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Unraveling the Sikasso Paradox: Agricultural Change and Malnutrition in Sikasso, Mali

Matthew William Cooper[a,b] and Colin Thor West[a,b]

[a]Conservation International, Moore Center for Science, Arlington, Virginia, USA; [b]University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA

ABSTRACT
When cash cropping leads to agricultural and livelihood changes in the Global South, concern about food security is common among policy makers. This is indeed the case in the Sikasso region of Mali, where many have suggested that the ubiquitous cash crop cotton is a cause of the unexpectedly high rates of malnutrition in the region. Using household and forest surveys, we found little evidence that cotton cultivation is associated with malnutrition or decreased food security at a household level, but we did find evidence of a coassociation between cotton cultivation, loss of natural capital, and malnutrition at the village level.

KEYWORDS
Cash cropping; cotton; ecosystem services; food security; Mali

Introduction

Academics and development practitioners who work in Mali have long puzzled over the surprisingly high rates of malnutrition in the region of Sikasso (Dury and Bocoum 2012; Eozenou, Madani, and Swinkels 2013). Of all the regions of Mali, this region has the most rainfall and therefore the most food diversity, the most productive crops, and the greatest access to cash income for smallholder farmers because of the cash crop cotton. While these factors would seemingly predict healthier children, the opposite is the case. This "Sikasso paradox" is often explained as a result of damaging effects of the cash crop cotton (Eozenou, Madani, and Swinkels 2013; Tefft and Kelly 2004), a hypothesis that this study seeks to investigate.

Theoretical framework

This study examines associations between cotton cultivation and malnutrition at a household and village scale to explore whether there is evidence that cotton cultivation is associated with malnutrition. We therefore draw on literature concerning cash cropping, diet, nutrition, and natural capital in the developing world.

CONTACT Matthew William Cooper, MA mw.coop.r@gmail.com Conservation International, Moore Center for Science, 2011 Crystal Drive, Suite 500, Arlington, VA 22202-3787.
Color versions of one or more of the figures in the article can be found online atwww.tandfonline.com/GEFN.

Sikasso paradox

The Sikasso paradox, or *paradoxe de Sikasso*, was first noticed in a national poverty survey in 1994. This survey measured poverty, not malnutrition, and found that the Sikasso region stood out. Subsequent national poverty surveys in 2001 and 2006 continued to make this observation (Delarue et al. 2009). Around this time, discussion around the paradox became increasingly linked to the cash crop cotton, especially as yields and income began to decrease in the mid-2000s.

Soon after these initial observations that poverty was worse in Sikasso, evidence began to emerge that child malnutrition and child health were also disproportionately poor in the region (Dury and Bocoum 2012; Tefft and Kelly 2004), and most recent literature on the subject now focuses on the phenomenon as a food security paradox as much as a poverty paradox. A recent assessment by the World Bank found that, although some of the earlier reports on poverty levels may have been overestimates, Sikasso is still disproportionately poor and malnourished (Eozenou, Madani, and Swinkels 2013). This report found that while the Sikasso region of Mali has only 16% of the country's population, it has 34% of the poor, 45% of the food poor, and the worst rates of stunting among children in the country (Dury and Bocoum 2012). Demographic and Health Surveys (DHSs) have also shown that Sikasso is among the regions with the worst health statistics in Mali: in the 2012–2013 DHS, the Sikasso region had the highest infant mortality rate and under-five mortality rate in the country (CPS/SSDSPF 2014), while in 2006, the Sikasso region had the highest infant mortality rate and the highest rates of children stunted and children underweight (CPS/MS 2007). A similar paradox has been observed in Burkina Faso in relation to cotton (Mesplé-Somps et al. 2008) and was even the subject of a documentary film (Maugerard and Ruiz 2015).

In addition to looking at the disproportionate prevalence of poverty and malnutrition in Sikasso, the World Bank report also looked explicitly at the situation of cotton farmers, located mostly in the Sikasso region. Farmers from cotton-producing districts were only 21% of Mali's population, but comprised 52% of the country's food poor and 28% of the country's malnourished (Eozenou, Madani, and Swinkels 2013). Thus, decades of research have established the Sikasso paradox as a real phenomenon relating to both poverty and nutrition, and possibly cotton. While many authors implicate cotton in this phenomenon (Delarue et al. 2009; Eozenou, Madani, and Swinkels 2013), no one has yet conducted a quantitative analysis at the household or village level to see whether this is the case.

Nutrition

In sub-Saharan Africa, more than 200 million people are malnourished (McMichael et al. 2008). This burden is most heavily borne by children, 28% of which are underweight in sub-Saharan Africa, and 36% of which are stunted in West Africa (UNICEF 2009). In Mali in particular, the effects of malnutrition are stark: 44% of households have a stunted child, with children in the Sikasso region being particularly vulnerable (Eozenou, Madani, and Swinkels 2013). Household food security in Mali is very vulnerable to drought, with childhood malnutrition expected to rise in some areas as climate change affects rainfall variability (Jankowska et al. 2012). Fluctuating cereal prices have also been shown to decrease food security in households that purchase a significant portion of their food (Eozenou, Madani, and Swinkels 2013), such as urban households or rural households that have invested heavily in cash cropping.

While cash cropping can greatly affect agricultural systems and therefore child nutrition, there are examples of cash cropping having positive, negative, and mixed effects on childrens' nutrition status (Von Braun 1995). Negative effects are especially likely when the cash crops are not edible and cannot be consumed by the households producing them, as well as when cash crops are produced for export and are affected by international market fluctuations (Von Braun and Kennedy 1994). Given the complex relationship between agricultural commodification and child nutrition, as well as the fact that there are some precedents of cash cropping hurting child health, it is certainly worth investigating whether cotton cultivation is related to the surprisingly high rates of malnutrition in the Sikasso region of Mali.

