Chali & Salazar-Carrasco 2008).

Cocoa and chocolate were commercially introduced into Spain at the end of sixteenth century (Coe & Coe 1996; McNeil 2006). Europeans created their own version of chocolate, mixing it with sugar, vanilla, and cinnamon. The demand for cocoa grew rapidly during the seventeenth century (Grivetti & Shapiro 2009) and so grew the demand

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for cocoa beans from America, the only producing region in the world at that time. Cocoa beans exported to Europe came from cocoa plantations in the Mesoamerica, Colombia, Venezuela, and Antilles (Touzard 1993) and from the extraction of wild cocoa in the Amazon–Orinoco–Guyana region (Bartley 2005). The extraction and export of wild cocoa became a lucrative business controlled by the religious missions. With a growing demand for chocolate in Europe, the extraction of wild cocoa intensified and the cultivation of cocoa extended throughout the Amazon region and to new zones in America (the lower reaches of the Amazon, Guyana, Colombia, Ecuador, and Antilles) and in all possessions under the control of colonial Spain. Throughout the eighteenth century, cocoa (both extractive and cultivated) was the principal export crop from the Amazon to Europe (Patiño 2002; Miller & Nair 2006).

Dominance in world cocoa production shifted from America to Africa in the second half of the nineteenth century and remains so to date (www.worldcocoafoundation.org). Extraction of wild Amazonian cocoa practically disappeared in the nineteenth century and was replaced by the extraction of quinine (*Cinchona* spp. L.), rubber [*Hevea brasiliensis* (Willd. ex A.Juss.) Müll. Arg.], and Brazil nut (*Bertholletia excelsa* Bonpl.; Miller & Nair 2006; Stoian 2006; Bazoberry-Chalis & Salazar-Carrasco 2008). Extraction of wild cocoa for national markets remained at low levels in the Amazon region throughout the twentieth century, as documented for the Bolivian Amazon (Bazoberri-Chali & Salazar-Carrasco 2008). At the beginning of the twenty-first century, there is a renewed commercial interest in the Amazonian extractive cocoa. Consumers of gourmet chocolates are looking for new, exotic cocoa flavors (Bazoberri-Chali & Salazar-Carrasco 2008; GTZ 2009; www.felchlin.com; www.repsa.com; www.originalbeans.com). The demand for extractive cocoa is fueling a new cycle of domestication and management intensification of the wild cocoa stands in the Amazon region, not only opening opportunities for development but also posing threats to the conservation of this "wild cocoa stands."

"Wild" cocoa stands resulting from human intervention and disturbance of the local forest ecosystem are called sub-spontaneous cocoa stands by cocoa geneticists. These sub-spontaneous cocoa forests are a new type of cocoa production system that we propose to call "successional cocoa agroforest." This article: (1) starts with a brief description of the history of extractive cocoa in the Amazon basin, (2) outlines the historic path of domestication and use of wild and sub-spontaneous cocoa stands in the Amazonian basin, (3) specifies the biophysical and cultural processes that determine the creation–destruction–regeneration of the successional cocoa agroforest, (4) proposes a model for the functioning of this cocoa production system, and (5) documents the scarce information available on the changes in both the forest successional vegetation and cocoa population along the course of forest succession. This paper shows the need to broaden the popular five classes classification of cocoa (and coffee) production systems (open sun cultivation, specialized shade, commercial shade, mixed shade, and rustic systems; Johns 1999; Moguel & Toledo 1999; Rice & Greenberg 2000) to include a sixth type, the "successional cocoa agroforest."

Wild and sub-spontaneous cocoa stands in the Amazon riverine system

The term "wild cocoa" as generically used in the scientific and technical literature on cocoa includes two types of "wild" looking cocoa stands: (1) truly wild stands, i.e., those that arouse as a result of natural dispersal of cocoa seeds and plants and (2) sub-spontaneous stands, i.e., those that result from human occupation of the site. Researchers (Patiño 2002; Bartley 2005) admit difficulty in determining whether a given cocoa stand is wild or sub-spontaneous, and recommend a thorough examination of the patterns of human occupation of the site before classifying it as either wild or sub-spontaneous.

