GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN IN PUBLICA COMMODA SEIT 1737

GRK 2654
Sustainable Food Systems

RTG 2654 Sustainable Food Systems

University of Goettingen

SustainableFood Discussion Papers

No. 7

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July 2024

RTG 2654 Sustainable Food Systems · Heinrich Düker Weg 12 · 37073 Göttingen · Germany
www.uni-goettingen.de/sustainablefood

ISSN (2750-1671)

Suggested Citation

Wätzold, M.Y.L., I. Abdulai, A. Cooke, K. Krumbiegel, C. Ocampo-Ariza, A. Wenzel, M. Wollni (2024). Do voluntary sustainability standards improve socioeconomic and ecological outcomes? Evidence from Ghana's cocoa sector. SustainableFood Discussion Paper 7, University of Goettingen.

Imprint

SustainableFood Discussion Paper Series (ISSN 2750-1671)

Publisher and distributor:
RTG 2654 Sustainable Food Systems (SustainableFood) – Georg-August University of Göttingen
Heinrich Düker Weg 12, 37073 Göttingen, Germany

An electronic version of the paper may be downloaded from the RTG website:

www.uni-goettingen.de/sustainablefood

Do voluntary sustainability standards improve socioeconomic and ecological outcomes? Evidence from Ghana's cocoa sector

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Abstract

Voluntary sustainability standards offer potential for sustainable development by improving the livelihoods of smallholder cash crop farmers while conserving biodiversity. However, their overall implications remain poorly understood, as studies have mostly focused on assessing their effects on single sustainability dimensions. Here, we use an interdisciplinary approach to understand the simultaneous effects of sustainability standards on socioeconomic and ecological outcomes in Ghana's cocoa sector. Our study is based on a rich dataset comprising representative household data from 814 smallholder cocoa-producing households from five major cocoa regions and ecological data from 119 cocoa plots. Results from the endogenous switching regression approach suggest that sustainability standards have positive effects on socioeconomic outcomes such as cocoa yield, net cocoa income and net returns to land. However, using generalized linear mixed effects models, we do not find any significant associations with ecological outcomes related to vegetation structure and animal diversity. Our results indicate that sustainability standards in Ghana's cocoa sector lead to socioeconomic benefits but not to ecological benefits for the plot environment. Nevertheless, yield increases do not come at the expense of biodiversity. We conclude that sustainability standards have the potential to improve socioeconomic outcomes, without significantly creating trade-offs with ecological outcomes.

Keywords

Sustainability standards; Certification; Cocoa; Ghana; Biodiversity; Trade-offs

JEL codes

Q01, Q56, Q57

Acknowledgments

We thank the German Research Foundation (DFG) who financially supported this research with the grant number RTG2654 Sustainable Food Systems, our research assistants John Akomatey, Michael Boateng, Yaw Bonsu, Christopher Dankwah and David Wagner who provided exceptional field assistance and all the farmers who devoted their time to answering our questions.

1. Introduction

The commodity crop production sector in many developing countries is associated with low productivity and low prices leading to poverty for smallholder farmers (FAO 2017). At the same time, it is a major contributor to climate change, deforestation, biodiversity loss and land degradation (Grass et al. 2020; Meyfroidt et al. 2014). Meanwhile, demand for sustainably produced products is growing, as consumers in many rich countries are increasingly concerned about how commodities such as tea, coffee or cocoa are produced (Tscharnktke et al. 2015). In response, voluntary sustainability standards have emerged as a promising market instrument to address the challenges of unsustainable production (Dietz et al. 2022). Sustainability standards are sets of social, economic and environmental criteria that define practices of agriculture to increase productivity while reducing environmental impacts and supporting rural livelihoods (Milder et al. 2015). If farmers comply with the criteria set by the sustainability standard, they are promised to receive benefits such as price premiums (DeFries et al. 2017), market access (Oya et al. 2018) or training and agricultural inputs (Sellare et al. 2020b).

Understanding the overall effects of sustainability standards for households and their plot ecosystems is pertinent because sustainability standards can only contribute to sustainable development if their adoption is economically and environmentally viable. However, whether sustainability standards can achieve these goals is still unclear (Meemken et al. 2021). The empirical literature has mainly focused on assessing their effects on either socioeconomic (see review by Meemken (2020) or Oya et al. (2018)) or ecological outcomes (e.g. see review by Tscharnkte et al. (2015) and recent studies by Asigbaase et al. (2019), Hardt et al. (2015) and Pico-Mendoza et al. (2020)); whereby studies that assess both effects are limited (Garrett et al. 2021). Therefore, in this study we seek to analyze the simultaneous effects of sustainability standards on socioeconomic outcomes and plot-level ecological outcomes. Our study uses household and ecological data from the cocoa sector of Ghana.

We use the endogenous switching regression approach to account for potential self-selection to evaluate the effects of sustainability standards on household socioeconomic outcomes including cocoa yield, net cocoa income and return to land. We use generalized mixed effects models to estimate the association between being certified and plot-level vegetation structure such as shade tree crown cover, shade tree diversity and herbaceous ground cover and plot-level animal diversity such as bird abundance, bird richness, biological predation rates and a bioacoustics index.

The primary contributions of this study to the literature are threefold. First, instead of relying on reported practices that are hypothesized to improve biodiversity (Gather and Wollni 2022; Mitiku et al. 2018), we use ecological data derived from extensive plot inventories based on a subsample of 119 cocoa plots. This allows for a reliable assessment of the association between sustainability standards on several ecological indicators.

Second, our household sample based on 814 cocoa farmers comes from a large geographic area that covers five major cocoa producing regions in Ghana and different agro-ecological zones. Apart from Meemken (2021) and Boonaert and Maertens (2023) who use a representative household dataset of Peru, we are not aware of any sustainability standard study covering such a large geographic area. Additionally, our ecological sample covers four cocoa regions. To our knowledge such a large geographic area surpasses previous sustainability standard studies using ecological data.

Third, most previous studies purposely select a few cooperatives or companies from which they sample certified and non-certified farmers and are therefore not fully representative of farmers in that country (Haggar et al. 2017; Mitiku et al. 2017; Vanderhaegen et al. 2019). Additionally, in such cases, bias may occur because cooperatives or companies potentially differ in how well they function, making it difficult to differentiate between certification and other cooperative or company specific factors (Sellare et al. 2020b). In our study, we randomly select farmers from randomly selected communities within our study regions. This makes our sample representative of the five cocoa regions, thereby increasing the external validity of our results.

2. Background

2.1. Conceptual framework and theoretical expectations

Sustainability standards include a bundle of interventions, such as training, provision of inputs or access to credit, that are intended to enhance social, economic and environmental sustainability of agricultural producers (Meemken et al. 2021). To facilitate a better understanding on how sustainability standards, through their interventions, may affect different outcomes at the plot and household level, we develop the following conceptual framework (Figure 1). Considering previous research by Boonaert and Maertens (2023), we relate 1. Price-related interventions, 2. Production-related interventions, and 3. Environment-related interventions to socioeconomic outcomes (such as yields and returns to land) as well as ecological outcomes (such as plot-level vegetation structure and animal diversity).

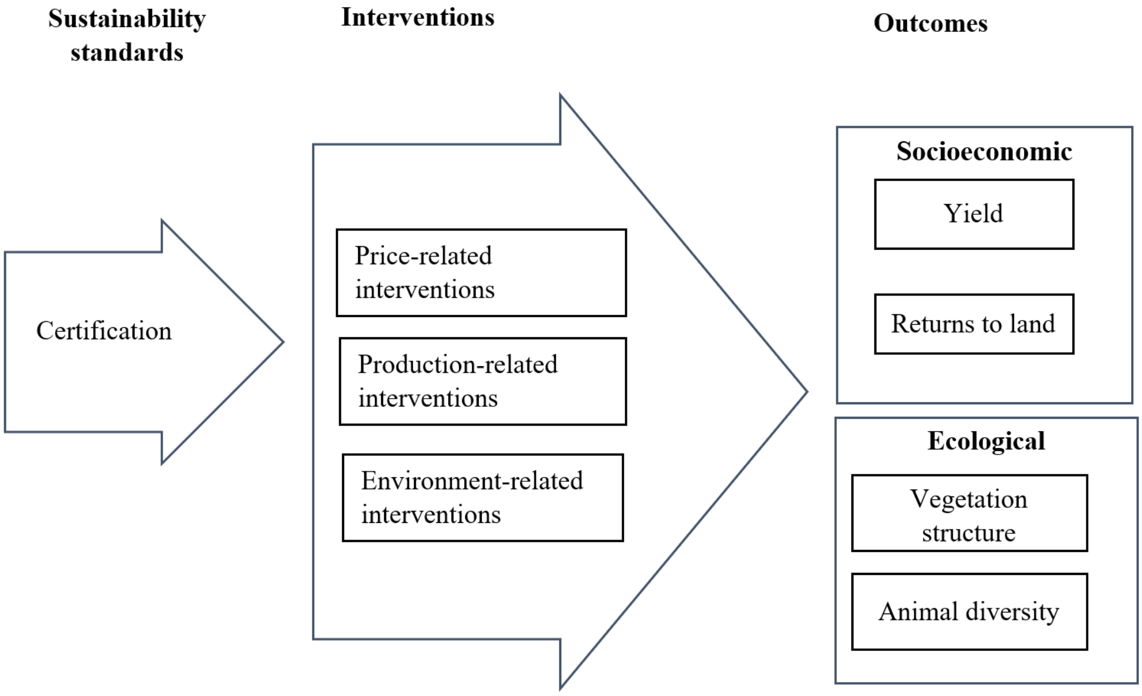

Figure 1: Conceptual framework of how sustainability standards affect outcomes

1. Price-related interventions

Price-related interventions relate to minimum floor prices or additional price premiums that farmers receive based on the amount of certified harvest they sell into the certified market (Oya et al. 2018) and are expected to increase net cocoa income (Boonaert and Maertens 2023). We acknowledge the caveat that markets for certified products are based on consumer demand. There may be occasions where farmers are unable to sell their certified cocoa to the certified market. However, new mechanisms like mass balance sourcing[1] allow for a more consistent demand for certified crops and therefore increasingly alleviate this limitation. We therefore expect certified producers to have higher net cocoa income through receiving price premiums.

