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Status of Cacao Trees Following Seasonal Floods in Major Watersheds of the Peruvian Amazon

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Abstract

Three cacao (*Theobroma cacao*) production systems (traditional, mixed and monoculture) were studied in Peru between February and July 2012 in order to evaluate the response of the species to an extremely high seasonal inundation along Amazonian rivers. Survival rates of cacao individuals after flooding varied greatly, between 0.6% to 100%, depending on the type of production system and the age of the plants. The highest number of flower cushions was found on trees from 8 to 10 years old, with an average of 9.7 flower cushions 30 cm above the high water line and 9.1 cushions 30 cm below the water line. Results indicate that younger, unshaded cacao trees are most vulnerable to floodwater mortality and flower cushion damage, and the importance of agroforestry systems in cultivating this tree species in highly disturbed and increasingly unpredictable floodplain environments.

Keywords: Theobroma cacao, flooding, agroforestry, climate change, Amazon

1. Introduction

Cacao (*Theobroma cacao* L.) is indigenous to the Amazon basin, but is generally believed to have been domesticated in Mesoamerica for the production of chocolate beverage. The highest levels of

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genetic diversity were observed in the Upper Amazon areas from southern Peru to the Ecuadorian Amazon and the border areas between Colombia, Peru and Brazil, indicating the possible location of origin of this tree species (Thomas *et al.*, 2012). Cacao trees are traditionally cultivated in agroforestry systems as it is a tree that has little tolerance to high sunlight, and shaded conditions also reduce the spread of disease (Balasimha, Daniel, & Bhat, 1991; Raja Harun & Hardwick, 1987; de Almeida & Valle, 2007; Beer, Muschler, Kass, & Somarriba, 1997; Duguma, Gockowski, & Bakala, 2001; Tiralla, Panferov, & Knohl, 2013). Cacao can tolerate flooding and has been cultivated along the Amazon floodplain for centuries. The widespread occurrence of cacao along the lower, eastern Amazon floodplain has led Smith (1999) to conclude that indigenous societies planted cacao in floodplain environments before the arrival of European explorers. In colonial Brazil, the principal economic activity along the Amazon floodplain was the growing cacao, and almost all cacao lands were along the seasonally flooded riverbank (Harris, 2011). Farmers grew seedlings in raised beds and then transplanted them in fields with other tree species that provided shade for the cacao trees, as cacao also became the main economic crop component in agroforestry systems during the 1700s (Miller, Penn Jr., & van Leeuwen, 2006).

Despite this history of floodplain cacao cultivation in Brazil, most agroforestry systems with cacao in western Amazonia in Peru have long been developed and promoted on terra firme soils, and much less in floodplain soils that are often quite fertile but inundated for long periods because seedlings are often killed by floodwaters. Flooding is also thought to damage productive cacao trees, including the flower cushions on the trunk and branches of the tree that are the only means for this species to produce inflorescences and eventually cacao fruits. The flower cushions continuously produce flowers and cacao fruit from the same spot for many years (Swanson, Carlson, & Guiltinan, 2008). Studies in nurseries with cacao seedlings of different genotypes have shown that another major effect of flooding is deprivation of O2 (hipoxia and anoxia) in the root zone, which effects several biochemical, physiological, morphological and genetic processes that can result in death of seedlings (Sena Gomes & Kozlowsky, 1986; Kozlowski, 1997; de Almeida & Valle, 2007; Rehem, De Almeida, Mielke, & Gomes, 2009; Bertolde *et al*., 2009), especially after 30 days of flooding (Bertolde *et al*, 2012). Recent years have seen changes in attitudes regarding cacao cultivation in seasonally flooded environments. Since 2007, the Peruvian government, together with non-governmental organizations (NGOs), has promoted the cultivation of cacao with smallholders in floodplain environments as a way to take advantage of the fertile soil conditions there.

The purpose of this study is to determine how *T. cacao* responds to seasonal inundations along large Amazonian rivers in western Amazonia, and the impact of prolonged flooding on the flower cushions of this species. The year 2012 experienced extremely high and prolonged floodwaters (Espinoza *et al*., 2013), which provided a unique opportunity to study the impact of this flooding in order to evaluate the viability of cacao agroforestry systems in highly disturbed floodplain environments.