No study known to the authors has sought to determine how the cocoa stands embedded in the forest matrix originate, develop, die, and regenerate. Nevertheless, accounts from expeditions to collect cocoa germplasm, data from agricultural historians, and bibliographic sources all clearly spell out the ecological conditions of the sites where wild cocoa occur (and do not occur) in the Amazon region, and sketch out its genesis, development, and renovation (Myers 1930; Barrau 1979; Allen & Lass 1983; Clement 1986; Allen 1987; Sabatier & Prévost 1987; Lachenaud & Sallée 1993; Almeida 1996; Lachenaud et al. 1997; Clement 1999; Patiño 2002; Coomes & Ban 2004; Bartley 2005; Miller & Nair 2006). A brief summary is presented as follows.

Wild cocoa is a riparian species that grows well (although not exclusively) on the alluvial banks along the rivers, up to 600–900 m altitude depending on the latitude at the site (greater altitudes near the equator). The wild cocoa tree grows in soils with a broad range of fertility levels, but the presence of cocoa is usually indicative of good soil fertility at the site. Greater populations of wild cocoa are found on the high terraces of large rivers rather than of small rivers, possibly because large rivers carry greater quantities of sediments and develop more fertile soils than do the small rivers. Cocoa grows in forests away from the river terraces, provided the site has a fertile soil. Wild cocoa stands may remain at one site for more than two centuries (Bartley 2005). Various authors point out the intolerance of cocoa to prolonged flooding. Flooding eliminates cocoa seedlings and saplings and reduces recruitment of new individuals into the local population (Coomes & Ban 2004; Bartley 2005). However, wild cocoa do occurs in lowland, humid places (Myers 1930; Lachenaud & Sallée 1993). Sub-spontaneous cocoa grows on “elevated islands” (relics of Precambrian shield domes) in the seasonally flooded plains of Moxos, Bolivia (Maldonado 2002; WWF 2005; Bazoberry-Chali & Salazar-Carrasco 2008). Wild cocoa reaches up to 25 m in height and >30 cm in trunk diameter (Carletto 1973; Lachenaud et al. 1997), occupying the lower and middle strata of the forest’s vertical profile.

Genesis of wild cocoa stands

Wild cocoa stands may result mainly from dispersal by animals, especially howler and spider monkeys (Lachenaud & Zhang 2008). Although this is controversial (Allen 1988), some authors have suggested that cocoa may also be dispersed by water when river floods and wash away cocoa pods or whole plants, depositing them in the riverbanks downstream (Almeida 1996). Wild cocoa stands may contain three kinds of cocoa trees: (1) individual trees, with only one trunk; this type occurs only seldom in nature; (2) sibling individuals, each with several trunks (up to 50 or more; Allen 1988), usually forming patches (demes, or genetic sub-populations; Lachenaud & Zhang 2008), and (3) genetically homogeneous, clonal cocoa stands that develop when fallen cocoa trees produce suckers that anchor themselves to the ground independently of the fallen tree, which eventually rots, leaving the old suckers separated as if they were different trees (Myers 1930; Allen & Lass 1983; Allen 1987; Sabatier & Prévost 1987; Lachenaud & Sallée 1993; Bartley 2005).

Population size and spatial dispersion vary from 10 to 30 trees in an isolated patch to thousands of sparse individuals in extensive areas (10–78 ha in Brazil) with various connected subpopulations and with densities up to 142 cocoa trees ha^{-1} (Almeida 1996); in Guyana, wild cocoa stands of 76–350 cocoa plants have been studied (Jennings et al. 1999). Cocoa population densities in wild stands vary widely. For instance, typical population densities are merely 5–10 trees ha^{-1} in Ecuador and Colombia (Allen & Lass

1983; Allen 1987), but reach 31 trees ha^{-1} along the high Camopi river in French Guiana (Sabatier & Prévost 1987; Lachenaud & Sallée 1993). In the mountains and valleys along the Jí-Paraná river, a tributary of the Madeira, wild cocoa stands may cover several hectares and have "high tree densities" (Bartley 2005). However, most wild stands have less than 50 cocoa trees ha^{-1}. Cocoa plantlets and seedlings could be found in wild cocoa stands in Brazil (Almeida 1996) and in French Guiana (Sabatier & Prévost 1987).