Human nutrition depends on natural capital, especially in parts of the world where livelihoods are still largely agrarian and largely based on local resources, such as in sub-Saharan Africa (Agarwala et al. 2014). There have been many calls for interdisciplinary research into the linkages between environmental health and human health, an emerging field that has been called "econutrition" (DeClerck et al. 2011; Remans et al. 2012). In sub-Saharan Africa, wild food species are an important source of both micronutrients and macronutrients (Myers et al. 2013), and there is an increasing awareness that the disappearance of these species will pose a nutritional challenge for people who cannot easily replace these food sources (Myers et al. 2013). One study illustrated this clearly by showing that households in Madagascar that were unable to harvest bushmeat had children with a 30% higher risk of iron deficiency and anemia (Myers et al. 2013). Diverse agroecological systems play an important role in human nutrition because healthy human diets depend on a wide variety of nutrients and food sources (DeClerck et al. 2011; Remans et al. 2012).

Socioecological context

While the entire study region is somewhat culturally homogenous, speaking mutually intelligible dialects of Bambara/Malinke and practicing an Africanized form of Islam, different areas have distinct cultural histories.

The western part of the study region is inhabited by Bambaraized Fulani in the *Cercle de Yanfolila*, while people who were historically Senufo inhabit the eastern part of the study area, in the *Cercle de Kolondiéba* (see figure 1). The ecosystem is best defined as a Sudanean savanna, and like all tropic savannas, it is characterized by disturbance-driven heterogeneity and shifting regimes of plant communities (Laris and Dembele 2011; Scholes and Archer 1997). Closed canopy forests are very rare, although they can occur in very mesic areas or in human-managed orchards. Much of what will be referred to as "forest" in this article could better be specified as wooded savanna, with woody shrubs and trees such as *Terminalia, Acacia, Isoberlinia*, and *Combretum*, as well as a continuous bed of grasses.

Communities in the area have traditionally grown sorghum (*Sorghum bicolor)*, millet (*Pennisetum glaucum*), fonio (*Digitaria exilis*), cowpeas (*Vigna unguiculata*), and peanuts (*Arachis hypogaea*) as field crops, supplemented with garden plants and root crops such as yams (*Dioscorea cayennensis)*, cassava (*Manihot esculenta*), and sweet potatoes (*Ipomoea batatas*). Nevertheless, the cultivation of maize and cotton using new techniques like animal-drawn plows, inorganic fertilizers, and permanent fields is increasingly common (Laris, Foltz, and Voorhees 2015; Moseley and Gray 2008). Some even argue that cotton cultivation has driven agricultural "extensification," which has degraded and reduced forested areas (Benjaminsen, Aune, and Sidibé 2010).

Amidst these significant agroecological changes, farmers are still very dependent on natural capital provided by forests and uncultivated areas. For example, a survey from the same ecoregion of southern Burkina Faso found that 82 unique species of trees provided useful nontimber forest products (Paré et al. 2010). Most prominently, shea trees (*Vitellaria paradoxa*) provide the ubiquitous shea oil, while Néré trees (*Parkia biglobosa*)

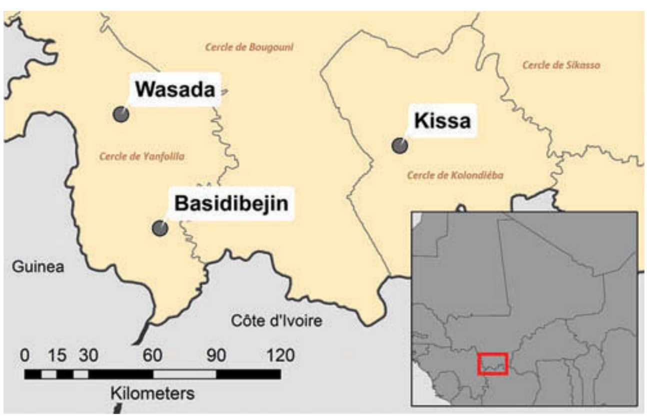

Figure 1. Study villages in southern Mali.

provide both a yellow powdery fruit and seeds that are fermented to create the protein-dense and nutritious food known as *soumbala*. Beyond tree products, bushmeat and fish are also frequently harvested, as well as a wide variety of greens that are used in sauces, providing micronutrients and making diets more diverse.

Methods and data

Our approach involved fieldwork in three villages in the study region. Household surveys collected data on farming practices, diet, income, food purchasing, and child health, as well as on possible controlling variables in 114 households. In addition, forest surveys collected biodiversity data in forest plots around each of the study villages. All of the variables used in analysis are presented in table 1. When selecting villages to conduct surveys, we first selected a village called Kissa in the Cercle of Kolondieba, which had high rates of cotton cultivation and was very typical of the entire Sikasso Region. The first author had served in this village as a Peace Corps Volunteer and had strong connections in the community. In the Yanfolila region, we asked the mayor to introduce us to villages with characteristics similar to Kissa in terms of population and distance to markets and hospitals. We requested that one of the villages be significantly invested in cotton cultivation and one be only slightly invested in cotton cultivation. We selected the villages of Wasada and Basidibejin using these criteria, giving a clear continuum of cotton investment, with Basidibejin as the most invested in cotton (on average, cotton was 40.6% of a household's total farming area, and 96% of households were growing cotton), Kissa as moderately invested (29.7% of total farming area and 88% of households growing cotton), and Wasada as the least invested (17.4% of total farming area and 65% of households growing cotton). There is little reason to suppose that the variations in cotton investment are due to anything other than natural variation as each village was roughly equidistant to a market town and each village had cotton cooperatives that worked with the cotton company CMDT. Interviews and surveys were conducted in Bambara with a local research assistant. The first author is fluent in the language.

Household-level analysis

From the household surveys, associations were tested at the household level between cotton cultivation and diet, cotton cultivation and food purchasing, cotton cultivation and food cultivation, cotton cultivation and malnutrition, and cotton income and malnutrition. While we collected data on cotton income, we were unable to collect data on every other possible form of household income, and therefore did not do any analyses using global

Table 1. Description and Summary of All Variables Used in Regressions.

