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Voluntary Sustainability Standards and Socioeconomic and Ecological Outcomes

Panel evidence from Rwanda's Coffee Sector

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Abstract: Voluntary sustainability standards (VSS) provide consumers with the assurance that certified products are produced under more sustainable conditions. While the literature on VSS has expanded considerably, most studies rely on cross-sectional data, thereby providing only a snapshot in time and focus on the effects on single sustainability dimensions, thereby neglecting potential trade-offs between multiple dimensions. In addition, little is known of the extent outcomes are influenced by the duration of participation. Economic gains may accrue in the short to medium term, whereas ecological effects often take longer to materialize. Our study addresses these gaps by using a unique three-wave panel dataset from Rwanda's smallholder coffee sector. We combine household-, buyer- and plot-level data to estimate how in-house certification (C.A.F.E. Practices), third-party certification (The Rainforest Alliance, Fairtrade, Organic, 4C), and certification duration are associated with both socioeconomic and ecological outcomes. Our results suggest that only third-party certification is significantly positively associated with socioeconomic outcomes such as coffee yield, prices, profits and returns to land. Moreover, we find that for both VSS types the socioeconomic outcomes increase, the longer a household is certified. Regarding ecological outcomes, only third-party certification duration shows significant positive associations with shade tree density. In addition, for both VSS types, we do not find any significant associations with outcomes related to animal diversity. Overall, the findings highlight that VSS should be understood as a long-term process where sustainability-related changes materialize over time. The findings also suggest that the environmental requirements – especially of in-house schemes – may be set too low.

Keywords: Voluntary sustainability standards, certification, Rwanda, coffee, biodiversity, socioeconomic and ecological trade-offs

JEL: Q01, Q56, Q57

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1) Introduction

The production of cash crops such as coffee, tea, cocoa, soy, and palm oil is associated with a range of severe and often interrelated socioeconomic and environmental challenges. Producers of these crops are frequently caught in cycles of persistent poverty, partially driven by low productivity stemming from limited access to credit, inputs, and the technical knowledge needed for sustainable production (Barbier 1997; Barbier and Hochard 2018). The lack of resources for sustainable production makes cash crop often a key driver of biodiversity loss (Cabernard et al. 2024). This loss, in turn, reduces yields further and increases the risk of deforestation as farmers seek new, more fertile land (Kalischek et al. 2023; Meyfroidt et al. 2014). At the same time, global demand for cash crops, particularly coffee and cocoa, is rising (European Commission 2024). Growing demand, coupled with stagnant or declining productivity, has led to dramatic increases in global prices (Rogna and Tillie 2025). Yet, the transmission of these price gains to producers is uneven, leaving them economically vulnerable and compounding existing sustainability challenges (Wienhold and Roberts 2025).

Against this background, growing consumer awareness in high-income countries about the social and environmental costs of cash crop production has driven the proliferation of voluntary sustainability standards (VSS), which currently certify 31% of cocoa, 15% of coffee and 13% of tea production area worldwide (Kemper et al. 2024). VSS signal to consumers - typically through product labels - that goods have been produced according to high ethical standards, focusing on either social, economic, or environmental sustainability, or a combination of all three. For farmers, traders, and companies throughout the supply chain, adopting VSS can serve as a marketing strategy and is often a prerequisite for accessing European or North American markets (Meemken et al. 2021).

A growing body of research has assessed the effectiveness of VSS in improving smallholder farmers' livelihoods and conserving the biodiversity on their farms. Systematic reviews by (Meemken et al. 2021; Oya et al. 2018; Dietz et al. 2022) generally find moderately positive effects on socioeconomic outcomes, while (Dietz et al. 2022) conclude that positive effects are found more frequently for intermediate outcomes (e.g., prices, yields) than for endpoint outcomes (e.g., income, food security). In contrast, studies focusing on ecological impacts show very mixed results, with earlier studies finding positive effects (Asigbaase et al. 2019; Pico-Mendoza et al. 2020; Hardt et al. 2015) while more recent studies finding no effects (Dröge et al. 2025a; Dröge et al. 2025b). Garrett et al. (2021) review studies assessing both dimensions simultaneously and conclude that VSS are often associated with improvements in either socioeconomic or ecological outcomes but rarely in both. Three recent case studies reach similar conclusions (Paz et al. 2025; Thompson et al. 2022; Wätzold et al. 2025). However, given the small empirical evidence base of studies assessing simultaneous effects, overall conclusions cannot be drawn.