Genesis of sub-spontaneous cocoa stands

At least four pathways (Figure 1) lead to the creation of sub-spontaneous cocoa stands: (1) species-rich, highland forest sites under successive cycles of shifting cultivation are enriched by planting cocoa and other useful tree species in crop fields, young fallows, and campsites; (2) the forest matrix of wild cocoa stands is cleared (sparing and protecting the cocoa trees) to cultivate food crops under various cycles of shifting cultivation; (3) cocoa plantations are abandoned and invaded by the forest succession, and later reoccupied and tended by partially clearing the forest matrix and replanting cocoa; and (4) cyclic occupation and abandonment of human settlement areas. Various sources of information document these pathways.

There is evidence that the patterns of land use and the prehistoric practices of agriculture, hunting, and fishing in Amazonia remain today (Clement et al. 2010). Amazonia dwellers live on high terraces along the rivers and cultivate food crops at various locations: (1) home gardens around the dwellings; (2) seasonally flooded, low-lying terraces with good soil fertility; and (3) high terraces and some inland forest sites selected for the cultivation of food crops using shifting, slash-and-burn agriculture to restore soil fertility (Almeida 1996; Smith et al. 1996; Coomes & Ban 2004; Miller & Nair 2006). Amazonia dwellers enrich their upland crop fields, fallow land, and campsites with valuable native fruits, either collected from the surrounding forests or brought from home gardens. Farmers protect recruits of useful species and eradicate species that are harmful or prejudicial to the species of interest. After a period of occupation and cultivation of food crops, the site is abandoned to restore soil fertility, giving rise to an enriched forest succession. After the fallow period, the site is reoccupied and the forest selectively cut to cultivate food crops again, sparing and protecting valuable fruit trees and other useful species when slashing and burning the vegetation for a new cycle of cultivation of food

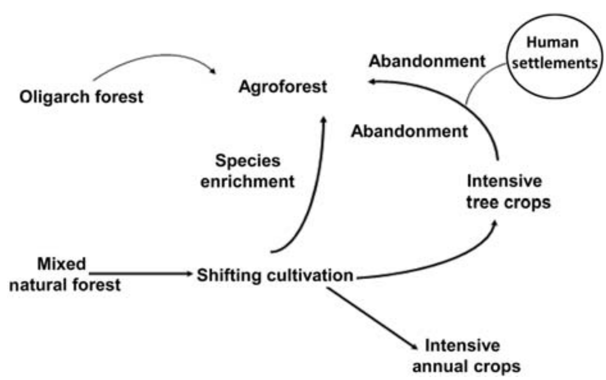

Figure 1. Pathways for the creation of the Amazonian successional cocoa agroforests (adapted from Van Noordwijk et al. (1996)).

crops (Allen & Lass 1983; Allen 1987; Miller & Nair 2006). The progressive increase in population density of cocoa and other fruit tree species (giving rise to an oligarchic forests *sensu* Ballée 1989; Peters et al. 1989; Van Noordwijk 1999) after various cycles of cultivation and fallow in a site is similar to the process that creates "fruit islands" in the Indonesian forests (Michon & de Foresta 1999). The genesis of the enriched Brazil nut forests of the Amazon and the Guianas is the result of the interplay between humans practicing cyclic, shifting cultivation of food crops, the presence of fallow vegetation, and agouties (*Dasyprocta* spp.; Cotta et al. 2008).

Sub-spontaneous cocoa stands also result from the patterns of occupation–abandonment–reoccupation of human settlement areas (Barrau 1979; Allen & Lass 1983; Allen 1987; Patiño 2002; Bartley 2005). Amazonia dwellers (prehistoric and contemporary) transport cocoa fruits to their settlements, dispersing cocoa seeds into home gardens, sometimes establishing small cocoa plantations, and randomly dispersing cocoa seeds along trails, plazas and other community spaces (Clement et al. 2010). After decades of occupation of the site, the population density of cocoa increases; eventually the site is abandoned due to floods, wars with neighboring tribes, plagues, relocation, evangelization, and other reasons (Barrau 1979; Allen 1987; Sanchez & Jaffe 1992; Almeida 1996; Clement 1999; Patiño 2002; Coomes & Ban 2004; Miller & Nair 2006), and later on the site is reoccupied with the forest cleared, sparing and protecting cocoa and other fruit tree species, and starting a new cycle of cocoa enrichment.