Variable	Description	Table	Mean	Maximum	Minimum	Median	n
Beans	Times beans consumed in a month	1	4.03	31	0	2.25	114
Bushmeat	Times bushmeat consumed in a month	1	1.75	31	0	0	114
Dairy	Times dairy consumed in a week	1	3.15	10	0	2.25	114
Dried fish	Times dried fish consumed in a month	1	22.6	31	0	31	114
Eggs	Times eggs consumed in a week	1	1.44	9	0	0.5	114
Fresh fish	Times fresh fish consumed in a month	1	8.45	31	0	4.5	114
Meat	Times meat consumed in a month	1	3.66	25	0	2.75	114
Household size	Individuals living in the household	1, 2, 4, 6	14.3	58	1	12	114
Cotton (ha)	Total hectares of cotton farmed	1, 2, 4, 6, 7	2.69	11.5	0	2	114
Non-cotton (ha)	Total hectares of non-cotton crops farmed	7	5.88	23	1	4.63	114
Bean	Whether beans purchased in a typical month	2	0.78	1	0	1	82
Bitter eggplant	Whether bigger eggplant purchased in a typical month	2	0.62	1	0	1	82
Cassava	Whether cassava purchased in a typical month	2	0.56	1	0	1	82
Eggplant	Whether eggplant purchased in a typical month	2	0.56	1	0	1	82
Flour	Whether flour purchased in a typical month	2	0.41	1	0	0	82
Hot pepper	Whether hot pepper purchased in a typical month	2	0.63	1	0	1	82
Potato	Whether potato purchased in a typical month	2	0.48	1	0	0	82
Rice	Whether rice purchased in a typical month	2	0.83	1	0	1	82
Salt	Whether salt purchased in a typical month	2	0.99	1	0	1	82
Sugar	Whether sugar purchased in a typical month	2	0.98	1	0	1	82
Sweet potato	Whether sweet potato purchased in a typical month	2	0.54	1	0	1	82
Tomato	Whether tomato purchased in a typical month	2	0.73	1	0	1	82
Yam	Whether yams purchased in a typical month	2	0.68	1	0	1	82

(*Continued*)

Table 1. (Continued).

Variable	Description	Table	Mean	Maximum	Minimum	Median	n
Bambara groundnut	Total hectares of bambara groundnut farmed in 2013	4	0.09	2	0	0	114
Cowpeas	Total hectares of cowpeas farmed in 2013	4	0.21	2	0	0	114
Fonio & dah	Total hectares of fonio & dah farmed in 2013	4	0.24	3	0	0	114
Maize	Total hectares of maize farmed in 2013	4	3.27	20	0	2	114
Millet	Total hectares of millet farmed in 2013	4	0.11	3	0	0	114
Peanuts	Total hectares of peanuts farmed in 2013	4	0.78	9	0	0.5	114
Rice	Total hectares of rice farmed in 2013	4	0.41	2	0	0.25	114
Sesame	Total hectares of sesame farmed in 2013	4	0.33	3	0	0	114
Sorghum	Total hectares of sorghum farmed in 2013	4	0.42	6	0	0	114
Soya	Total hectares of soya farmed in 2013	4	0.04	1	0	0	114
Income per hectare	Income from cotton in 2013	5	6,530	149,000	−86,800	9,020	85
5-year infant mortality rate	Number of infant deaths in the past year, divided by the number of household members	5, 6	0.05	0.67	0	0	108
Animal wealth	Total market value of livestock owned by household	5, 6	1,560,000	12,300,000	0	883,000	114
Child care	An index of household investment in child care (see Household-level analysis section)	5, 6	1.69	2	0	2	108
Literacy per capita	Number of individuals in household who can read, divided by household size	5, 6	0.21	1	0	0.22	114
MUAC	Mid-upper arm circumference	5, 6, 8, 9	−1.33	2.41	−5.12	−1.30	364
Biodiversity	Number of unique trees per village, divided by the number of sample plots	7, 8, 9	3.39	3.82	2.94	3.44	3
Market distance	Distance to a market town	8	4.74	7	2.7	4	3
Population density	Population per square kilometer	9	25.0	32.5	7.07	31.4	3

household income. To examine rates of cotton farming within a household, we used the number of hectares of cotton that a household reported farming in the previous cotton season (2013). In every regression run with this variable, we controlled for variation in household size. To look at household diet, household heads were asked how frequently various food items were eaten within the household—a common technique in assessing diet in household surveys (Aberman, Merrman, and Benson 2015). Although some staple foods were found to be eaten daily with little variation between households, other foods were found to have highly variable rates of consumption between households, especially investment-intensive proteinaceous foods such as meat, eggs, and dairy. These were the food items used in our analyses. For food purchasing, households were asked whether they had purchased a large variety of food items within the past month. Again, those that varied significantly between households were used in the regressions. To look at cotton income, we used profits per hectare from cotton cultivation instead of raw cotton income. For households that finished the season in debt, negative values were used in the regressions. Finally, for child health, two variables were used: the *z* score of the child's mid-upper arm circumference (MUAC) for the child's age based on a WHO reference table (De Onis, Yip, and Mei 1997) and the household's five-year child mortality rate, measured as the number of children that passed away in the household in the past five years, normalized by the household size. Both variables applied to children under five years of age, and 364 children less than five years old were found among the 114 households.

Controlling variables were also included in the regressions when necessary. Variables measured were the number of people living in the household, the market value of the household's livestock, the number of literate people in the household, and the amount of child care provided by the household. The latter variable consisted of an index from 0 to 2 calculated as the number of children who had received vaccines only available at a hospital, plus the number of children who had received oral antiparasitic medicines, divided by the total number of children. This was because households vary in the amount of time and money they choose to invest in child care: some poorer households may invest more into child care and therefore have healthier children than their income or diet may reflect. This variable was meant to explain such variability.

To test these associations, multiple linear regressions were run between the variables in question. When ANOVA or MANOVA tests showed significant intervillage variation for a given variable, village dummy variables were included to account for these village-level fixed effects. For every regression, appropriate validation was conducted, including testing for normality among the residuals and testing to assure there was no multicollinearity among multiple predictor variables. The study protocol was approved by UNC-Chapel Hill's internal review board, and every study subject gave consent before being surveyed. Furthermore, parents gave consent before their child's mid-upper arm circumference (MUAC) was measured.