Beyond the lack of such studies, two further gaps limit our understanding of VSS effects. First, most studies to date rely on cross-sectional data, offering only a limited snapshot of certification effects. This approach makes it difficult to disentangle VSS effects from time-specific influences, such as global price fluctuations or government interventions (e.g., ecosystem restoration programs (van der Hoek and Tuyisingize 2025)), which may affect outcomes in one year but not in others. Therefore, tracking farmers over time is essential to get a more robust understanding of VSS effects. A few studies to date rely on panel data. For instance Boonaert and Maertens (2023), Holzapfel and Wollni (2014) and Meemken et al. (2017) make use of two-wave household panel data sets from Thailand and Uganda, respectively, and Boonaert and Maertens (2023) and Meemken (2021) make use of a five-wave household dataset from Peru. However, these studies focus exclusively on the effects of VSS on socioeconomic outcomes while multidimensional assessments are essential to fully understand whether VSS foster synergies or trade-offs between sustainability goals (Wollni et al. 2025). To our knowledge, no study has combined household panel- and ecological plot-level panel data, leaving an important gap in our understanding of the broader impacts of VSS.

Second, while most studies focus on average certification effects, there is limited evidence on whether and how the length of participation influences outcomes. Certification effects are unlikely to be immediate, as farmers may need time to adopt new practices, and new practices may need time to reflect benefits. For example, yield improvements are expected to only materialize once agronomic practices are applied consistently and soil conditions gradually improve (Maggio et al. 2022). Ecological outcomes are expected to evolve even more slowly, since changes in vegetation structure and biodiversity typically occur over longer time horizons (Raveloaritiana and Wanger 2024).

Our study simultaneously addresses these gaps: We use a rich, unique, three-wave panel dataset (t = 2022, 2023, 2024) that includes both household-, buyer- and plot-level data from Rwanda's coffee sector. First, *we assess the association between certification and household socioeconomic and plot-level ecological outcomes*. We differentiate between company-led in-house certification and third-party certification because these two VSS types differ in their design and ownership (Paz et al. 2025). Second, *we assess whether and how the certification duration, i.e., the length of being in-house and/or third-party certified, is associated with household-level socioeconomic and plot-level ecological outcomes*.

Our dataset includes 2,492 household observations and a subset of 289 plot observations. We use the correlated random effects approach to estimate how in-house certification, third-party certification, and their duration are associated with both socioeconomic outcomes such as coffee yield, coffee prices, coffee profit and returns to land and ecological outcomes such as shade tree diversity and density, arthropod predation rate and predator richness as an indicator of ecosystem service provision, and sound acoustic indicators, as a proxy of animal biodiversity.

Our contributions to the VSS literature are threefold. First, this is the first study to simultaneously assess household-level socioeconomic outcomes and plot-level ecological outcomes using panel data. Second, our analysis draws on the largest ecological sample used to date in any VSS study, thereby improving the reliability of the estimates compared with earlier research based on smaller samples (Asigbaase et al. 2019; Dröge et al. 2025b; Dröge et al. 2025a; Pico-Mendoza et al. 2020). Third, this study is the first to examine how the duration of VSS participation is associated with sustainability outcomes.