Sub-spontaneous cocoa stands are also created when cocoa plantations are abandoned (and the site reclaimed by the forest succession) due to inadequate cocoa prices, pest and disease outbreaks, and other causes. When market or other conditions are appropriate, the forest matrix is partially cleared to increase light transmission and hence, cocoa yields. Notorious examples of this type of sub-spontaneous cocoa stands can be found in the seasonally flooded plains of Moxos, Bolivia, which resulted from plantations established more than 200 years ago by religious missions during the colonial times (Bazoberry-Chali & Salazar-Carrasco 2008).

Successional cocoa agroforest model

The basic dynamics of the sub-spontaneous cocoa stands of the Amazon–Orinoco–Guyana region can be visualized as having various sequential cycles, each cycle with two sequential phases: occupation and abandonment (Figure 2). During occupation of the site, cocoa population numbers increase as forest cover decreases; during abandonment, forest succession sets in, forest biomass and shade levels increase over time and cocoa population numbers decline. Eventually, a new cycle begins when the site is reoccupied and the forest heavily reduced. The successional cocoa agroforest model is analog to those proposed for shifting cultivation systems (Van Noordwijk 1999). A summary follows of what is known on the changes in both the vegetation and the cocoa population during forest succession in the successional cocoa agroforest.

Forest succession

A lot is known about forest succession (botanical composition, biomass, etc.) in various types of Amazonian forests (Guariguata & Ostertag 2001). However, no studies have been published on the dynamics of the successional cocoa agroforest. The few studies available have been confined to the inventory of the vegetation at one particular site and in one moment in time. For instance, in the lowland floodplains of French Guiana wild cocoa may

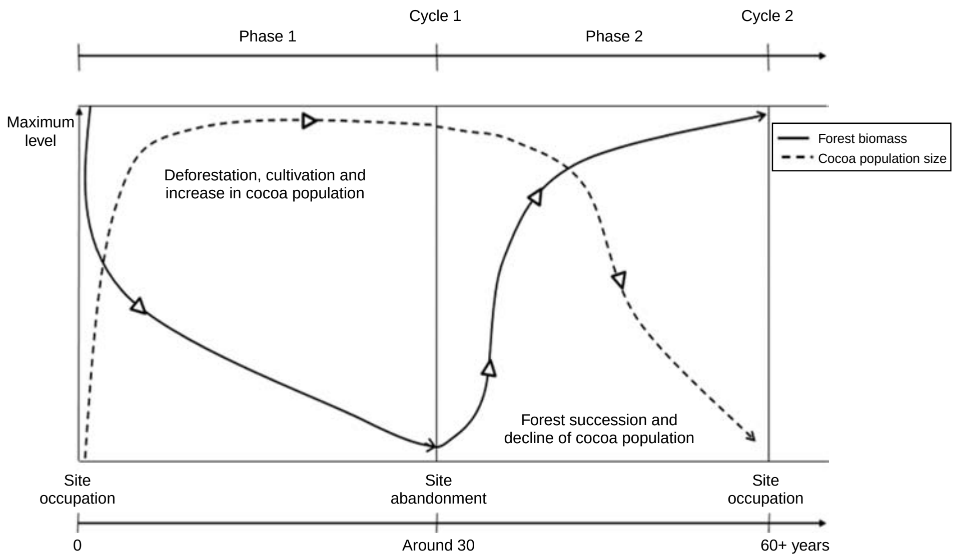

Figure 2. Life cycle of the successional cocoa agroforest of the Amazon.

grow under natural stands of *Virola surinamensis* (Rol. ex Rottb.) Warb. and *Euterpe oleracea* Mart. (Sabatier & Prévost 1987; Lachenaud & Sallée 1993). The cocoa agroforests of 38 islands in the floodplains of the municipalities of Baures and Huacaraje in Iténez, Beni, Bolivia are secondary forests with more than 100 species of trees above 10 cm Diameter at Breast Height and densities of 500–600 stems ha^{-1} (Maldonado 2002; WWF 2005).