Village-level analysis

In addition to examining associations between cotton cultivation, diet, income, and health at the household level, we tested to see whether there were relationships between child health, household cotton area, and biodiversity in terms of tree species richness at the village level. For this analysis, our child health outcome variables were child mid-upper arm circumference (MUAC) and household child mortality rate. To measure tree species richness, we identified trees with the assistance of local hunters in a total of 36 plots of 10-meter radius. These plots were selected using a transect-based sampling method that involved walking in each cardinal direction from the village center, pausing every 250 meters to assess whether there were more than three woody plants that were greater than two inches at breast height within 10 meters. If so, the area was counted as forest and all the trees within the plot were measured and identified. Then, the total number of unique tree species was divided by the number of plots per village, yielding an indicator of tree species richness per plot area. Because each village did not have the same number of sample plots, the raw number of unique tree species could not be used without first normalizing by the number of sample plots. This tree species richness variable was then related to either child health variables or household cotton area, with the village-level controlling variables of population density and distance to market. Population density was calculated as people per square kilometer at the administrative level of the Commune, using data from Mali's 2010 census (Institut National de la Statistique 2009), while distance to town was drawn from Harvest Choice's market distance data (Harvest Choice 2011), which is based on road distances and qualities. Population density in the regressions was meant to account for the amount of natural capital available per individual, and distance to town was meant to account for the availability of markets and hospitals for households within a given village.

Results

Cotton and diet

To determine whether cotton-cultivating households had significantly different diets from non–cotton cultivating households, a multiple linear regression was run for all households between a household's total cotton hectares and frequency of consumption of various food items (see table 2). Foods used in this regression were meat, bushmeat, beans, dry fish, dairy, and eggs (see figure 2). Other foods that were reported to be eaten very regularly across all households and villages were not included in the regression. This includes foods such as *toh* (the ubiquitous staple dish), rice, peanuts, and couscous. For example, 94.7% of households said they ate *toh* twice a day, and 95.1% said they ate peanuts at least once a day.

Table 2. Food Consumption and Cotton Area.

	Estimate	Standard error	Pr(>|t|)
Intercept	3.37	0.574	5.40e-08***
Meat	0.0673	0.0502	0.183
Bushmeat	−0.0314	0.0417	0.454
Beans	−0.0152	0.0327	0.643
Fresh fish	−0.0131	0.0197	0.507
Dried fish	−0.0117	0.0170	0.494
Dairy	0.133	0.0712	0.0652
Eggs	0.0283	0.107	0.792
Household size	0.0767	0.0195	0.000153***
Village: Kissa	−2.12	0.483	2.86e-05***
Village: Wasada	−3.45	0.611	1.44e-07***

Note. Relationship between high value food items (independent variable) and household total cotton area (dependent variable), with village dummy variables and household size as a controlling variable (*n* = 114). Pr = the p-value for the hypothesis test as the test statistic; *** = significant at alpha < 0.001.

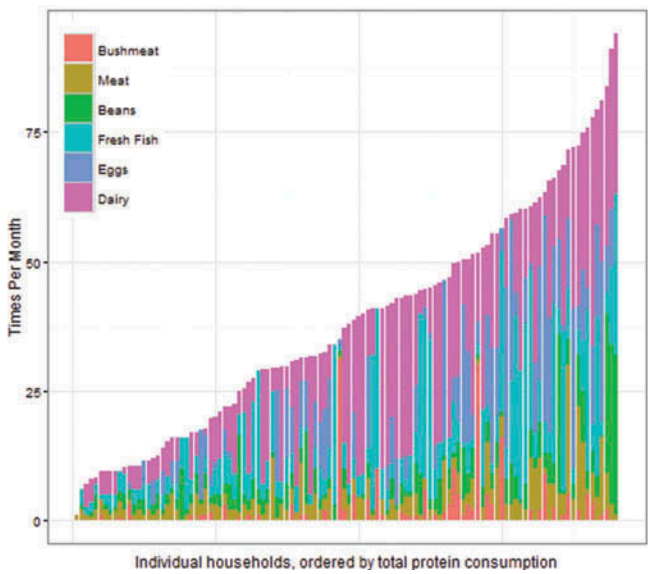

Figure 2. Frequency of major protein sources per month.

A MANOVA showed that the villages did not have significantly different diets for nearly all food items, but an ANOVA test showed that the three study villages had significantly different levels of cotton cultivation with a *p* value of 1.85e-07. To account for village-level fixed effects in exploring the relationship between diet and cotton cultivation, village dummy variables were added to the model. Furthermore, because household size could affect both a household's total hectares of cotton cultivated and the household's diet, it was included as a controlling variable.

This regression showed that there was no relationship between cotton cultivation and frequency of consumption of high-value proteinaceous foods. Thus, our results suggest that households' diets vary independently of households' investment in cotton cultivation.

Cotton and food purchasing

To see whether cotton-producing households supplement their diets with purchased food, data were also collected on whether households purchase various food items in a typical month. These data were collected in every household in Wasada and Kissa. However, due to time constraints, the surveys were simplified in Basidibejin, and food-purchasing data were not collected there, leaving a sample size of 82 for this subanalysis. The food items that purchasing data were collected for included items that almost all households purchase, such as cooking oil and sugar; items that households could grow but could also purchase, such as tomatoes and beans; and items that are not grown in the study region and are viewed as luxury items, such as potatoes. Two food items—salt and Maggi (bouillon cubes)—were purchased by every household. All other food items were used as binary predictor variables in a multiple linear regression with a household's total cotton hectares as the outcome variable (see table 3). In this regression, household size was included as a controlling variable. In testing for multicollinearity among the predictor variables, the variable inflation factor (VIF) was used instead of a matrix of Pearson's correlation coefficients because the predictor variables were binary variables.