2) Background and conceptual links

Background and evolution of VSS

VSS are grouped into government-led, non-governmental organization (NGO)-led, and company-led VSS schemes. Government- and NGO-led VSS are among the earliest widely institutionalized standards (Giuliani et al. 2017; Lambin and Thorlakson 2018). For example, the first government-led VSS was Germany's Blue Angel eco-label, introduced in 1978, followed by prominent NGO-led VSS such as Fairtrade, and The Rainforest Alliance, which were established in 1988 and 1987, respectively (Lambin and Thorlakson 2018; Marx et al. 2024; The Rainforest Alliance 2024). These standards set important models for subsequent initiatives, including many company-led (in-house) VSS schemes which expanded in the early 2000s (Lambin and Thorlakson 2018). Examples include Starbucks' C.A.F.E. Practices launched in 2004, Nespresso's AAA Sustainable Quality Program launched in 2003 and Mondelēz International's Cocoa Life launched in 2012 (Cocoa Life 2023; Nespresso 2025; C.A.F.E. Practices 2024).

The main difference between government-led, NGO-led, and company-led VSS lies in their ownership, rule-setting, and compliance monitoring (Lambin and Thorlakson 2018). Government-led and NGO-led VSS, commonly referred to as third-party VSS, are owned and developed by independent organizations, often NGOs, multi-stakeholder initiatives, or international non-profit organizations (Tscharntke et al. 2015). Third-party certified entities are monitored by external accredited auditors, a governance system designed to ensure impartiality but one that also entails relatively high auditing fees and substantial compliance costs for certificate holders (Lambin and Thorlakson 2018).

In response to these high costs, private companies introduced their own standards, commonly referred to as in-house VSS. These schemes are owned, developed, and managed internally by companies, typically processors, retailers, or multinationals, allowing them to tailor sustainability requirements to their supply chain needs and brand strategies. Unlike third-party schemes, in-house standards rely primarily on internal monitoring and inspections, although some, such as Starbucks' C.A.F.E. Practices, also engage independent auditors. While this approach gives companies greater control over compliance costs, it has raised concerns about the credibility of their monitoring system (Giuliani et al. 2017; Lambin and Thorlakson 2018).

On the ground, the organization of VSS has evolved over the past three decades. In the 1990s, NGOs largely drove VSS uptake by supporting groups of farmers through the certification process. Today, as certified products have gained significant market share (UNFSS, 2022), this responsibility has moved to supply chain actors such as cooperatives, trading companies, or processing firms (Meemken et al., 2021). These buyers pursue certification in order to access premium markets or meet exporter requirements (UNFSS, 2022). They usually act as certificate holders and oversee the certification process on behalf of affiliated farmers (Meemken et al., 2021). Farmers are hence not individually certified, but part of a certified group. This set-up reduces individual certification costs as they are spread across a larger group of farmers (Steidle and Herrmann 2019).

VSS and their hypothesized effects on socioeconomic and ecological outcomes

VSS require certificate holders to implement interventions that help farmers meet requirements and improve sustainability outcomes (Boonaert and Maertens 2023; UNFSS 2022). Some interventions must be implemented strictly, while others are more loosely defined, leaving certificate holders flexibility in how they organize them (Bemelmans and Maertens 2025). At the farmer level, certification schemes typically distinguish between a set of minimum core requirements that must be fulfilled by farmers to participate in the program and a set of additional requirements that allow for more flexibility in the implementation. For example, both the in-house scheme C.A.F.E. Practices and the third-party scheme Rainforest Alliance require farmers to comply with a set of minimum core requirements. However, while C.A.F.E. Practices awards points when farmers meet additional requirements, Rainforest Alliance obliges farmers to demonstrate continuous improvement based on an additional set of requirements (C.A.F.E. Practices 2024; Rainforest Alliance 2023).

Figure 1 displays how VSS are expected to affect different sustainability outcomes for farmers and their plots through the implementation of the interventions. In this paper, we focus on interventions aimed at enhancing household socioeconomic outcomes and plot-level ecological outcomes as these are typically promoted by both third-party and in-house certifications[1]. Specifically, socioeconomic outcomes are targeted through price- and production interventions (Boonaert et al. 2024).

Price-related interventions are intended to improve farmers' income in exchange for the additional costs incurred when implementing more sustainable practices (Oberlack et al., 2023). In in-house certification schemes, such interventions often take the form of discretionary, company-specific payments. For

[1] More interventions which focus on other dimensions such as gender and equity are more often implemented by third-party certifications and are discussed in Wollni et al. 2025).

example, under C.A.F.E. Practices, the size of the premium depends on the number of points the certificate holder achieves. In contrast, third-party certifications such as Fairtrade and Organic, have mandatory price interventions. These include guaranteed minimum prices or standardized premium payments, which are designed to provide farmers with more stable benefits independent of market fluctuations (Meemken and Qaim, 2018; Oya et al., 2018).