[1] Mass balance sourcing, as compared to segregated sourcing, allows certified and non-certified cocoa to be mixed at different stages of the supply chain. This makes it more affordable for companies to source certified crops because they do not need to keep separate tanks or silos and thus is expected to increase demand for certified cocoa at the farm level (Rainforest Alliance 2023b).

2. Production-related interventions

Production-related interventions include farmer training, group formation and improved access to agrochemical inputs (Oya et al. 2018; Sellare et al. 2020a). The training offered to farmers includes topics such as farm business management, record keeping and "Good Agricultural Practices" (GAP) (Schulte 2020). The farm business management and record keeping helps farmers to better plan their farm business, such as making responsible investment decisions, and therefore is expected to increase net cocoa income. GAP refer to a set of sustainable agricultural farming practices that aim to increase productivity while maintaining on-farm ecosystem health (Asare and David 2011). Examples of GAP include adequate fertilizer and agrochemical use, soil management practices such as mulching, integrated pest and weed management and agroforestry or intercropping practices (in the context of cocoa or coffee) (Ibanez and Blackman 2016; Schulte 2020). Furthermore, sustainability standards sometimes support farmer group formation to support collective action (Oya et al. 2018). Farmer groups allow the exchange of information regarding better agricultural practices, joint saving accounts to collectively purchase agrochemicals and the sharing of farming equipment (Abdul-Rahaman and Abdulai 2018). In some cases, sustainability standards also facilitate access to agrochemical inputs through purchases on credit, subsidized distribution and other forms of financial support (Schulte 2020).

These production-related interventions are likely to increase productivity through more and better applied GAP and inputs, which in turn are expected to increase yield and net cocoa income. Increases in productivity can be associated with decreases in ecological outcomes because some yield-enhancing practices have detrimental effects on the environment (Bisseleua et al. 2009). However, potential negative effects should be outweighed by positive effects from environment-related interventions, as explained in the following.

3. Environment-related interventions

To receive or maintain their certification status, farmers must comply with specific requirements, ranging from the prohibition of child labor or fulfilling hired labor conditions (Oya et al. 2018) to the avoidance of deforestation (Garrett et al. 2021). In this paper, we focus on environmental requirements. For instance, sustainability standards promote the correct application of agrochemicals and prohibit the use of certain agrochemicals (Sellare et al. 2020a). Moreover, certain sustainability standards require farmers to maintain a certain percentage of shade tree cover, for example 15% in the case of Rainforest Alliance (Rainforest Alliance, 2020). In order to achieve this, some sustainability standards distribute shade tree seedlings (Schulte 2020; Sellare et al. 2020a). Sustainability standards also offer training on environmentally-friendly practices such as integrated pest management to help farmers reduce the use of agrochemicals and adopt practices that increase biological control agents such as maintaining habitats for beneficial predators on their plots (Rainforest Alliance 2023a).

However, while such environment-related interventions aim to improve or maintain biodiversity and ecosystem health at the plot-level, they could also have negative effects on yield and total net income. For example, resource competition with shade trees might negatively affect cocoa yield (Abdulai et al. 2018b). In addition, higher opportunity costs of household labor or additional hired labor costs needed to perform environmentally friendly practices might reduce total net income (Hörner and Wollni 2021). On the other hand, an improved ecosystem health reduces the risk of pest and disease pressures and the resulting yield loss (Ocampo-Ariza et al. 2023). Moreover, shade trees can improve soil fertility and provide erosion control (Tscharntke et al. 2011). Given that environment-related interventions may have both negative and positive effects on socioeconomic outcomes we expect that their overall effects on socioeconomic outcomes are neutral and socioeconomic outcomes are primarily affected positively by the production and price-related interventions.

2.2. Study context

Cocoa production

Ghana is the world's second largest cocoa producer, yet cocoa yields per hectare remain among the lowest globally (FAO 2023). Reasons for low productivity are linked to lack of knowledge on agricultural technologies and practices, lack of agrochemical inputs, aging cocoa trees, depleted soils and high pest and disease pressures (Schroth et al. 2016; Bymolt et al. 2018). Low productivity coupled with low commodity prices lead to poverty amongst smallholder cocoa farmers (Boysen et al. 2023) and poses environmental challenges such as land degradation (Ruf et al. 2015), land-use change connected to illegal cocoa-driven deforestation (Ruf et al. 2015; Kalischek et al. 2023) and illegal artisanal mining (Attuquayefio et al. 2017).

Traditionally, farmers in Ghana cultivate cocoa under the shade of native forest trees or other crop trees, or a combination of both (Sanderson et al. 2022). While these agroforests cannot fully replace native forests, they play a crucial role in conserving biodiversity by hosting species found in natural forests (Deikumah et al. 2017) and serving as habitat corridors between forest fragments (Asare et al. 2014). Beyond biodiversity conservation, cocoa agroforests can provide a range of beneficial provisioning ecosystem services. For example, shade trees provide fruits, fuel wood, traditional medicine, fodder and building material (Abdulai et al. 2018a). In addition, selected shade tree species improve yields compared to full-sun cocoa plantations under low-input systems (Asare et al. 2017; Asitoakor et al. 2022).

However, many farmers reduce the number of shade trees on their cocoa plots, fearing that these compete with cocoa trees for light, water and nutrients (Asitoakor et al. 2022). These fears arise because under certain conditions, when hybrid cocoa genotypes are planted or extensive agrochemicals are used, low or no-shade cocoa farming may yield more but have a shorter lifespan compared to agroforestry systems (Asare et al. 2019). Moreover, there is a widespread perception among farmers that agroforestry systems create microclimates suitable for pests and disease (Armengot et al. 2016).

Cocoa supply chain and sustainability standards

Major international traders and chocolate companies drive the demand for certified cocoa in Ghana. These companies operate through affiliated government-licensed buying companies (LBCs) that locally source cocoa and are responsible for implementing the desired sustainability standard (Gockowski et al. 2013). LBCs reach out to the farmers through their purchasing clerks: middlemen and women who usually live in the same community, buy cocoa directly from the farmers and channel it to their LBC on a commission basis. In Ghana, the government sets the cocoa price so it is common for farmers to sell to multiple purchasing clerks and LBCs to receive benefits from different buyers (e.g. a purchasing clerk may lend money or guarantee timely payments) (Nitidae and EFI 2021). Many LBCs, independent of their certification status, offer different benefits to cocoa farmers to compete for market share. Benefits include training, group formation, price premiums and the provision of certain agricultural inputs. However, certified LBCs usually offer more trainings per year and provide higher price premiums ranging from 20-35 GHC, which is equivalent to 3-5% of the value of one cocoa bag of 64kg.

Currently, several types of sustainability standards operate in Ghana (Thompson et al. 2022) that differ in their governance structure. First-party certification schemes are private initiatives, where monitoring is based on self-assessment by the company. Second-party certification schemes are governed by interest groups such as industry associations or NGOs. Third-party certification involves governance by external, independent groups who monitor implementation of and compliance with the criteria set by the standard (Steering Committee of the State-of-Knowledge Assessment of 2012). While the primary goal of all standards is to enhance sustainable productivity, initially, some standards used to have a specific focus. Fairtrade, for example, emphasized social aspects such as labor rights and fair prices (Fairtrade 2023b), while the Rainforest Alliance concentrated on environmental conservation and forest protection (Rainforest Alliance 2023c). Over time and in alignment with global sustainability objectives, these standards have evolved to address a broader spectrum of sustainability challenges, and their goals have converged (Lambin and Thorlakson 2018; Meemken et al. 2021). Now most sustainability standards claim to improve productivity and profits by promoting GAP and offering price premiums as well as taking environmental considerations into account to protect biodiversity[2] (Fairtrade 2023a; Lindt & Sprüngli Farming Program 2023; Rainforest Alliance 2023a)

[2] This does not apply to Organic certification, which differs from other sustainability standards by prohibiting the use of all agrochemicals (Ibanez and Blackman 2016).

3. Materials and methods

3.1. Sampling, data collection and measurement of variables

Sampling and household data collection

A main motivation for our study design was to create a representative sample of five main cocoa growing regions within Ghana. Additionally, we aimed to increase external validity by capturing the heterogeneity of sustainability standards, operational units of LBCs and geographic regions. Therefore, we applied a two-stage sampling strategy in which we randomly selected communities based on existing population census data. To ensure that regions with higher production levels were proportionately represented, the number of communities in each region was identified based on their 2019 production volumes. We randomly selected 18-19 cocoa farming households in each community based on existing lists that extension officers provided. In total, we selected 839 households in 46 communities, 24 districts, and five regions (Figure 2).