Only a slightly significant relationship was found between the purchasing of hot peppers and household's total cotton area. Given that the relationship is weak and there is no a priori reason why purchasing fewer hot peppers in particular should relate to cotton production, this is likely a coincidental relationship. Thus, we found no meaningful association between a household's total cotton area and a household's food purchasing patterns.

This lack of a statistical association between cotton cultivation and food purchasing matches well with our data on what households purchased with their income (see table 4). Only 2 households reported that one of the top two things they spent their cotton money on was food (2.3%). Much more common responses were paying off loans (45.2%), purchasing livestock (32.1%), purchasing farming equipment (16.7%), or paying a bride price (13.1%). Furthermore, all of the 114 households surveyed produced food crops in addition to cotton: None had switched entirely to growing cotton.

Cotton and cultivation of other crops

In investigating whether there were tradeoffs between cotton cultivation and cultivation of food crops, we ran a multiple linear regression with hectares of food crops predicting the hectares of cotton cultivated within a household (see table 5). The food crops included in this regression were every major

Table 3. Food Purchasing and Cotton Area.

	Estimate	Standard error	Pr(>|t|)
Intercept	4.26	2.31	0.0688
Sugar	−0.0584	1.35	0.966
Flour	0.438	0.406	0.285
Salt	−2.48	1.94	0.207
Tomato	0.455	0.557	0.416
Yam	−0.492	0.471	0.300
Rice	−0.558	0.583	0.342
Bean	−0.401	0.505	0.429
Potato	−0.187	0.423	0.660
Hot pepper	−0.999	0.585	0.0921
Bitter eggplant	0.0522	0.587	0.929
Eggplant	0.379	0.496	0.447
Sweet potato	−0.332	0.488	0.498
Cassava	0.404	0.522	0.441
Household size	0.0769	0.0182	7.13e-05***

Note. Relationship between purchasing of various food items (independent variable) as predictors of total cotton hectares (dependent variable), by household (n = 82). Pr = the p-value for the hypothesis test as the test statistic; *** = significant at alpha < 0.001.

Table 4. Household purchasing from cotton income.

Household purchased	Number of households	Percentage
Paid off loans	38	45
Livestock	27	32
Farming equipment	14	17
Marriage	11	13
Housing	10	12
Medicine	5	6
Moto	4	5
Food	2	2
Grain mill	2	2
Shop	1	1
Kids' toys	1	1
Clothes	1	1

Note. Top two items households purchased with the previous year's income from cotton farming (n = 93).

field crop cultivated in the Sikasso region of Mali: maize, sorghum, millet, rice, peanuts, cowpeas, Bambara groundnuts, sesame, fonio & dah (*Hibiscus sabdariffa*, grown alongside fonio), and soybeans. Household size and village dummy variables were also included as controlling variables.

This regression showed that the only crop that varied significantly with cotton cultivation was maize, and increased maize cultivation in fact predicted increased cotton cultivation. No crop decreased as cotton cultivation increased.

Cotton income and child health

Some farmers had official paperwork on the total amount of money they received from the most recent season of growing cotton after they had paid off their loans for cottonseed, fertilizers, pesticides, and other inputs, and these data were used in

Table 5. Cotton Area and Food Crop Area.

	Estimate	Standard error	Pr(>|t|)
Intercept	2.96	0.565	9.11e-07***
Maize	0.169	0.0774	0.0318*
Sorghum	0.0479	0.244	0.845
Millet	0.0340	0.507	0.947
Rice	0.0970	0.446	0.828
Peanuts	0.212	0.211	0.318
Cowpeas	−0.523	0.657	0.427
Bambara Groundnut	0.516	0.769	0.504
Sesame	0.360	0.399	0.370
Fonio & dah	−0.182	0.531	0.732
Soya	1.33	1.45	0.362
Household size	0.0470	0.0279	0.0945
Village: Kissa	−1.68	0.702	0.0187*
Village: Wasada	−3.33	0.611	3.77e-07***

Note. Relationship between total hectares of food crops produced (independent variable) and total cotton area (dependent variable), with village dummy variables and household size as controlling variables (n = 114). Pr = the p-value for the hypothesis test as the test statistic; * = significant at alpha < 0.05, *** = significant at alpha < 0.001.

an analysis of cotton income and child health. Households that could not give the exact amount that they had received the previous year were excluded from the analysis. The most any farmer received was 372,813 West African Francs (FCFA), or about $613 USD, while the greatest debt any farmer was left with was 143,600 FCFA or $236 USD. Many farmers, after months of toil, only find themselves in debt: 27% of farmers surveyed ended their most recent farming season with debt. Only 73% of farmers made money from cotton farming, and only a quarter made more than $100 USD (see figure 3). Some farmers interviewed had opted out of cotton farming because they did not see the possible payoff as worth the investment in time, labor, and land. Others chose to farm cotton, even with very low margins and a significant risk of debt, because this gives them access to fertilizer and other inputs, which can be used on food crops.

Given that cotton farming is a financially risky prospect, sometimes leaving farmers with debt or yielding little income after a season of labor and investment, we tested to see whether a famer's per-hectare income from the most recent year of cotton farming could be related to their children's MUAC or the household's five-year infant mortality rate (see table 6). However, there was no significant relationship between a household's cotton income and its health statistics. Multiple linear regressions were run at the individual level, with MUAC as the outcome variable, and at the household level, with household infant mortality rate as the outcome variable. Controlling variables included were household animal wealth, household literacy per capita, household child-care investment, and village dummy variables. The outcome variable used was cotton income per hectare. This was because absolute income is not a clear indication of a household's return on investment; for example, even with a moderate cotton income, if a