2. Methods and Study Area

The study was conducted from February to June 2012, in two cultivated cacao production systems and one natural cacao population, located along two different rivers of the Peruvian Amazon. The smallholder parcels of land that were studied (hereafter referred to as gardens) generally lack adequate management (such as weeding), average about 1 ha in size, and were planted with cacao seeds of different origins. Farmers cultivate cacao in three main ways, two of which mix cacao with other tree species. Some farmers plant cacao as a minor component of a traditional agroforestry system with many other tree commercial crops ("sistema tradicional"), while other farmers cultivate cacao as their main commercial crop in these gardens, mixing cacao in dense plantings with other tree species that serve primarily for shade ("sistema mixto"). The third cultivation method is to monocrop cacao as the only tree species in a garden ("monocultivo"). Soils in all the gardens are seasonally inundated, with floodwaters generally reaching only around .20m in depth up to 45 days, except when floods are exceptionally high or prolonged, as occurred in 2012.

In the lower Ucayali River, in the communities of Bagazán (4º 76' 66" S and 73 º 61' 67" W) and Jenaro Herrera (4º 54' 13" S and 73 º 40' 13" W), 12 cacao gardens were studied; five of mixed tree species and six monocrops of cacao of different ages plus a wild stand of cacao. In the wild stand, surveys were conducted in twenty 10 x 10m plots, and two plots contiguous to the wild stand containing wild plants that farmers had protected when they opened up the fields. In the upper Amazon River, in the community of Cañaveral (4º 91' 32" and 73 º 65' 54" W), six cacao gardens were studied - three of mixed tree species and three monocrops of cacao of different ages (Table 1). Water temperatures, dissolved oxygen concentrations, and electrical conductivity were also measured in the gardens.

During 2012 the upper Amazon basin experienced one of the greatest and highest flooding events in the last 40 years (Espinoza *et al*., 2013; Martin, Peters, & Ashton, 2014). The number of living cacao trees were counted before flooding and 30 days after floodwaters receded in each garden and the plots. Ten days after waters receded, the number of flower cushions was counted on 61 cacao trees from 4 to 5 years and 8 to 10 years of age, 30 cm above the high water line and 30 cm below the water line. A statistical comparison was made between cacao trees in the monocropped garden plots and the mixed species plots aged four to five years in the Ucayali and Amazon River locations in order to determine the effects of flooding on both the formation of flower cushions and the survival of the cacao trees.

3. Results

3.1. Garden and Water Conditions

In the mixed and monocropped systems that were in the first years of growth, cacao was intercropped with plantain (*Musa paradisiaca*), and papaya (*Carica papaya*), along with annual crops such as maize (Zea mais), yuca (Manihot esculenta), peanut (*Arachis hypogaea*), watermelon (*Citrullus lanatus*), melons (*Cucumis melo*), and tomato (*Solanum licopersicum*). In cacao gardens managed in the traditional agroforestry method, 13 fruit tree species and two timber species were found, while in the mixed systems 5 fruit trees and one timber species were growing with cacao (Table 1).

While floodwaters generally reach only around .20m in depth for up to 45 days in the study area, in 2012 the cacao gardens studied were flooded up to .90m for a period of 72 days, and in the wild stands of cacao floodwaters reached 2.1m in depth. Floodwaters began to enter the gardens in February, and reached their maximum levels in late April. Rains are most frequent of the year, while hours of sunlight are lowest during this time period. In the last week of April and first weeks of May, floodwaters are backed up and stagnant before receding, as rains lessen in frequency and sunlight increases. After six days of stagnant floodwaters in cacao gardens, water temperatures ranged from 26.9 to 28.1°C, with concentrations of 0.22 to 0.67mg/l in dissolved oxygen and electrical conductivity ranging from 167.5 to 174.3µS/cm. These conditions reflected the lower rainfall, higher sunlight, and decomposition of organic matter as floodwater volume declined and waters became more stagnant. Many local farmers believe that stagnant water conditions are what kill cacao and other tree crops.