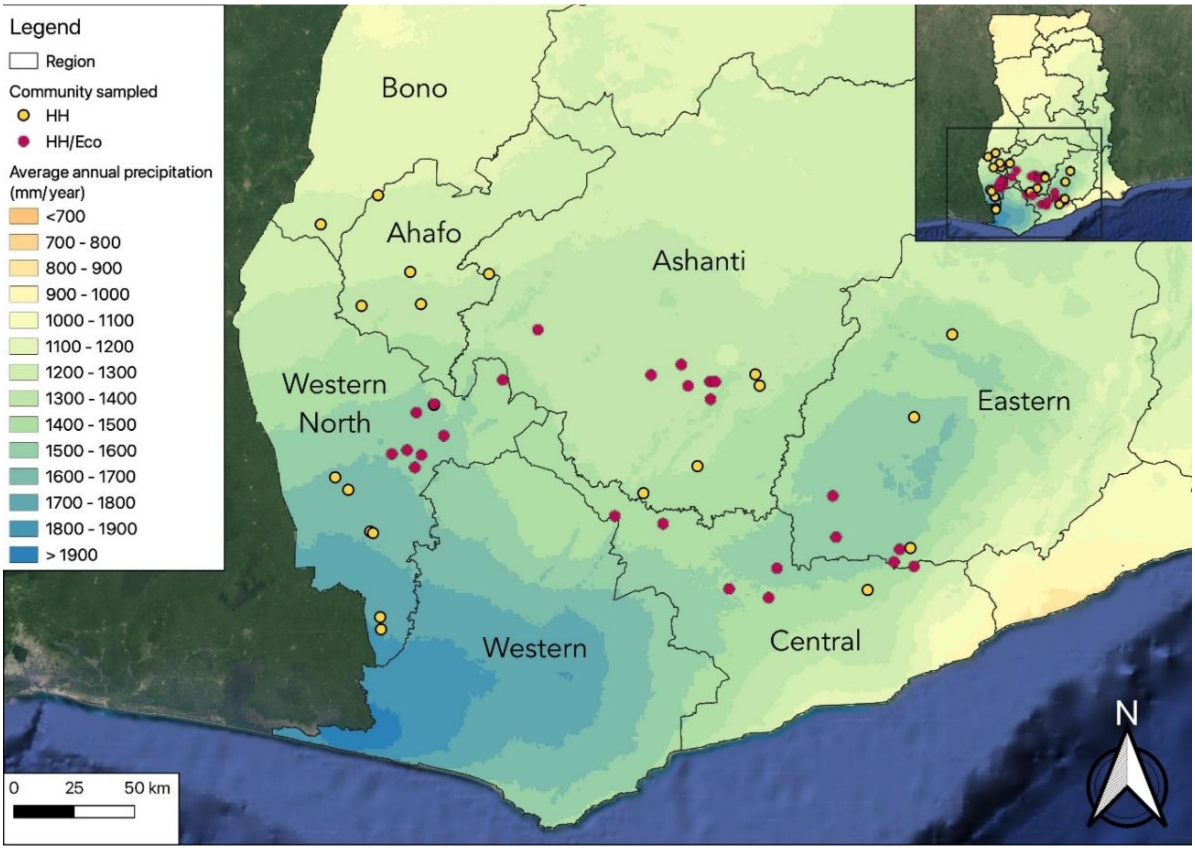

Figure 2: Map of sampled communities in Ghana. Yellow circles indicate communities where only household data was collected and are labelled as "HH" in the legend. Red circles indicate that additional ecological data was collected and are labeled as "HH/Eco" in the legend. Note: Ghana recently divided the Brong Ahafo region into the Bono and Ahafo regions; these were considered as one region at the time of the sampling. The map was created using publicly available rainfall data from Fick and Hijmans 2017.

We collected household data from November 2022 to January 2023. A team of local enumerators, who the first author trained, monitored and accompanied throughout the data collection, conducted computer-assisted personal interviews with the heads of the cocoa farming households. Our questionnaire focused on household demographics, community characteristics, detailed questions about the characteristics of all cocoa plots under cultivation, general cocoa farm management activities, agricultural practices, cocoa marketing and other agricultural and non-agricultural income generating activities. Additionally, we held semi-structured interviews with cocoa extension officers, community leaders and all available purchasing clerks in every community in order to get an overview of the LBCs operating in the area and whether these LBCs implemented sustainability standards. In the case that some purchasing clerks were not available, we conducted separate phone surveys with them.

From the household sample, we collected ecological data on a subset of 119 cocoa plots. In total, our ecological sample includes 65 plots from certified cocoa farming households and 54 plots from non-certified cocoa farming households in 18 communities, located in 10 districts and four of the five initially sampled regions (see Figure 2). The fifth region, which was the Brong Ahafo region, had the least sampled communities and therefore was excluded due to logistic constraints. Table A1 in the appendix shows the differences in means between the full household sample and the ecological subsample. The ecological data collection required repeated travelling to the study sites and long walking distances from the community to the cocoa plots. Therefore, we had to exclude some of the very remote communities that were too difficult to access. As a result, we observe significant differences in characteristics related to infrastructure and accessibility of the community between the ecological subsample and the full sample. Besides these differences, the ecological subsample has similar average characteristics to the full sample.

Treatment variable "Certification"

Although farmers are aware of the LBCs' sustainability program activities, they are sometimes not well informed that this is part of a "formal" sustainability standard scheme and are therefore unaware of their certification status (Bymolt et al. 2018). Therefore, simply asking farmers about their certification status may result in underreporting. To address this challenge, we established two conditions that must be fulfilled jointly to consider a farmer as certified.

The first condition is that the cocoa farmer sells their cocoa to a certified purchasing clerk and LBC. During the survey, we asked the farmers the names of the purchasing clerk purchasing their cocoa and the names of the LBCs employing the purchasing clerks. Based on semi-structured interviews with purchasing clerks, extension agents and community leaders, as well as publicly available information provided by some sustainability standards, we identified the LBCs operating in each community, their certification status and the names of their purchasing clerks.

Fulfilling only the first condition is insufficient to consider a farmer as being certified, because certified purchasing clerks often buy cocoa from certified as well as non-certified farmers. To ensure that only registered certified farmers are included in our treatment group, the second condition requires that the farmer selling to the certified purchasing clerk reports his or her participation in at least one of three certification activities: 1) signing a registration form provided by their purchasing clerk, 2) that staff from their LBC has geo-mapped the farmer's cocoa plot or 3) inspected the farmer's cocoa plots[3]. In total, we identified 338 certified farmers and 476 non-certified farmers[4]. The distribution of certified and non-certified cocoa farmers in our sample seems largely representative for Ghana's cocoa sector, since according to Nitidae and EFI (2021) about 38% of Ghana's cocoa is certified.[5] Our random sample covers a wide range of sustainability standards, such as Fairtrade, Rainforest Alliance, Cocoa Life, Cocoa Horizon and Cargill Cocoa Promise. Organic was not sampled, which is likely because Organic represents less than 1% of the sustainability standards in Ghana (Thompson et al. 2022) and is mainly sourced in a district that was not on our sampling list.

Socioeconomic outcome variables

We use three indicators to measure the socioeconomic effects of sustainability standards: cocoa yield per hectare, net cocoa income per hectare and return to land per hectare. Cocoa yield per hectare is measured as the quantity of dried cocoa beans in kilogram per hectare produced on productive cocoa area during the past 12 months. Net cocoa income per hectare is measured in the local currency Ghanaian cedis (GHC) per hectare of productive cocoa area and calculated as the total sales value in GHC derived from the harvested cocoa minus the costs of all variable inputs, land and hired labor plus

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[3] Robustness checks confirm that reporting to participate in at least two or three certification activities leads to the same direction of the estimates. However, since we rely on reported data, it could be possible that we incorrectly categorized a few truly certified farmers as non-certified: this holds for registered certified farmers that did not report to have participated in any of the mentioned activities and that we therefore categorize as non-certified.

[4] We omitted 25 farmers from the sample because we could not identify their certification status. This was because 1) the farmers did not know to which LBC they were selling and could not provide the name of their purchasing clerk 2) we could not verify that the LBC they mentioned existed in the community, or 3) we could not verify if the LBC was certified because the purchasing clerks, extension officers or community leaders were uncertain about the status.

[5] We could not find exact the numbers of farmers officially certified in Ghana, however, the estimate of Nitidae and EFI (2021) seems consistent with the share of 41% of certified farmers found in our sample.

any additional price premiums that were received during the year preceding the survey date. Net return to land per hectare is measured in GHC per hectare of productive cocoa area and calculated as net cocoa income plus the monetary value of all other intercrops and shade tree fruits on the cultivated cocoa land that were sold or consumed by the household.

Ecological outcome variables

We categorize the ecological outcome variables into indicators related to the plot's vegetation structure and indicators related to the plot's animal diversity. Indicators that relate to cocoa plot vegetation structure include shade tree crown cover, shade tree diversity and herbaceous ground cover. We chose these ecological indicators because more and diverse shade trees are expected to improve animal diversity and ecosystem functioning (Tscharntke et al. 2011). Herbaceous ground cover is a good indicator of resources available for ground-nesting and flying arthropods (Landis et al. 2005). A detailed description of how we collected and processed the data for our ecological outcome variables is provided in the appendix.

Shade tree crown cover is defined as the crown area of all shade trees in m^2 per ha. We used the Shannon and Simpson diversity indices as measures of shade tree diversity. We chose these indices for their complementary aspects of measuring diversity. The Shannon index emphasizes the richness component and gives more weight to rare shade tree species than the Simpson index, which is a measure of evenness and is weighted by the abundances of dominant species (Magurran 2007).

The Shannon index typically ranges from 1.5-3.5 when using empirical data and indicates the uncertainty in identifying the species of a random shade tree with higher values suggesting higher diversity (Magurran 2007). The Simpson index ranges from 0 to 1, representing the likelihood that two randomly selected trees are of different species; higher values denote greater diversity (since it is more likely to have two selected trees belonging to different shade tree species when there is greater diversity) (Magurran 2007). Herbaceous cover is measured as the proportion of meters covered with herbaceous plants on transects that we laid in each plot.

The indicators that capture animal diversity include bird abundance and species richness, biological predation rates and bioacoustics diversity. They are influenced by the cocoa plot's prevailing vegetation structure, as well as landscape factors such as the surrounding landscape composition (Sanderson et al. 2022). The chosen animal diversity variables are good indicators for ecosystem functioning and overall biodiversity because bird communities and predators respond quickly to changes in the environment and changes in species compositions are early signs of biodiversity loss and ecosystem functioning (Duffy 2002). Additionally, we recorded the soundscape of each cocoa plot to calculate the bioacoustics index. The bioacoustics index indicates the animal diversity on the cocoa plot by including the sounds of all animals within the recorded frequency range such as birds, insects, mammals, and amphibians (Bradfer-Lawrence et al. 2020; Boelman et al. 2007).