Cocoa populations

Cocoa population size and density in the successional cocoa agroforest vary widely. For instance, in the valley and headwaters of the Purús River they can contain several thousand cocoa trees (Huber 1906), in Bolivia cocoa productive populations range between 100 and 300 plants ha^{-1} (averaging 250 stems ha^{-1}) of all sizes (Maldonado 2002); local experts set typical cocoa population densities between 10 and 100 plants ha^{-1} in Iténez, Bolivia (Volker Lehman 2011, personal communication, http://www.repsa.com). Cocoa population densities vary from 950 plants ha^{-1} (including plantlets) on the riverbanks to 240 plants ha^{-1} in inland forests (Maldonado 2002). In the “chocolate islands” of the plains of Moxos, Beni, Bolivia, cocoa populations include trees of all sizes. In closed forest, under conditions of considerable shade, cocoa trees often occur as isolated trees, without any evidence of natural regeneration (Bartley 2005). No information is available on the changes in the cocoa population dynamics parameters (population size and age structure, growth, mortality, recruitment, and yield) during the course of forest succession.

Typology of cocoa production systems

Several authors (Johns 1999; Moguel & Toledo 1999; Rice & Greenberg 2000) have proposed a five classes classification of cocoa (and coffee) production systems: (1) monoculture without shade; (2) cocoa plantations with specialized shade (various species of *Inga*, *Erythrina*, *Gliricidia*, and *Albizia*); (3) commercial polyculture (combinations of cocoa–*H. brasiliensis*, cocoa–*Cocos nucifera* L., cocoa–bananas, cocoa–*Elaeis guineensis* Jacq., cocoa–timber trees, cocoa–fruit trees, etc.); (4) cocoa plantations with mixed shade; and (5) cocoa plantations under thinned forest, known as rustic cocoa plantations – in Brazil called *cabrucas* (Sambuichi 2006) and in Central and West Africa called "jungle cocoa" – (Sonwa et al. 2007). Similar *cabrucas*-like examples have been observed for *Coffea arabica* L. in Ethiopia (Michon et al. 2007) and for benzoin resin producing trees (*Styrax benzoin* Dryander) in Indonesia (Michon & de Foresta 1999; García-Fernández et al. 2003). We propose that the five classes classification be expanded to accommodate a sixth type of cocoa production system: the "successional cocoa agroforest" described in this paper. In current scientific literature, the term cocoa agroforest is used loosely to denote all kinds of shaded cocoa systems, from very simple, monospecific, one single strata shade canopy (Smiley & Kroschel 2008) to species-rich, structurally complex rustic cocoa system (e.g., Jagoret et al. 2011; Ruf 2011).

Conclusions and recommendations

The successional cocoa agroforest described in this paper is a new type of cocoa agroforestry system, with very long cycles (more than 50 years), each cycle made up of two phases: (1) a "cocoa phase" during human occupation of the site when forest biomass decreases and cocoa population numbers increase and (2) a "forest phase" when the site is abandoned and forest succession sets in, forest biomass and shade increases, and cocoa population numbers decrease over time. Eventually, the site is reoccupied and a new cycle begins.

Virtually everything is yet to be known on the successional cocoa agroforest. A priority list of research topics would include the analysis of: (1) the biophysical and cultural dynamics that gives rise to the cyclical increase in the cocoa population at a site and then abandonment; (2) the evolution and development (within and among cycles) of the forest botanical composition, biomass and shade levels along forest succession; and (3) the impacts of forest succession on the cocoa population dynamics parameters (population size, age or size structure, growth, survival, fertility, recruitment, and yield).

The recent upsurge in commercial interest on extractive cocoa motivates Amazonia dwellers to manipulate both the forest matrix and the population density of cocoa to increase cocoa yields. How and to what degree is it possible to intensify the management and domestication of the successional cocoa agroforest without losing its "wild" nature is not known. Cocoa occupies the lower vertical stratum in the forest's vertical profile, and therefore experiences severe shade levels. Heavily shaded cocoa in the understory rarely bears fruits. Cocoa yields, tree fertility, recruitment and survival are all likely to decrease with increasing shade. By reducing shade (thinning or periodic pruning of the forest vegetation) both cocoa yields and population density can be increased. A good balance between increased cocoa productivity and retention of its "wild" attributes must be achieved. The model for the functioning of the successional cocoa agroforest described in this paper could be used to explore alternatives for its domestication and management intensification.

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