Table 1. Associated tree crops and different cacao cultivation systems, percentage of survival after the inundation, and different age categories along the Ucayali and Amazon rivers

Area	Cultivation system	Associated species	Gardens	Survival (%)	Gardens	Survival (%)	Gardens	Survival (%)
Lower Ucayali	Traditional	*Inga edulis,Genipa americana, Mangifera indica, Spondias dulcis, Persea americana, Pouteria caimito, Mangifera indica, Carica papaya, Theobroma bicolor, Bactris gasipaes, Grias neuberthi, Myrciaria dubia, Swietenia macrophylla, Calycophyllum spruceanum*					31 trees in 12 gardens aged 3 to 16 years	100
	Mixed	*Inga edulis, Mangifera indica, Spondias dulcis, Calycophyllum spruceanum*	2 gardens aged 2-3 years	25	3 gardens aged 5 years	78.6		
	Monocrop of cacao		1 garden aged 2 years	0.6	3 gardens aged 5 years	59.3	2 gardens aged 8 to 10 years	97
	Wild cacao inside a traditional system	*Eugenía stipitata, Musa paradisiaca, Citrus sp. Rollinia mucosa, Persea americana, Bactris gasipae, Manguifera indica*	9 trees in 2 gardens aged 3 to 4 years	100				
	Wild, natural cacao stand	*Virola elongata, Maquira coriácea, Couroupita guianensis, Grias neuberthii, Sorocea steinbachi, Scheelea brachyclada, Guarea macrophylla, Unonopsis floribunda.*					10 x 10m plots in 20 gardens, 19 trees per plot	100
Upper Amazon	Mixed	*Inga edulis, Inga sp, Spondias dulcis, Musa paradisiaca, Pouteria caimito*			3 gardens aged 5 years	31.6		
	Monocrop of cacao				3 gardens aged 4 to 5 years	12.6		

3.2. Cacao Mortality

A total of 7,767 cacao trees in the cultivated production systems and the wild stand of cacao were surveyed to determine if they had survived or died due to record high flooding. Most of the trees (5,429) found in mixed and monocropped systems of four to five years in age. The lowest survival rate found was 0.6%, in monocropped gardens with young cacao trees two years in age. The highest survival rate was 100% in traditional agroforestry systems, where cacao was three to 16 years in age, and in the wild stand of cacao. In the monocropped gardens with trees from 8 to 10 years of age, the survival rate was 97%. In mixed and monocropped systems with younger trees, survival rates were much lower (Figure 1, Table 1).

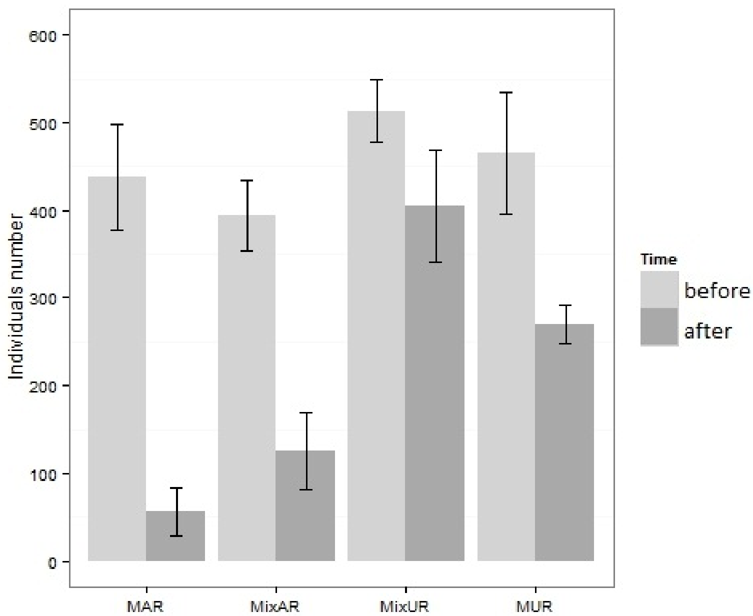

Figure 1. Average number of living cacao trees aged 4 to 5 years, before and after the inundation. Mixed cultivation gardens in the Ucayali River (MixUR) and in the Amazon River (MixAR). Monocropped gardens in Ucayali (MUR) and in the Amazon River (MAR)

In mixed systems 5 years in age, cacao survival averaged 78.6% (SD 8.7) in the Ucayali River (MixUR) and 59.3% (SD 12.0) in the Amazon River (MixAR) gardens. The survival rate for monocropped systems in Ucayali (MUR) was 31.6% (SD 7.6), but just 12.6% (SD 4.5) in the Amazon River (MAR, Figure 1, Table 1). When we compared the survival rates between the monocropped and mixed systems in each area, the only significant difference was between the mixed gardens in the Ucayali and the monocropped gardens in the Amazon River (Kruskal-Wallis P < 0.05).