We assessed bird diversity metrics from short recordings of the soundscapes. Abundance corresponds to the total number of birds heard in the recording, while richness is the total number of bird species heard on the cocoa plots. Predation rates are measured as the share of predated fake plasticine caterpillars that we deployed in each plot (Schwab et al. 2021). The bioacoustics index is measured as a function of the total sound level and number of frequency bands used by the animals (Boelman et al. 2007).

3.2. Estimation methods

3.2.1. Endogenous switching regression approach for estimating socioeconomic outcomes

Certification as a treatment variable is potentially endogenous and prone to selection bias when estimating socioeconomic outcomes. This is because sustainability standards are not randomly assigned, since farmers voluntarily decide to which purchasing clerk(s) they sell; and if they want to become certified with the respective purchasing clerk. For instance, very motivated and capable farmers are more likely to sell to a certified purchasing clerk in order to benefit from the offered interventions. At the same time, these more capable farmers may also perform better in certain income-enhancing agricultural activities.

In order to account for this potential endogeneity bias, we use the endogenous switching regression (ESR) approach (Maddala 1983) to estimate the effect of sustainability standards on socioeconomic outcomes. We estimate the ESR with the survey data of the full sample. The ESR is a two-stage parametric approach that has been widely applied for impact assessments (Abdulai 2016; Noltze et al. 2013; Melaku et al. forthcoming), including certification impact assessments (Kleemann et al. 2014; Krumbiegel and Tillie 2024). In the first stage, a probit model of selection into treatment is estimated. The second stage estimates outcome equations for the treatment and control group and includes corresponding inverse mills ratios from the first stage as additional covariates.

Based on a utility maximization function, in the first stage, we use a probit model to estimate a farmer's probability of being certified:

$$VSS_i = Z_i\gamma + n_i \qquad \textit{Sustainability standard participation function} \qquad (1)$$

where VSS_i relates to the voluntary sustainability standard certification status, Z_i is a vector of explanatory control variables, including at least one instrument, γ is a parameter to be estimated and n_i is an error term with mean zero and variance σ^2.

In the second stage, we use a switching-regression model which specifies two separate equations for certified households (2.1) and non-certified households (2.2)(2.2):

$$Y_{i,VSS} = X_{i,VSS}\beta_{VSS} + \sigma_{VSS,n}\lambda_{i,VSS} + \vartheta_{i,VSS} \text{ if } VSS_i = 1 \quad (2.1)$$

Outcome equation for certified farmers

$$Y_{i,N} = X_{i,N}\beta_{N} + \sigma_{N,n}\lambda_{i,N} + \vartheta_{i,N} \text{ if } VSS_i = 0 \quad (2.2)$$

Outcome equation for non-certified farmer

where $Y_{i,N}$ and $Y_{i,VSS}$ are outcome variables for certified and non-certified farmers, respectively; X_i is a vector of control variables and β is a vector of parameters to be estimated. To address selection bias due to unobservable factors, following Heckman (1978), we include the inverse mills ratios from the selection equation (equation (1) represented by $\lambda_{i,VSS}$ for certified and $\lambda_{i,N}$ for non-certified farmers, and the covariance terms $\sigma_{VSS,n}$ and $\sigma_{N,n}$. Finally, $\vartheta_{i,VSS}$ and $\vartheta_{i,N}$ are the error terms with conditional zero means.

At the household level, we control for the household head’s age and sex and the number of adults, total cocoa land cultivated and whether the household receives non-agricultural income. Additionally, we incorporate characteristics that may capture unobservable traits, including leadership status and risk aversion. At the community level, we control for the availability of electricity and the distance to nearest agricultural input shop and tarred road. We control for regional characteristics by including regional dummy variables. For the socioeconomic estimations, we control for whether the farm has experienced a pest or disease attack or drought within the past 12 months. Moreover, we control for the share of cocoa trees under 5 years and above 25 years of age to account for lower productivity levels and for the share of fertile soil reported by the farmer. Additionally we create a dummy variable for farmers located in areas with Nitisols[6], which are considered favorable soils for cocoa (FAO 2015).

While the variables in equation (1) and equations (2.1) and (2.2) are allowed to overlap, there should be at least one or more variables that appear in Z_i but not in X_i for the model to be identified correctly. This implies that the choice criterion function is estimated based on control variables plus one or more instruments (Abdulai 2016). A valid instrument that fulfils the exclusion restriction is defined as an instrument that influences the probability of being certified but does not directly influence the outcome

[6] Soil types were identified in QGIS using publicly available data from Dewitte et al. (2013).

variables (Wooldridge 2013). We include the following two instruments: 1) the share of certified farmers living within a radius of 1 to 3 km and 2) the share of certified LBCs buying in the community.

The first instrument, the share of certified farmers living within a radius of 1 to 3 km, captures social network effects and is adapted from Di Falco et al. (2020). It is calculated by subtracting the share of certified farmers in a 1 km radius of each farmer *i* from the share of certified farmers in a 3 km radius of farmer *i*. The assumption is that farmer *i* interacts with farmer *j* who lives within the 1 km radius of farmer *i*, but not with farmer *k* who lives outside the 1 km radius, whereas *j* interacts with *k* since they live in proximity. If farmer *k* is certified, farmer *j* – being farmer k's neighbor, is more likely to learn about sustainability standard interventions and their possible benefits. Farmer *j* may become interested in selling to purchasing clerks offering these services and become certified as a result. Farmer *j*'s choice subsequently influences farmer *i*. We therefore assume that farmer *i*'s choice of being certified is influenced by farmer *k*, through farmer *j*. We display robustness checks testing different distance thresholds in Tables A3 in the appendix.

The second instrument is defined as the share of certified LBCs operating in each community. We expect that if more certified LBCs are operating in a community, it is more likely that farmers learn about the benefits of sustainability standards and will sell to purchasing clerks working for these certified LBCs in order to benefit from the interventions.

A simple falsification test proposed by Di Falco et al. (2011) gives some indication that the exclusion restriction holds for the instruments used in the household analyses (see Table A2 in the appendix). Using the Wald test, we show that our instruments are jointly significantly correlated with being certified and not with the outcome variables.

We estimate the ESR model using a full-information maximum likelihood method (Lokshin and Sajaia 2004) to simultaneously estimate the selection and outcome equations with standard errors clustered at the community level. We use this procedure to compute the average treatment effects on the treated (ATT) which is the expected effects of being certified. The ATT (equation (3.3)) is calculated as the difference between expected outcomes of actual certified farmers (equation (3.1)) and their hypothetical counterfactuals (hypothetical non-certified farmers) (equation (3.2)) as follows:

$$E(Y_{i,VSS}|VSS_i = 1) = X_{i,VSS}\beta_{VSS} + \sigma_{VSS,n}\lambda_{i,VSS} \tag{3.1}$$

Expected value for actual certified farmers

$$E(Y_{i,N}|VSS_i = 1) = X_{i,N}\beta_N + \sigma_{N,n}\lambda_{i,VSS} \tag{3.2}$$

Expected value for counterfactuals (hypothetical non-certified)

$$ATT = E\left(Y_{i,VSS} \middle| VSS_i = 1\right) - E\left(Y_{i,N} \middle| VSS_i = 1\right) \tag{3.3}$$

$$= X_{i,VSS}(\beta_{VSS} - \beta_N) + \lambda_{i,VSS}\,(\sigma_{VSS,n} - \sigma_{N,n})$$

3.2.2. Generalized linear mixed effects models for estimating ecological outcomes

We use ecological data and survey data from our subsample of 119 cocoa plots to estimate the ecological outcomes. Estimations with ecological outcome variables are less prone to endogeneity in our research context. This is because the farmers' unobservable characteristics that are correlated with being certified are more likely correlated with outcomes that will increase the farmer's welfare rather than the biodiversity in their plot. Moreover, due to their spatial vicinity, environmental outcomes within cocoa plots coming from the same community are more likely correlated than outcomes across communities, leading to correlation in the error term. To account for this we follow Krumbiegel et al. (2018) and Rana and Sills (2024) and use generalized linear mixed effects models (GLMM) to estimate the association[7] between sustainability standards and ecological outcome variables. GLMM relax the assumption of no linear dependence in the error term.

In the GLMM estimations we include the community as a random effect and use different specifications for different outcome variables depending on the nature of the data. We use Poisson GLMM for the bird richness and abundance estimations as these are count variables and Gamma GLMM for the herbaceous cover estimation since the data is non-normally distributed. For all other outcomes, we use Gaussian GLMMs since the data is normally distributed. For all models we use a log-link function for easier interpretation and robust standard errors to account for potential overdispersion. The GLMM takes the following form:

$$Ecol_{i,p,c,l} = \mu_0 + \mu_1 VSS_{i,p,c,l} + \mu_2 HH_{i,p,c,l} + \mu_3 P_{i,p,c,l} + \mu_4 L_l + C_c + \epsilon_{i,p,c,l} \tag{4}$$

where $Ecol_{i,p,c,l}$ refers to the respective ecological outcome variable of cocoa plot p from household i in the community c, in the landscape l, $VSS_{i,p,c,l}$ refers to household's certification status, $HH_{i,p,c,l}$ refers

[7] Due to the comparably small plot sample size, it is not possible to apply the ESR approach. We therefore avoid the term "effect" which would imply a causal relationship.

to a set of household-level and infrastructure control variables, $P_{i,p,c,l}$ refers to a set of cocoa plot-level control variables, L_l are landscape control and regional dummy variables, C_c are community level random effects and $\epsilon_{i,p,c,l}$ refers to the error term. The data for $HH_{i,p,c,l}$ and $P_{i,p,c,l}$ is derived from the household survey. For the shade tree crown cover estimations, we additionally include the cocoa plot's mean normalized difference vegetation index (NDVI) from the year 2000 (Landsat - 7) as a lagged control variable. We use this variable as a proxy to account for differences in shade tree levels before the farmers became certified[8,9]. For the animal diversity estimations, we include the distance to primary forest and the area in m^2 covered in small-scale gold mining sites [10] within a 1 km radius, as these potentially influence the animal diversity on the plots.