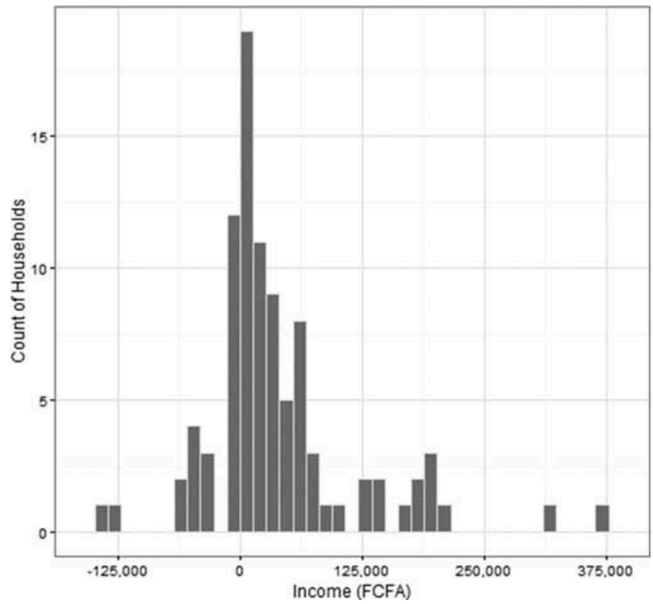

Figure 3. Distribution of household-level income from cotton.

Table 6. Relationship Between Cotton Income and Child Health.

	5-year infant mortality rate		MUAC	
	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
Intercept	5.43E-02	0.0502	−1.61E+00	1.13e-13***
Income per hectare	2.50E-07	0.338	−2.07E-06	0.264
Animal wealth	−4.00E-09	0.320	9.75E-10	0.968
Literacy per capita	−5.85E-02	0.296	3.31E-01	0.428
Child care	−1.46E-02	0.261	1.36E-01	0.156
Village: Kissa	2.17E-02	0.218	−1.87E-01	0.133
Village: Wasada	5.33E-02	0.0500	2.67E-01	0.201

Note. Two regressions showing the relationship between cotton income per hectare of cotton farmed (independent variable) and child health (dependent variable) as measured by 5-year infant mortality rate (at household level, $n = 93$) and MUAC (at individual level, $n = 286$). Household wealth, per capita literacy rate, and child-care investment are included as controlling variables. Pr = the p-value for the hypothesis test as the test statistic; *** = significant at alpha < 0.001.

household committed significant time and energy into cotton cultivation instead of focusing on child care, food production, or other income-generating activities, this could theoretically have a negative effect on child health. A household earning 50,000 CFA from five hectares of cotton and a household earning 50,000 CFA from one hectare of cotton should not be treated the same in a regression, and so normalizing income by total cotton area adjusts for this.

After looking at two different indicators of child malnutrition, no relationship was found between cotton income and children's health.

Cotton area and health

Having found no evidence that cotton cultivation or cotton income was related to a household's diet or child health outcomes, two models were run to determine whether a direct statistical relationship existed between cotton cultivation and child health outcomes (see table 7).

We found no significant relationship at the household level between cotton cultivation and two different indicators of child health when accounting for various controlling variables and for village-level fixed effects.

Cotton and biodiversity

There are theoretical reasons why cotton cultivation in a village would lead to decreased natural capital: Cotton is a very environmentally taxing crop that some authors argue has contributed to deforestation and land degradation in Mali (Benjaminsen, Aune, and Sidibé 2010; Stechert et al. 2014). We examine this empirically for our study villages by testing for an association between a given household's cotton area and the tree species richness in areas surrounding that household. We found the highest tree species richness in Wasada, with 3.81 unique tree species per plot area; moderate species richness in Basidibejin, with 3.44 trees per plot area; and the least diversity in Kissa, with 2.97 trees per plot area. In testing for association, we used a simple linear regression at the household level (see table 8).

We found that the total number of cotton hectares a household cultivates is significantly associated with the biodiversity levels in the forests around that household's village, while at the same time biodiversity has no significant association with a household's agricultural area that is not used for cotton. Every additional two hectares of cotton that a farmer cultivates was associated with one fewer tree species in a 20-m diameter forest plot.

Table 7. Cotton Area and Child Health.

	MUAC		5-year infant mortality rate	
	Estimate	Pr(>|t|)	Estimate	Pr(>|t|)
Intercept	−1.816e+00	3.81e-08***	7.37E-02	0.114
Cotton (ha)	−3.81E-02	0.298	−1.26E-04	0.984
Literacy per capita	−1.21E-01	0.784	−8.24E-02	0.232
Child care	2.69E-01	0.0618	−1.24E-02	0.561
Animal wealth	1.70E-08	0.614	−5.32E-09	0.308
Household size	4.25E-03	0.607	−1.41E-03	0.282
Village: Kissa	−2.88E-02	0.878	4.40E-02	0.146
Village: Wasada	1.03E-01	0.644	7.30E-02	0.0431*

Note. Two regressions showing the relationship between total hectares of cotton farmed (independent variable) and child health (dependent variable) as measured by 5-year infant mortality rate (at household level, n = 114) and MUAC (at individual level, n = 364). Household wealth, per capita literacy rate, and child-care investment are included as controlling variables. Pr = the p-value for the hypothesis test as the test statistic; * = significant at alpha < 0.05, *** = significant at alpha < 0.001.

Biodiversity and health

To examine linkages between biodiversity and human health, separate regressions were run for household infant mortality rate and child mid-upper arm circumference (MUAC) with village-level biodiversity as the predictor variable. Household infant mortality rate was measured at the household level (n = 114), and child MUAC was measured at the individual level (n = 364). Biodiversity was measured at the village level, as were the controlling variables of population density and distance to town. Because the sample size was three villages, only two predictor variables at the village level could be used in one regression, meaning that separate regressions had to be run to account for population density (see table 9) and distance to town (see table 10), and no single model could account for both controlling variables.

While no relationship was found between a household's child mortality rate and biodiversity, biodiversity was a significant predictor of MUAC, even when considering a village's distance to market or the population density of the area.

When accounting for a village's distance to market, every additional tree species in a plot was associated with an increase in children's MUAC z score of 0.58. This is significant, given that the average MUAC for the study villages

Table 8. Cotton Area and Biodiversity.