3.3. Flower Cushion Survival

The number of flower cushions was counted on 61 cacao trees from 4 to 5 years and 8 to 10 years of age, 30 cm above the high water line and 30 cm below the water line. The trees from 4 to 5 years of age had a significantly different number of viable flower cushions above water line in the trunk than below the water line (Mann – Witney $p< 0.05$)., with an average of 3.1 (SD 2.4) viable flower cushions above, but an average of just 1.6 (SD 1.5) below. However, in trees aged eight to 10 years there was no significant difference, with an average of 9.7 (SD 3.5) flower cushions above water and 9.1(SD 2.2) below water (Figure 2).

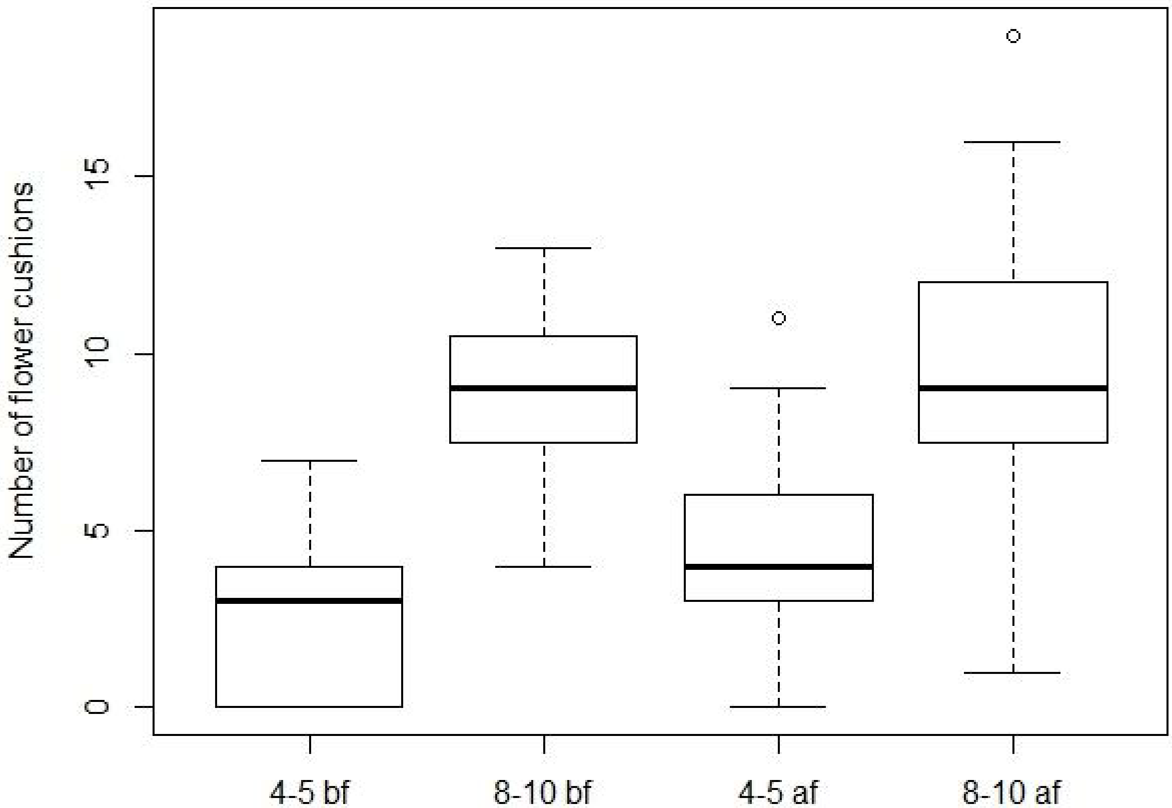

Figure 2. Average number of flower cushions surviving on cacao trees 30 cm above the high water line (a.f.) and 30 cm below the water line (b.f.) in trees from 4 to 5 and 8 to 10 years of age, Ucayali River

4. Discussion

What explains the variance in mortality in cacao trees in these gardens, and why did some trees have much higher rates of survival than others? Much of this can be explained by the type of cultivation system used by the cacao farmers, and the age of the cacao trees. In the traditional agroforestry systems cacao was associated with other tree species that were older and taller, shading the cacao trees. In the monocropped systems of cacao aged eight to 10 years, the trees had developed canopies that grow into and over one another, as the trees were not pruned. In both systems, the shading caused by these factors prevents or reduces sunlight from reaching the floodwater surface.