As discussed earlier it is unlikely that selection bias among farmers with respect to ecological outcomes is prevalent in our research context. However, the possibility still exists for outcomes related to vegetation structure. For instance, farmers with existing extensive shade tree coverage on their cocoa plots may be more likely to join certification because their costs of meeting the requirements of the sustainability standard are lower compared to farmers who would require additional investments in planting shade trees. Although we try to account for this by including the NDVI from the year 2000 as a lagged variable, we estimate our indicators related to vegetation structure using an instrumental two stage least squares (IV-2SLS) approach as a precautionary robustness check[11]. The two instrumental variables utilized in our socioeconomic regressions do not consistently satisfy the criteria outlined in the falsification test proposed by Di Falco et al. (2011) for our subsample. Consequently, we opt for the instrument that meets the criteria and use it for the IV-2SLS estimation. Table A4 in the appendix shows the results of the falsification test for the instruments applied for each estimation.

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[8] NDVI measures surface reflectance and gives a quantitative estimation of vegetation growth and biomass (Jiang et al. 2006). This means that the NDVI does not only relate to shade trees but also to cocoa tree health, hence the values of this variable only serve as a rough proxy. Mean NDVI values from 2000 were calculated in QGIS.

[9] Due to data limitations we do not know the exact year in which each farmer became certified. Therefore, we choose the year 2000 since this was roughly the time before most sustainability standards were introduced in Ghana.

[10] Area of forest cover and mining sites were mapped in QGIS using Google Earth Imagery (2023).

[11] The IV-2SLS approach has the disadvantage that it does not account for the similar environmental characteristics of plots within one community and for this reason we use the GLMM approach as our main model.

4. Results

4.1. Sample characteristics

Table 1 shows the descriptive statistics of our sample's characteristics. On average, certified farmers have 1.58 more years of education compared to their non-certified counterparts. Furthermore, certified farmers have an 7% lower prevalence of female-headed households and a 11% higher prevalence of household heads holding leadership positions[12] in the community. Overall, certified farmers seem to have a locational advantage, since they are at a shorter distance from tarred roads, more often located in communities with electricity and more often located on Nitisols soils, which are favorable for cocoa cultivation. Access to input, however, is not conclusive. While certified farmers are located further away from input shops than non-certified farmers, on the average, they have more often received subsidized input applications by governmental extension officers in the year preceding the survey date. Regarding our subsample of 119 cocoa plots, the data shows that certified plots are on average further away from primary forests and are on average located in places with larger areas of artisanal mining in their surroundings. Lastly, there is no significant difference in NDVI on the cocoa plot from the year 2000. This suggests that selection based on existing shade tree levels into certification is unlikely.

Table 1: Descriptive statistics of farmer and cocoa plot characteristics

	Certified farmers		Non-certified farmers		Mean difference
	mean	sd	mean	sd	
Household characteristics					
HH years of education	10.33	3.53	8.74	4.37	1.58***
HH head is female	0.15	0.36	0.22	0.42	0.07**
Age of HH head	54.23	12.92	54.02	13.71	0.22
No. of adults in HH	3.41	1.91	3.20	1.85	0.21
Risk aversion	5.13	3.31	5.11	3.33	0.02
HH head is leader	0.28	0.45	0.17	0.37	0.11***
Received gov. inputs subsidized	2.27	2.49	1.97	2.46	0.29*
HH has non-agric. income	0.59	0.49	0.58	0.49	0.01
Total cocoa area (ha)	4.36	3.38	4.02	3.23	0.35

[12] Leadership position refers to positions such as community chiefs, landlords, community chief farmers, executives of farmer groups, assemblymen/women or similar.

Location characteristics					
Community has electricity	0.92	0.28	0.83	0.37	0.09***
Distance HH to input shop (km)	11.25	11.74	9.29	9.83	1.95**
Distance HH to tarred road (km)	5.43	7.48	6.63	10.27	1.19*
Nitosol soil (favorable)	0.19	0.39	0.13	0.34	0.06**
Cocoa plot characteristics					
HH experienced drought	0.43	0.50	0.45	0.50	0.02
HH experienced pest attack	0.48	0.50	0.54	0.50	0.06*
Share of rich soil	0.77	0.39	0.79	0.37	0.03
Share cocoa trees < 5 years	0.02	0.10	0.06	0.21	0.04***
Share cocoa trees > 25 years	0.27	0.38	0.20	0.36	0.06**
Mean NDVI from 2000†	0.22	0.16	0.20	0.16	0.02
Landscape characteristics					
Mining area (m2) within 1 km of plot †	96953.68	237349.40	4238.41	15850.74	92715.27***
Distance to primary forest (km) †	6.14	5.09	4.77	4.05	1.37
Distance to road (km) †	0.61	0.44	0.61	0.44	0.00
Regions					
Western region	0.26	0.44	0.33	0.47	0.07**
Brong Ahafo region	0.12	0.32	0.07	0.26	0.04***
Eastern region	0.14	0.35	0.22	0.41	0.08***
Central region	0.12	0.33	0.14	0.35	0.02
Ashanti region	0.36	0.48	0.23	0.42	0.12***
Instrumental variables					
Share cert. farmers between 1-3 km	0.17	0.33	0.06	0.20	0.11***
Share cert. LBCs in community	0.64	0.27	0.40	0.29	0.25***
Observations	338		476		814

Note: sd = standard deviations. * p < 0.1, ** p < 0.05, *** p < 0.01. 1 GHC ≈ 0.08 Euro to the time of the data collection. † data of these variables are from the subsample of 119 farms where N for certified plots = 65 and N for non-certified plots = 54

4.2. Participation in sustainability standard interventions

To gain a better understanding of the extent to which certified farmers participate in the different sustainability standard interventions that we discussed in Section 2.1, we descriptively show the mean differences in participation in price, production and environment-related interventions between certified and non-certified farmers (Table 2). Overall, we see that certified farmers benefit more from a range of individual and group activities compared to non-certified farmers. Certified farmers have significantly better access to price premiums than non-certified farmers. 21% of certified farmers report that receiving price premiums are linked to meeting certain requirements, such as attending training, having their farming practices checked or following regulations on their farm. In terms of production-related interventions, certified farmers participate on average in 1.6 more training sessions per year compared to non-certified farmers. A higher proportion of certified farmers (9%) have access to agrochemical inputs that are either subsidized or purchased on credit by their LBC compared to non-certified farmers (3%). In addition, 33% of certified farmers belong to farmer groups initiated by their LBC compared to 9% of the non-certified group. In terms of environment-related interventions, 24% of certified farmers have received training in biological pest, disease or weed control. 28% of certified farmers have received free or subsidized shade tree seedlings, compared to 20% of non-certified farmers.

Table 2: Descriptive statistics of participation in sustainability standard interventions

	Certified farmers		Non-certified farmers		Mean difference
	mean	sd	mean	sd	
Price-related interventions					
Access to price premiums	0.70	0.46	0.23	0.42	0.47***
Price premiums linked to requirements	0.21	0.41	0.01	0.11	0.20***
Production-related interventions					
No. of trainings attended	3.08	3.88	1.48	2.28	1.60***
Received subsidized agrochemicals	0.09	0.29	0.03	0.18	0.06***
Part of an LBC group	0.33	0.47	0.09	0.29	0.23***

Environmental-related interventions					
Training on biological controls	0.24	0.43	0.14	0.34	0.11***
Received subsidized/free shade tree seedlings	0.28	0.45	0.20	0.40	0.07**
Observations	338		476		814

Note: sd refers to standard deviations. * p < 0.1, ** p < 0.05, *** p < 0.01.

4.3. Effects on socioeconomic outcomes

We used the ESR approach to estimate the effects of sustainability standards on socioeconomic outcomes. Table A5, Table A6 and Table A7 in the appendix present the estimated coefficients of the first stage selection equations, as well as the estimates of the separate outcome functions for certified and non-certified households. Table 3 shows the average treatment effects of the treated (ATT) on the socioeconomic outcome variables. The results suggest an ATT of 46 kg per hectare for cocoa yield, an ATT of 311 GHC per hectare for net cocoa income and an ATT of 895 GHC per hectare for net returns to land. These results correspond to an average increase of 12.4% in yield per hectare, an average increase of 11.6% in net cocoa income per hectare and an average increase of 15.8% increase in net returns to land per hectare compared to the counterfactual of hypothetical non-certified farmers. All our socioeconomic results are statistically significant at the 1% level and therefore provide evidence for a positive effect of sustainability standards on socioeconomic outcomes.

Table 3: Expected ATT for socioeconomic outcomes for total household sample

	Certified	Hyp. non-certified	ATT	P-value	N
Yield (kg/ha)	420.62	374.13	46.49	0.00	814
Net cocoa income (GHC/ha)	2986.48	2675.60	310.87	0.00	814
Net return to land (GHC/ha)	6568.02	5672.58	895.44	0.00	814

4.4. Associations between certification and ecological outcomes

Table 4 presents the results of the GLMM estimations that show the associations between being certified and outcomes related to vegetation structure based on the ecological subsample. The GLMM results show that being certified is associated with more shade tree crown area, and negatively associated with both shade tree diversity indices (Simpson and Shannon). Furthermore, being certified is associated with less herbaceous cover. The estimated associations are mostly small in magnitude and do not reach conventional levels of statistical significance. The results of our robustness check using the IV-2SLS approach are very similar to the GLMM estimations (see Table A9 in the appendix).

Table 4: Association between being certified and vegetation structure for ecological subsample

Outcome	GLMM certification coefficient	Robust standard error	P-value	N
Shade tree crown area	0.07	0.07	0.34	119
Shade tree diversity -Simpson index	-0.06	0.04	0.11	119
Shade tree diversity -Shannon index	-0.02	0.05	0.63	119
Herbaceous cover	-0.20	0.16	0.22	118

Full regression output is presented in Table A8.