	Estimate	Standard error	Pr(>|t|)
Intercept	3.45	0.0668	<2e-16***
Cotton (ha)	−0.0326	0.162	0.0468*
Non-cotton (ha)	0.00441	0.0101	0.663

Note. Relationship between raw hectares of cotton per farmer (independent variable) and biodiversity as measured by tree species richness (dependent variable) (n = 114). Pr = the p-value for the hypothesis test as the test statistic; * = significant at alpha < 0.05, *** = significant at alpha < 0.001.

Table 9. Biodiversity and MUAC, with Population Density. Pr = the p-value for the hypothesis test as the test statistic; *** = significant at alpha < 0.001.

	Estimate	Pr(>|t|)
Intercept	−3.01	3.14e-12***
Biodiversity	0.456	9.27e-05***
Population density	0.00421	0.292

Note. Relationship between biodiversity (independent variable) and child mid-upper arm circumference (dependent variable), with population density as a controlling variable (n = 114). Pr = the p-value for the hypothesis test as the test statistic; *** = significant at alpha < 0.001.

Table 10. Biodiversity and MUAC, with Market Distance.

	Estimate	Pr(>|t|)
Intercept	−3.55	2.86e-06***
Biodiversity	0.589	0.000841***
Market distance	0.0406	0.292

Note. Relationship between biodiversity (independent variable) child mid-upper arm circumference (dependent variable), with distance to market as a controlling variable (n = 364). Pr = the p-value for the hypothesis test as the test statistic; *** = significant at alpha ≤ 0.001.

had a z score of −1.33. If the relationship between tree species richness and child MUAC is causal, then increasing the number of unique trees around a village could have positive child health outcomes. According to the regression presented in table 8, increasing the number of unique tree species per plot area by 2.29 could lead to an average MUAC z score of 0, meaning that children have adequate body mass according to WHO standards.

Discussion

Cotton, diet, and farming systems

Associations were tested at the household level between cotton cultivation and diet, food purchasing, and food cultivation. In addition, we tested for associations between malnutrition and both cotton income and cotton cultivation in hectares.

It was hypothesized that households dedicating a significant proportion of their farmland to cotton cultivation would have significantly different diets from those that do not invest in cotton cultivation. This is a possible explanation of the Sikasso paradox: Cotton production and malnutrition overlap in Mali because cotton cultivation competes with food production and decreases food security. This hypothesis assumes that there are necessary tradeoffs between investment in food crop production and investment in cotton production in terms of time, land area, and agricultural inputs. We hypothesized that cotton-growing households would eat less nutritious, protein-dense, and investment-intensive foodstuffs like meat, beans, fresh fish, dairy, and eggs, which play a more critical role in nutrition (FAO 1997; Remans et al. 2012; Schönfeldt and Gibson Hall 2012). However, cotton-farming households are able to secure those foods at the same rate as non–cotton-farming households.

This would seem to indicate that while cotton farmers could not directly produce as much food as non–cotton-farming households, they purchased additional food from their cotton earnings. However, we found no relationship between cotton farming and food purchasing at the household level for any food item, suggesting that cotton-farming households do not supplement their diets with purchased goods. A naïve model of livelihood diversification would maintain that there are tradeoffs between subsistence crop production and cash crop production. Thus, investing less in subsistence farming and more in cash crop production allows households to increase their financial capital, but at the expense of subsistence crop production. Our research does not entirely support this hypothesis: Although cotton-farming households are able to secure proteinaceous foods at the same rate as non–cotton-farming households, this is not because they are purchasing foods with their cotton income. Not only did cotton-farming households report purchasing food at the same rates as non–cotton-farming households, only 2% of them even mentioned food as something they bought with their cotton income.

Rather, our evidence suggests that for cotton farmers in the Sikasso region of Mali, there is not a direct trade-off between cotton cultivation and food cultivation. This is supported by our findings that no food item decreased in area under cultivation as cotton area increased. In fact, maize cultivation increased alongside cotton cultivation within households because of the higher-impact tools and inputs made available by cotton cultivation, such as ox-drawn plows and artificial fertilizers. This is shown by our evidence and has been documented by other researchers (Laris, Foltz, and Voorhees 2015). In fact, some of the fertilizers offered on loan by the Malian cotton company CMDT are intended specifically for use on maize.

The evidence seems to indicate that, for farmers in southern Mali, cotton cultivation is done in addition to subsistence agriculture, rather than in place of subsistence agriculture. This fits with a long history of cotton cultivation leading to increasing agricultural sophistication, from the postcolonial Rural Development Organizations that first supported farmers in agricultural modernization and began to encourage cotton cultivation (Moseley and Gray 2008) to the relatively recent adoption of animal-drawn plows in the Sikasso region of Mali (Laris and Foltz 2014). Farmers thus do not plan to significantly supplement their diet with food purchased from their cotton income, but rather continue to cultivate the same amount of food as they did previously. Rather than competing with food production at the household level, cotton cultivation appears to have facilitated agricultural intensification, allowing households to access agricultural inputs and tools on credit, as well as purchase them directly. Indeed, the second-most-purchased good from cotton income was agricultural tools and inputs, and the most commonly purchased good, livestock, can play a significant role in increasing agricultural output. Thus, it seems that farmers can cultivate cotton without having to grow less food or jeopardize their household food security.

Cotton and malnutrition

The only significant agricultural change in terms of food availability that cotton has brought about has been an increase in maize production and therefore an increase in maize consumption relative to traditional grains such as sorghum, millet, and fonio. Nevertheless, the nutritional differences between maize and traditional grains such as sorghum and millet are marginal (McKevith 2004). All of these crops provide mostly carbohydrate energy, some protein, and some minerals (FAO 1997) and would not be said to be significantly different functionally (Remans et al. 2012). Thus, cultivating and consuming these crops at different rates would be unlikely to significantly affect child health.

It is unsurprising that we found no relationship between cotton cultivation and child malnutrition at the household level, given that we also found no overall relationship between a household's rate of cotton cultivation and that household's diet. Even when using cotton income per hectare as a measure of a household's success at cotton cultivation, we still did not find a significant relationship with malnutrition. Whether a household was very successful or very unsuccessful at growing cotton in no way predicted how well nourished the children of that household were.