In the monocropped systems from three to five years in age, the smaller, young cacao trees were associated with other tree species that were also young in age, low in height, and with small canopies, leaving the floodwater surface exposed to sunlight. A more sunlit water surface produces a rise in water temperature, CO_2, and other toxic gases associated with anaerobic decomposition, while oxygen levels drop to where hipoxia and anoxia conditions occur (Junk, Soares, & Carvalho, 1983; Kozlowski, 1997). This depletion of oxygen in the water will damage *T. cacao*, especially the younger plants (Bertolde *et al*., 2009, 2012). Moreover, younger cacao trees are simply less resistant to floodwaters than older trees, with the problem of oxygen deficiency exacerbating this problem. Even five year old cacao trees, when monocropped in gardens, experienced 82% mortality from flooding (Figure 3).

Figure 3. Monocropped gardens of 5 year old cacao trees in the Amazon River, where 82% mortality occurred from flooding

Figure 4. Cacao tree with aerial roots (pneumataphores) of 28cm in length, Ucayali River

The same was found to be true with respect to the survival of the fruit-producing flower cushions on younger trees. While older trees experienced no significant loss in the number of flower cushions that were submerged during the flood, younger trees experienced significant loss of flower cushions, which damages the trees and causes a significant drop in their ability to produce fruit. However, due to challenging floodwater conditions, our study of flower cushion survival was limited in size, and a larger study of flower cushion survival rates in these different cultivation systems and their unique environments will improve our understanding of how cacao fruit production is impacted by floodwaters that submerge the trunk and lowers branches of the trees.

Mortality in young cacao trees due to inundated conditions may vary among in cacao genotypes, due to genetic, physiological and morphological differences (Sena Gomes & Kozlowsky, 1986; Rehem *et al*., 2009; Bertolde *et al.*, 2009, 2012). We observed cacao in the different production systems with very pale leaves, indicating chlorosis, probably the result of oxygen deficiency in the trees. In the wild stands we observed the emergence of aerial roots (Figure 4), a morphological adaptation to seasonal flooding and oxygen deficiency. Given that these wild cacao trees have evolved on the floodplain for an unknown number of years, with very high survival rates, it is logical that they have adapted to extreme flooding events with the use of aerial roots.

The higher planting densities of the monocropped cacao gardens raise additional concerns about this form of production system. Cacao trees are prone to disease, especially witches' broom (*Crinipellis perniciosa*) in northern Amazonia. Dias *et al*. (2000) have found that higher planting densities increased the incidence of witches' broom in monocropped cacao in Brazil. As the market for cacao pods in our study area is limited, farmers using the monocropped cacao production system need to add additional tree crop species to this system in order to obtain more sources of income and enhance their own food security in these floodplain environments.

Climate models show significant future change for the Amazon, with extreme rainfall and flooding events such as the 2012 flood season projected to increase in frequency over time in western Amazonia (Marengo, Jones, Alves, & Valverde, 2009). Besides the high mortality rates in young cacao trees, associated tree species in the agroforestry systems also were killed by the flooding. Many avocado, citrus species, and native fruit trees such as *Bactris gasipaes* ("pijuayo") and *Pouteria caimito*, ("caimito"), sources of important income and nutrition for farmers, were also killed in the 2012 flood. This loss of income and tree crop diversity in the gardens must be replaced with more flood tolerant tree species that are large enough in size to shade the cacao trees and the floodwater surface, which represents another challenge for floodplain farmers. Two tree species that thrive in floodwaters that could be of great help in these production systems are *Mauritia flexuosa* ("aguaje") and *Myrciaria dubia* ("camu-camu"). Aguaje palms produce a nutritious fruit with a very strong market in our study area (Penn Jr., 2008), while camu-camu also produces a nutritious tree fruit that supplies a fruit products market in Peru and for export (Penn Jr., 2006; Pinedo-Panduro & Penn Jr., 2008). Camu camu is a floodplain tree species similar in size to cacao that matures quickly. In our study, we found that farmers were indeed cultivating *M. dubia* in association with cacao in the lower Ucayali productions systems with the highest survival rates (Figure 1).

5. Conclusion

The results of this study suggest that so far, seasonal inundations along Amazonian rivers in Peru have caused little mortality in cacao trees and little effect on cacao flower cushions when cacao is cultivated in an environment with adequate shade, which was present in production systems with older and larger cacao trees. However, climate change will make floodplain agriculture in western Amazonia more risky in the future, and ensuring the survival of young cacao trees is likely to become more difficult. This demonstrates the importance of utilizing agroforestry systems when cultivating this tree crop in increasingly unpredictable Amazonian floodplain environments.

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