Table 5 presents the results of the GLMM models estimating the associations between sustainability standards and animal diversity. Being certified is associated with less bird abundance, bird richness, predation rates and lower values for the bioacoustics index. Similar to the vegetation structure results, these associations do not reach conventional levels of statistical significance. In conclusion, our results fail to generate evidence supporting a link between certification and ecological indicators.

Table 5: Association between being certified and animal diversity for ecological subsample

Outcome	GLMM certification coefficient	Robust standard error	P-value	N
Bird abundance	-0.06	0.05	0.25	119
Bird richness	-0.02	0.05	0.67	119
Predation rate	-0.05	0.04	0.20	119
Bioacoustics index	-0.08	0.06	0.20	115

Full regression output is presented in Table A10

5. Discussion and conclusion

In this study, we assessed the socioeconomic and ecological effects of sustainability standards in the cocoa sector of rural Ghana. Conceptually, we discussed the support that sustainability standards can offer to certified farmers to improve socioeconomic and plot-level ecological outcomes. The pathways we identified fall into the categories of price-, product- and environment-related interventions. Empirically, our results strongly indicate that sustainability standards have positive effects on cocoa yield, net cocoa income and return to land. Net returns to land which includes revenue from shade trees and intercrops shows the highest increase, suggesting that certified farmers are able to economically leverage their shade trees more effectively. Such knowledge could have been acquired through training on resilience and livelihood diversification strategies that some sustainability standards advocate (The Rainforest Alliance, 2020).

Certified farmers benefit from price-related interventions, such as price premiums, and production-related interventions, such as access to increased number of training or access to group membership (Table 2), which can contribute to the positive socioeconomic effects. Indeed, we find significant positive correlations between price-, and production-related interventions and socioeconomic outcomes (see Table A11 in the appendix). Overall, our socioeconomic results are in line with the literature that finds positive socioeconomic effects of voluntary sustainability standards for cocoa farmers in West Africa (Dompreh et al. 2021; Iddrisu et al. 2020; Sellare et al. 2020b).

In contrast to the socioeconomic results, we do not find any significant associations for the ecological results. In fact, for many of the ecological indicators the GLMM coefficients have negative signs. This points towards a trend that certification is associated negatively with ecological outcomes (apart from shade tree crown cover).

These ecological results are not necessarily in line with our expectations, as certification schemes claim to provide training to farmers on environmentally friendly practices such as agroforestry practices or integrated pest and disease management. However, ecological effects may need a longer time to materialize than socioeconomic benefits. For instance, although descriptive results show that certified farmers have better access to shade tree seedlings (Table 2), sustainability standards might have provided farmers with these shade tree seedlings only recently. Hence, the resulting expected increases are not yet reflected in higher shade tree cover on their cocoa plots. Moreover, nation-wide biodiversity initiatives may be confounding the differences between certified and non-certified farms. For example, government extension officers are actively promoting agroforestry practices nationwide as part of climate change mitigation efforts (Ghana Cocoa Board 2018), which could result in similar levels of shade cover on all cocoa plots regardless of the certification status.

Additionally, environmentally-friendly practices may be insufficiently reinforced to observe positive outcomes. It is more often recommended (rather than required) to perform certain environmentally-friendly practices (Cocoa Life 2023; Lindt & Sprüngli Farming Program 2023). Additionally, the implementation of requirements may be weak and compliance checks of little consequence for the farmers regarding certification status or price premium distribution. Indeed, our descriptive statistics show that only 21% of the certified farmers report that they need to fulfill certain requirements in order to receive price premiums (Table 2). This could imply that farmers put more emphasis on applying the knowledge gained from the training on yield-enhancing practices rather than on biodiversity-enhancing practices.

Our results indicate that the way sustainability standards are currently implemented lead predominantly to economic benefits for farmers rather than ecological benefits for the plot environment. Nonetheless, yield increases do not come at a large expense to the biodiversity of the farm. Although in smallholder settings it is sometimes possible to combine high yields with high levels of biodiversity (Clough et al. 2011; Wurz et al. 2022), there is the risk and general trend that more intensification leading to higher yield comes at the expense of biodiversity, resulting in trade-offs between these two dimensions (Daum et al. 2023; Grass et al. 2020). Indeed Vanderhaegen et al. (2018) find that in Uganda, coffee certification is associated with trade-offs since it either improves socioeconomic outcomes and worsens ecological outcomes or vice versa (depending on the type of certification). In our study, where high yield gaps and low prices are a major concern for Ghanaian cocoa farmers' livelihoods, sustainability standards improve socioeconomic outcomes, without exhibiting strong trade-offs with ecological outcomes.

Our paper does not come without shortcomings. We only account for participation and non-participation in certification schemes, while the length of participation would have more explanatory power on certain outcome variables. A panel rather than a cross-sectional data set would allow for more long-term outcome measurements. A larger ecological sample would enable the use of more advanced econometric approaches[13]. Additionally, future research could explore the effects of sustainability standards on biodiversity at the landscape level rather than on the plot-level as the landscape serves as a more comprehensive habitat compared to a single plot. Nonetheless, up to date and to the best of our knowledge, this study is one of the few sustainability standard studies combining socioeconomic and ecological datasets and our dataset surpasses those of other interdisciplinary studies in terms of sample size and geographic coverage.

[13] Due to the substantial logistical effort required, collecting a larger ecological dataset may still be unfeasible in practice.

Acknowledgments

We thank all those that made the implementation of the data collection in Ghana possible, particularly our research assistants John Akomatey, Michael Boateng, Yaw Bonsu, Christopher Dankwah and David Wagner who provided exceptional field assistance and all the farmers who devoted their time to answering our questions.

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Appendix

Description of ecological sampling

Shade tree crown cover and diversity

A local tree expert identified all shade trees on each plot with a maximum plot size of 1 hectare. If the plot was more than 1 hectare in size, we randomly laid a 1-hectare subplot into the main plot using QGIS and identified all trees in this subplot. We measured the diameter at 1.3 m height (DBH) of all shade trees and define shade trees as woody plant species with a DBH of above 10 cm, including palms and papaya trees of reproductive maturity. We measured the DBH of all shade trees. We gathered a subset of crown widths (26% of all shade trees in total) to develop a multi-species allometric linear model to estimate the crown area of unmeasured trees, using DBH as the explanatory variable (Tiralla et al. 2013). We measured two orthogonal crown widths at the widest points, excluding measurements from unhealthy or abnormally growing trees. We calculated crown area using the formula $A = \frac{1}{4}\pi d^2$, where the average of the two crown width measurements served as the diameter. For multi-stemmed trees, we used a DBH derived from the average basal area to predict their crown areas. Shade tree crown cover is calculated as the crown area of all shade trees in m^2 divided by the area of the plot in ha.

We used two measures of diversity to define shade tree diversity on the plots. Shade tree diversity is defined as the Shannon diversity index: $H = -\sum_{i=1}^{S} log_b(p_i)$ and the Simpson diversity index: $D = 1 - \sum_{i=1}^{S} p_i^2$ where p_i is the proportion of species i and S is the number of species in the cocoa plot (Magurran 2007).

Herbaceous cover

To determine herbaceous cover, we laid four transects of 10 meters in each plot and recorded the number of meters covered in non-woody plants such as grasses, weeds, and intercrops (Lutes et al. 2006). We calculated herbaceous cover as the total share of meters covered with herbaceous plants compared to the total number of meters of transects that were laid in the cocoa plots.

Predation rates

Following Howe et al. (2009), Nurdiansyah et al. (2016) and Schwab et al. (2021), we assessed predation rates using fake caterpillars made from green plasticine. Predators usually do not remove the inedible artificial caterpillars but they do leave characteristic bite marks on the surface, enabling the quantification of predation rates and identification of predators. On every plot visited, we deployed 40 evenly shaped plasticine cylinders (35 x 6.5 mm) that mimic green caterpillars in five plots that were located 20 steps from the plot center in each of the four cardinal directions. Within every individual plot we selected two cocoa trees and glued one artificial caterpillar at the ground-level of each tree trunk and on the trunk, a branch and a leaf. After 24 hours we retrieved the artificial caterpillars and individually assessed the predation bitemarks. We identified the predation bitemarks using images available in the literature (Howe et al. 2009; Nurdiansyah et al. 2016; Schwab et al. 2021), complemented by direct observations and reference bite marks derived from intentional exposure of fake caterpillars to identified predators. We calculated predation rate as the percentage of predated caterpillars to the total number of retrieved caterpillars per plot (Schwab et al. 2021).

Bioacoustics index

We deployed AudioMoth sound recorders at the center of each plot at 1.3 m height for 24 hours. We programmed the devices to record sounds up to a frequency of 96 kHz, at 192 kHz sample rate, 16-bit resolution with medium gain of 30.6 dB (Hill et al. 2019). We used the recordings from 5:00-7:00a.m. and cut the recordings into one-minute segments to facilitate processing. The recordings of four plots were corrupted and omitted from the sample. We calculated the bioacoustics index from 0 to 30 kHz with an Fast Fourier Transform size of 512 for each one minute recording using Kaleidoscope Pro software following Boelman et al. (2007). The bioacoustics index describes the mean spectral power from 0 to 30 kHz. This frequency range includes most ecological sounds, including some ultrasonic insect sounds outside the range of human hearing.

Bird richness and abundance

To assess bird abundance and richness, an experienced local ornithologist identified and recorded the abundance of each species heard within two 10-minute recordings from 6:00 to 6:10 a.m. and 7:00 to 7:10 a.m. that had been cut from the 24-hour recordings on each plot. We chose these time frames because birds are most active around sunrise (Ocampo-Ariza et al. 2022). We define bird abundance as the total number of individual birds recorded and bird richness as the total number of bird species identified within the 2 x 10-minute recordings.