The fact that no significant relationship was found between income from cotton cultivation and children's health may simply reflect the fact that our data set only included one year of cotton income data. If income and debt from cotton cultivation do affect child health, this process may be cumulative over several years. Furthermore, a household's income from cotton cultivation may vary significantly from one year to the next. So, a one-time snapshot of a long-term process may not accurately show an association between two phenomena when this association does in fact exist. However, if there is an association, it is not salient enough to be apparent in our sample of 114 households. There may very well be no overall relationship between a household's cotton income and the health of that household's children. Von Braun found several examples of cash cropping increasing a household's income but having no effect on a household's child health rates (Von Braun 1995). Our data suggest that cotton farming could be another example of this phenomenon.

Overall, we found no evidence of cotton cultivation significantly affecting a household's ability to feed its children, probably because households have a wide variety of income diversification and livelihood enhancement strategies. While alternative income strategies to cotton cultivation were not quantified in this study, many exist in the study region: Charcoal production, sending family to work abroad or in urban centers, gold mining, animal investment, and commerce are all practiced by households. Thus, households are highly adaptable in managing their access to capital and ensuring their children's food security. They surely would not invest significantly in a livelihood strategy that clearly does not lead to sustainable livelihood improvements.

Cotton and natural capital

While we found no evidence that growing cotton as a livelihood strategy hurts a household's overall food security, we found some limited evidence that the area of cotton grown is associated with less biodiversity, which is an indicator of ecosystem functioning and thus available ecosystem services and natural capital (Mertz et al. 2007). This diminished natural capital was associated with higher rates of child malnutrition: The biodiversity levels around a village were a significant predictor of the arm circumference of any given child from that village. Furthermore, we found no significant relationship between non-cotton crop area and biodiversity, suggesting that it may be cotton production alone that is affecting biodiversity. As has been discussed, cotton cultivation requires a significant amount of pesticides and fertilizers, degrades soils (Benjaminsen, Aune, and Sidibé 2010; Moseley 2008), and can hurt pollinators (Stechert et al. 2014). Cotton is usually grown in fields using animal-drawn plows, and these fields take longer to return to a forested state when left swidden compared to fields cultivated using hand plows (Laris 2008). The agricultural intensification associated with cotton also increases agricultural land rents, which can incentivize agricultural expansion and deforestation (Phelps et al. 2013). This is especially significant in rural Mali, where livelihoods still depend directly on forest resources. Thus, it is possible that cotton cultivation plays some role in affecting child health at the village level by reducing the critical natural capital on which livelihoods depend.

However, this study was limited in several ways. It only sampled from three villages and did not have enough data to demonstrate a causal relationship between cotton growing, natural capital, and malnutrition. Thus, we are only able to present limited evidence of an association between the three trends, and we found no relationship between biodiversity and one of the two child health outcomes that we measured. There are also many other possible interpretations of our findings. For example, it is possible that farmers select areas that are already less biodiverse to grow cotton, perhaps because those areas are closer to villages or already have a history of agricultural production. We also did not have enough data to account for edaphic and other factors that could affect biodiversity, such as a village's land use history or the relative scarcity of land available for conversion to agriculture within a village's environs. Given these alternative factors that affect biodiversity that we were unable to measure, as well as our small sample size, our findings at the village level should be taken as suggestive and not conclusive.

Managing natural capital that is a commonly held good can be very difficult for communities when new livelihood strategies (i.e., cotton cultivation) incentivize individuals to take as much of that capital as they can. Our evidence suggests that this is the case in the Sikasso region of Mali: People's livelihoods depend on a mix of food produced on their own fields, financial capital obtained from cotton cultivation and various other sources, and natural capital procured from uncultivated areas such as forests, rivers, and savannas. These uncultivated areas and the resources they provide are traditionally available to anyone in a community (Wily 2008) and are often a major livelihood resource for more marginalized households within a community (Agarwala et al. 2014). So while households are investing in cotton to increase agricultural productivity and available financial capital, an externality of this investment may be that villages are losing the natural capital that provides the food, fuelwood, and resources that are necessary for adequate child nutrition.

Nevertheless, households and communities in Sikasso are adapting their livelihoods within this dynamic agroecological context. Some adaptation is taking place at the household level: In one of the villages, some farmers were growing soybeans, explicitly as a dietary substitute for the increasingly rare forest resource of soumbala. Households are planting tree plantations of eucalyptus, mangoes, gmelinia, teak, citrus, and cashews as a way to produce tree-based resources such as fruit and timber that were traditionally available in forests. Furthermore, nearly all farmers surveyed recognized that loss of natural capital was a critical and worrying issue that was affecting their livelihoods. Because of this recognition, communities are continuing to enforce traditional taboos against harvesting resources from certain parts of forests. Thus, while the loss of natural capital and cash crop expansion may be playing a role in harming child health in Sikasso, it is already clear that households and communities are adapting their livelihoods to these changes. Indeed, malnutrition rates in Sikasso are less outstanding than they used to be: The 2012 Demographic and Health Survey showed a marked improvement in multiple indicators of child heath for the Sikasso region compared to the 2006 Demographic and Health Survey (CPS/MS 2007; CPS/SSDSPF 2014), both by absolute metrics and relative to other regions.

Conclusion

It is highly unlikely that households would do something as irrational and self-defeating as grow a crop that bankrupts them and leaves children malnourished, as some interpretations of the Sikasso paradox suggest. Our study confirms this: We found no association between cotton cultivation and malnutrition at the household level. Thus, while our study did not fully explain the Sikasso paradox, it did disprove one explanation. However, pursuing one form of capital can often happen at the expense of another, especially at different scales, and this can lead to unintended consequences and externalities. Our study offers a possible example of trade-offs between household-level and village-level capital in the context of cash cropping. While our study offers very limited evidence that cotton is causing malnutrition by depleting villages' natural capital, it presents strong evidence that household-level agricultural decision making is not the reason that the Sikasso region has such unexpectedly high rates of malnutrition.

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