Table A1: Balance tests between households that were ecologically sampled and those that were not (households from Brong Ahafo region are excluded)

	Ecologically sampled HHs		Non-ecologically sampled HHs		Mean difference
	mean	sd	mean	sd	
HH head years of education	9.95	3.47	9.41	4.15	0.55
HH head is female	0.24	0.43	0.18	0.38	0.06
Age of HH head	55.98	12.83	53.53	13.28	2.45*
Nr. of adults in HH	3.66	2.06	3.25	1.83	0.41**
Risk aversion	5.01	3.52	5.09	3.26	0.08
HH head is leader	0.18	0.39	0.22	0.42	0.04
Received gov. inputs subsidized	1.57	2.14	2.19	2.58	0.62**
HH has non-agric. income	0.66	0.47	0.58	0.49	0.09*
Community has electricity	0.95	0.22	0.85	0.36	0.10***
Distance HH to input shop (km)	8.26	9.02	10.40	10.86	2.14**
Total cocoa area (ha)	3.88	3.34	4.22	3.34	0.34
HH experienced drought	0.40	0.49	0.45	0.50	0.05
Nitosol soil (favorable)	0.21	0.41	0.16	0.37	0.05
Share of rich soil	0.69	0.43	0.79	0.37	0.10***
Share cocoa trees < 5 years	0.04	0.14	0.05	0.18	0.01

Share cocoa trees > 25 years	0.15	0.30	0.24	0.37	0.08**
HH experienced pest attack	0.50	0.50	0.51	0.50	0.02
Western region	0.31	0.46	0.34	0.47	0.03
Eastern region	0.15	0.36	0.21	0.41	0.06
Central region	0.21	0.41	0.14	0.35	0.07**
Ashanti region	0.33	0.47	0.31	0.46	0.02
Observations	119		620		739

Note: sd = standard deviations. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table A2: Results of the falsification test for socioeconomic sample

	(1) Certification (1/0)	(2) Cocoa yield (kg/ha)	(3) Net cocoa income (GHC/ha)	(4) Return to land (GHC/ha)
Share cert. farmers within 1-3 km	.69***	82.79	85.39	2053
	(0.25)	(89.37)	(642.79)	(1591.)
Share cert. LBCs in community	1.79***	-0.12	-36.56	-582.01
	(0.31)	(1.01)	(648.83)	(717.03)
Control variables	YES	YES	YES	YES
Wald test on instruments	$\chi^2 = 55.72$	F = 0.62	F = 0.99	F = 1.62
Observations	814	476	476	476
Pseudo R^2	0.2	0.25	0.12	0.21

Robust standard errors clustered at the community-level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A3: Effect of instrumental variables using different distance thresholds for socioeconomic sample

	(1)	(2)	(3)	(4)
	Certification (1/0)	Certification (1/0)	Certification (1/0)	Certification (1/0)
Share cert. farmers within 1-5 km	.53**			
	(0.23)			
Share cert. farmers within 0.2-3 km		1.53***		
		(0.58)		
Share cert. farmers within 1-2 km			0.66**	
			(0.32)	
Share cert. farmers within 2-5 km				0.53**
				(0.24)
Share cert. LBCs in community	1.74***	1.75***	1.84***	1.72***
	(0.32)	(0.58)	(0.32)	(0.33)
Control variables	YES	YES	YES	YES
Observations	814	814	814	814
Pseudo R^2	0.2	0.2	0.2	0.2

Robust standard errors clustered at the community-level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A4: Results of the falsification test for ecological subsample sample

	(1)	(2)	(3)	(4)	(5)
	Certification	Shade tree crown area	Shade tree diversity - Simpson index	Shade tree diversity - Shannon index	Herbaceous cover
Share cert. farmers within 1-3 km	1.22**	133.49	-0.13	-0.42	-0.56*
	(0.6)	(800.46)	(0.11)	(0.47)	(0.29)
Share cert. LBCs in community	2.61***	554.87			-0.12
	(0.68)	(831.99)			(0.16)
Control variables	YES	YES	YES	YES	YES
Wald test on instruments	χ^2 = 27.49	F = 0.23	F = 1.40	F = 0.79	F = 1.96
Observations	119	55	55	55	55
R-squared	0.26	0.4	0.22	0.24	0.34

Robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A5: Results of selection and outcome equations for cocoa yield

	(1)	(2)	(3)
VARIABLES	First stage: Selection into certification	Outcome equation for non-certified households	Outcome equation for certified households
HH head years of education	0.05***	3.55	-3.93
	(0.02)	(2.64)	(4.31)
HH head is female	-0.13	2.65	-72.59
	(0.14)	(33.27)	(46.40)
Age of HH head	-0.00	-3.66***	-3.05*
	(0.00)	(0.88)	(1.61)
Nr. of adults in HH	0.03	10.15*	-0.98
	(0.03)	(5.79)	(7.87)
Risk aversion	0.00	6.12	1.91
	(0.02)	(3.92)	(4.87)
HH head is leader	0.23*	24.83	119.48***
	(0.14)	(36.35)	(36.17)
HH has non-agric. income	0.10	-1.07	-3.12
	(0.09)	(25.46)	(37.66)
Total cocoa area (ha)	0.02	-9.55	-17.81***
	(0.01)	(7.18)	(4.44)
Community has electricity	0.09	74.25***	79.49*
	(0.18)	(19.89)	(43.48)
Distance HH to tarred road(km)	-0.00	-0.62	-1.68
	(0.01)	(0.94)	(2.68)
Distance HH to input shop(km)(log)	-0.01	-9.76	-32.20*
	(0.06)	(9.56)	(17.89)
Nitosol soil (favorable)	-0.01	-24.14	-32.14
	(0.28)	(29.96)	(41.18)
HH experienced drought		-89.95***	-7.82
		(25.11)	(30.97)
HH experienced pest attack		-12.25	-42.06

		(24.59)	(38.68)
Share of rich soil		58.20***	116.03***
		(22.37)	(40.39)
Share cocoa trees < 5 years		-217.79***	-152.47*
		(28.63)	(90.38)
Share cocoa trees > 25 years		-36.50	-26.19
		(25.50)	(44.42)
Received gov. inputs subsidized		17.49**	9.86
		(7.48)	(6.29)
Western region	-0.31	-67.30	-104.45**
	(0.25)	(41.34)	(42.47)
Brong Ahafo region	0.26	36.53	-55.75
	(0.37)	(63.48)	(55.44)
Eastern region	-0.55*	131.72***	224.07***
	(0.28)	(45.36)	(51.43)
Central region	-0.16	32.95	207.31***
	(0.22)	(45.82)	(66.61)
Share cert. farmers between 1-3km	0.65***		
	(0.24)		
Share cert. LBCs in community	1.81***		
	(0.31)		
Constant	-1.78***	421.15***	575.31***
	(0.51)	(72.44)	(156.59)
lns		3.55	-3.93
		(2.64)	(4.31)
rho		2.65	-72.59
		(33.27)	(46.40)
Observations	814	814	814

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A6: Results of selection and outcome equations for net cocoa income

	(1)	(2)	(3)
	First stage: Selection into certification	Outcome equation for non-certified households	Outcome equation for certified households
VARIABLES			
HH head years of education	0.05***	-9.85	0.25
	(0.02)	(36.06)	(67.53)
HH head is female	-0.13	-19.80	-450.37
	(0.14)	(399.60)	(578.63)
Age of HH head	-0.00	-33.50***	-17.77
	(0.00)	(12.42)	(20.24)
Nr. of adults in HH	0.03	250.12***	-3.64
	(0.03)	(80.61)	(103.10)
Risk aversion	0.00	34.48	24.13
	(0.02)	(48.46)	(75.79)
HH head is leader	0.23*	223.04	1,393.26***
	(0.14)	(524.46)	(473.64)
HH has non-agric. income	0.10	-293.35	-483.73
	(0.09)	(299.85)	(404.42)
Total cocoa area (ha) (log)	0.02	-75.32	-150.81***
	(0.01)	(74.04)	(51.54)
Community has electricity	0.09	524.54	397.32
	(0.19)	(359.11)	(631.64)
Distance HH to tarred road (km)	-0.00	-5.60	5.90
	(0.01)	(12.25)	(26.31)
Distance HH to input shop (km) (log)	-0.01	16.15	-501.94**
	(0.06)	(127.85)	(215.14)
Nitosol soil (favorable)	-0.01	121.52	409.80
	(0.28)	(354.49)	(407.31)
HH experienced drought		-674.83**	-143.46
		(293.87)	(420.18)
Share of rich soil		38.01	-334.03

		(313.36)	(462.54)
Share cocoa trees < 5 years		889.68***	1,239.43**
		(308.47)	(517.07)
Share cocoa trees > 25 years		-2,484.55***	-2,235.36
		(408.82)	(2,087.44)
Received gov. inputs subsidized		-241.42	118.10
		(311.40)	(583.45)
Western region		145.86	131.27
		(101.39)	(99.52)
Eastern region	-0.31	-318.02	-871.79*
	(0.25)	(555.89)	(519.65)
Central region	0.26	249.91	-217.13
	(0.37)	(588.14)	(457.17)
Brong Ahafo region	-0.55*	719.50	2,228.20***
	(0.28)	(637.59)	(686.88)
Share cert. farmers between 1-3 km	-0.15	22.99	1,635.60*
	(0.22)	(620.98)	(951.64)
Share cert. LBCs in community	0.66***		
	(0.24)		
Constant	1.81***		
	(0.32)		
lns	-1.78***	2,642.50***	3,752.22*
	(0.51)	(973.48)	(2,152.81)
rho		8.09***	8.17***
		(0.06)	(0.07)
Observations	814	814	814

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A7: Results of selection and outcome equations for net returns to land

	(1)	(2)	(3)
VARIABLES	First stage: Selection into certification	Outcome equation for non-certified households	Outcome equation for certified households
HH head years of education	0.05***	-57.14	-57.21
	(0.02)	(57.34)	(104.50)
HH head is female	-0.13	-103.75	-522.06
	(0.14)	(674.38)	(1,158.75)
Age of HH head	-0.00	-75.64***	-64.42**
	(0.00)	(18.88)	(27.27)
Nr. of adults in HH	0.03	207.55**	38.56
	(0.03)	(94.52)	(161.77)
Risk aversion	0.00	124.65	54.37
	(0.02)	(75.80)	(91.38)
HH head is leader	0.23*	191.53	2,075.07***
	(0.14)	(610.92)	(560.08)
HH has non-agric. income	0.10	-70.09	-461.20
	(0.09)	(516.27)	(654.95)
Total cocoa area (ha) (log)	0.02	-253.17**	-345.79***
	(0.01)	(104.24)	(86.31)
Community has electricity	0.09	1,293.15**	1,156.27
	(0.19)	(566.25)	(1,006.10)
Distance HH to tarred road (km)	-0.00	27.08	10.00
	(0.01)	(20.85)	(49.83)
Distance HH to input shop (km) (log)	-0.01	190.75	-745.94**
	(0.06)	(220.96)	(324.80)
Nitosol soil (favorable)	-0.00	-232.11	317.16
	(0.28)	(573.64)	(798.27)
HH experienced drought		-1,433.76***	-601.38
		(396.11)	(578.57)
Share of rich soil		-96.57	-982.84

		(477.72)	(683.37)
Share cocoa trees < 5 years		1,175.25***	1,910.34***
		(452.45)	(638.82)
Share cocoa trees > 25 years		-4,184.75***	-3,677.63
		(743.55)	(2,793.50)
Received gov. inputs subsidized		-1,158.57**	-449.09
		(521.91)	(759.81)
Western region		162.65	175.90
		(146.62)	(143.69)
Eastern region	-0.31	-363.69	-517.70
	(0.25)	(683.61)	(857.53)
Central region	0.26	572.54	485.24
	(0.37)	(1,030.70)	(769.00)
Brong Ahafo region	-0.54*	3,338.59***	5,061.55***
	(0.28)	(665.80)	(1,060.56)
Share cert. farmers between 1-3 km	-0.15	384.04	3,633.91**
	(0.22)	(781.19)	(1,669.95)
Share cert. LBCs in community	0.66***		
	(0.24)		
Constant	1.80***		
	(0.32)		
lns		8.51***	8.57***
		(0.09)	(0.05)
rho		0.04	-0.05
		(0.23)	(0.20)
Observations	814	814	814

Standard errors clustered at the community level are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A8: Full regression output of GLMM estimations for associations between being certified and vegetation structure for ecological subsample

	(1) Shade tree crown area	(2) Shade tree diversity - Simpson index	(3) Shade tree diversity - Shannon index	(4) Herbaceous cover
Certified	0.07	-0.06	-0.02	-0.2
	(.07)	(.04)	(.05)	(0.16)
HH head years of education	-0.02***	0	0	0.04
	(0.01)	(0.01)	(0.01)	(0.02)
Age of HH head	0	0	0	0.01
	(0)	(0)	(0)	(0.01)
HH head is female	-0.17*	-0.05	-0.11	0.01
	(0.09)	(0.04)	(0.07)	(0.28)
Nr. of adults in HH	0	0	0	0.06*
	(0.02)	(0.01)	(0.01)	(0.03)
HH head is leader	-0.18	0.01	-0.04	-0.13
	(0.11)	(0.05)	(0.05)	(0.22)
Total cocoa area (ha)	0.01	0	0	0.02
	(0.01)	(0.01)	(0.01)	(0.03)
Distance HH to extension	0	0*	0	.02*
office (km)	(0)	(0)	(0)	(0.01)
Community has electricity	-0.02	-0.1**	-0.21**	-0.27
	(0.11)	(0.04)	(0.09)	(0.24)
Area of sampled farm (ha)	-.02	.03	.06*	-.1
	(0.05)	(0.02)	(0.03)	(0.12)
NDVI from 2000	0.48***	-0.03	0.05	
	(0.18)	(.12)	(0.16)	
Western region	0.02	-0.03	-0.08	0.53**
	(0.08)	(0.04)	(0.06)	(0.27)
Eastern region	0.25***	-0.08	-0.06	-0.02
	(0.09)	(0.08)	(0.12)	(0.27)
Central region	-0.29***	-0.01	0.01	0.23
	(0.1)	(0.05)	(0.09)	(0.19)

Constant	8.25***	-.05	1.01***	-2.25***
	(0.24)	(0.14)	(0.25)	(0.64)
Group-level variance	0	0	0	.04
	(0)	(0)	(0)	(0.04)
Residual variance	1125929.2***	0.02***	0.28***	-0.22***
	(141618.36)	(0.01)	(0.06)	(0.06)
Observations	119	119	119	118

Robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A9: IV-2SLS approach to estimate associations between being certified and vegetation structure for ecological subsample

	(1) Shade tree crown area	(2) Shade tree diversity - Simpson index	(3) Shade tree diversity - Shannon index	(4) Herbaceous cover
Certified	751.27	-0.07	0.04	-0.12
	(559.57)	(0.14)	(0.48)	(0.08)
HH head years of education	-75.57*	0	0	0.01**
	(39.08)	(0.01)	(0.02)	(0.01)
Age of HH head	0.72	0	0	0
	(10.15)	(0)	(0.01)	(0)
HH head is female	-530.04*	-0.04	-0.21	.01
	(293.22)	(0.04)	(0.15)	(.05)
Nr. of adults in HH	-16.89	0	0	.02**
	(61.06)	(0.01)	(0.03)	(0.01)
HH head is leader	-597.39**	0.01	-0.11	-0.03
	(295.67)	(0.04)	(0.15)	(0.05)
Total cocoa area (ha)	47.79	0	0	-0.01
	(34.8)	(0)	(0.02)	(0.01)
Distance HH to extension	4.43	0*	0.01	0**
office (km)	(12.62)	(0)	(0.01)	(0)

Community has electricity	11.89	-0.08***	-0.5***	-0.05
	(364.46)	(0.03)	(0.18)	(0.07)
Area of sampled farm (ha)	-97.96	0.02	0.12	-0.03
	(152.43)	(0.02)	(0.08)	(0.03)
NDVI from 2000	1342.06**	-0.02	0.1	
	(618.22)	(0.09)	(0.32)	
Western region	224.75	-0.03	-0.13	0.14***
	(324.22)	(0.04)	(0.15)	(0.06)
Eastern region	980.62**	-0.06	-0.08	-0.03
	(389.96)	(0.07)	(0.23)	(0.06)
Central region	-468.74	-0.01	0.08	0.04
	(392.62)	(0.06)	(0.23)	(0.06)
Constant	3138.38***	0.95***	2.66***	0.07
	(1031.77)	(0.14)	(0.55)	(0.16)
Observations	119	119	119	118
R-squared	0.17	0.13	0.16	0.2

Robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1 We use the share of certified LBCs in the community and share of certified farmers living within a 1 and 3 km radius as instruments to estimate the association between being certified and shade tree crown cover area and herbaceous cover. For the Simpson and Shannon diversity index estimations we only use one instrumental variable which represents the share of certified farmers living within a 1 and 3 km radius.

Table A10: Full regression output of GLMM methods for associations between being certified and animal diversity for ecological subsample

	(1) Bird abundance	(2) Bird richness	(3) Predation rate	(4) Bioacoustics index
Certified	-0.06	-0.02	-0.05	-0.08
	(0.05)	(0.05)	(0.04)	(0.06)
HH head years of education	0.01	0.01	0.03***	0.01
	(0.01)	(0.01)	(0.01)	(0.02)
Age of HH head	0	0	0	0*
	(0)	(0)	(0)	(0)

HH head is female	0.07	-0.01	0.03	-0.06
	(0.05)	(0.05)	(0.07)	(0.08)
Nr. of adults in HH	0	-0.01	0.02**	-0.02
	(0.01)	(0.01)	(0.01)	(0.02)
HH head is leader	0.02	-0.02	0.1	-0.04
	(0.06)	(0.05)	(0.07)	(0.04)
Total cocoa area (ha)	0	-0.01	0	-0.01
	(0.01)	(0.01)	(0.01)	(0.02)
Distance HH to extension	0	0**	0.01**	0
office (km)	(0)	(0)	(0)	(0)
Community has electricity	-0.3***	-0.32***	-0.17***	-0.02
	(0.1)	(0.09)	(0.06)	(0.12)
Area of sampled farm (ha)	0.01	0.04	-0.01	-0.02
	(0.03)	(0.02)	(0.03)	(0.06)
Western region	-0.03	-0.03	0.14**	0.16
	(0.07)	(0.04)	(0.06)	(0.11)
Eastern region	0.12	0.11***	0.1	0.51***
	(0.07)	(0.04)	(0.12)	(0.12)
Central region	0	0	0.07	0.4***
	(0.07)	(0.04)	(0.07)	(0.12)
Age of cocoa trees	0	0	0**	0.01
	(0)	(0)	(0)	(0.01)
Mining area (m^2) within 1	0***	0	0**	0
km of plot	(0)	(0)	(0)	(0)
Distance to primary	-0.01	-0.01	0.01	-0.02**
Forest (km)	(0.01)	(0)	(0.01)	(0.01)
Distance to road (km)	0.02	0.03	0	0.08
	(0.04)	(0.04)	(0.05)	(0.13)
Constant	3.84***	3.23***	3.66***	4.81***
	(0.23)	(0.21)	(0.22)	(0.35)
Group-level variance	0	0***	0*	0
	(0)	(0)	(0)	(0.01)
Residual variance			286.23***	3395.56***

			(44.1)	(905.16)
Observations	119	119	119	115

Robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1

Table A11: Pairwise correlations between socioeconomic outcome variables and price-, and production related interventions of household sample

Variables	Yield (kg/ha)	Net cocoa income (GHC/ha)	Net return to land (GHC/ha)
Access to price premiums	0.19***	0.13***	0.13***
Nr. of trainings	0.10**	0.10**	0.07**
Part of an LBC group	0.08**	0.03	0.06*
Received subsidized agrochemicals	0.00	0.01	-0.01

*** p<.01, ** p<.05, * p<.1