Production-related interventions, including the provision of training or agricultural inputs for farmers, aim to enhance agricultural productivity (Bemelmans and Maertens 2025). Both third-party and in-house certifications typically put a strong emphasis on these types of interventions (Schulte 2020).

The goal of environmental interventions is to minimize the negative impacts of agricultural production on biodiversity, soil quality and other environmental factors. These interventions include the promotion of intercropping or agroforestry practices for crops like coffee and cocoa, the restriction of harmful agrochemicals or training on how to conserve the local biodiversity in their farm (Schulte 2020; Wätzold et al. 2025). Both in-house and third-party schemes promote such practices, but their requirements differ. For example, neither C.A.F.E. Practices nor the Rainforest Alliance sets a minimum shade tree level as an entry condition. However, while Rainforest Alliance certified farmers must demonstrate continuous improvements until a minimum of 15% shade cover is reached, under C.A.F.E. Practices, farmers earn points for shade tree cover as part of their overall evaluation (C.A.F.E. Practices 2024; Rainforest Alliance 2023).

VSS, through the promotion of different interventions, can entail trade-offs and synergies between different sustainability dimensions. For example, increased access to agrochemicals may improve yields but reduce on-farm biodiversity, while promoting agroforestry can enhance biodiversity but shade trees can compete with other crops for resources, thereby reducing yields (Wollni et al. 2025). Conversely, sustainable practices such as integrated pest management (IPM), pruning, or the use of organic fertilizers (e.g., manure or mulch) can increase productivity without harming biodiversity and can substitute the use of excessive agrochemicals (Rainforest Alliance 2023).

Given the strong emphasis on productivity, we expect positive associations with productivity-related socioeconomic outcomes for both certification types. As discussed above, third-party schemes impose stricter environmental requirements. While these may increase the adoption of sustainable but often labor-intensive practices, they potentially raise costs (Daum et al. 2023; Santalucia, Wollni 2025). At the same time, third-party certification also entails more mandatory price-related interventions, hence the higher costs are expected to be compensated through higher farm-gate prices.

As both in-house and third-party schemes promote ecological practices such as shade tree planting, we anticipate positive ecological associations in both cases. Yet, given the stricter requirements of third-party schemes, we expect their effects to be larger in magnitude compared to in-house certification.

VSS and its hypothesized effects over time

We expect a temporal lag between the introduction of certification and the manifestation of positive effects. First, the certificate holder may require time to fully understand the certification requirements and establish the necessary interventions. For instance, the distribution of shade or crop tree seedlings is costly so that certificate holders may need to secure external funding before these activities can be implemented. Second, it may take some time for farmers to realize VSS benefits. For instance, farmers must first attend trainings to acquire new agricultural knowledge. Additionally, the adoption of improved practices tends to occur gradually as it is shaped by socioeconomic and demographic constraints as well as peer influence (Di Falco et al. 2020; Rizzo et al. 2024). Yield improvements are likely to become visible only after several seasons, once changes in agricultural practices begin to enhance soil fertility (Raveloaritiana and Wanger 2024; Maggio et al. 2022).

Likewise, ecological outcomes are expected to take longer to materialize (Raveloaritiana and Wanger 2024). Interventions related to the promotion of shade tree planting or intercropping can increase the biodiversity within plots, but trees must first grow before they contribute to a denser vegetation structure capable of attracting insects, birds, and other species. Therefore, positive effects on animal diversity may take even longer. Recognizing these challenges, many schemes use a continuous-improvement approach. As discussed earlier, some core requirements must be met immediately, while others are either phased in and monitored through continuous improvement indicators (as in the case of the Rainforest Alliance) or kept flexible, allowing certificate holders to gather points (as in the case of C.A.F.E. Practices) (UNFSS 2022).

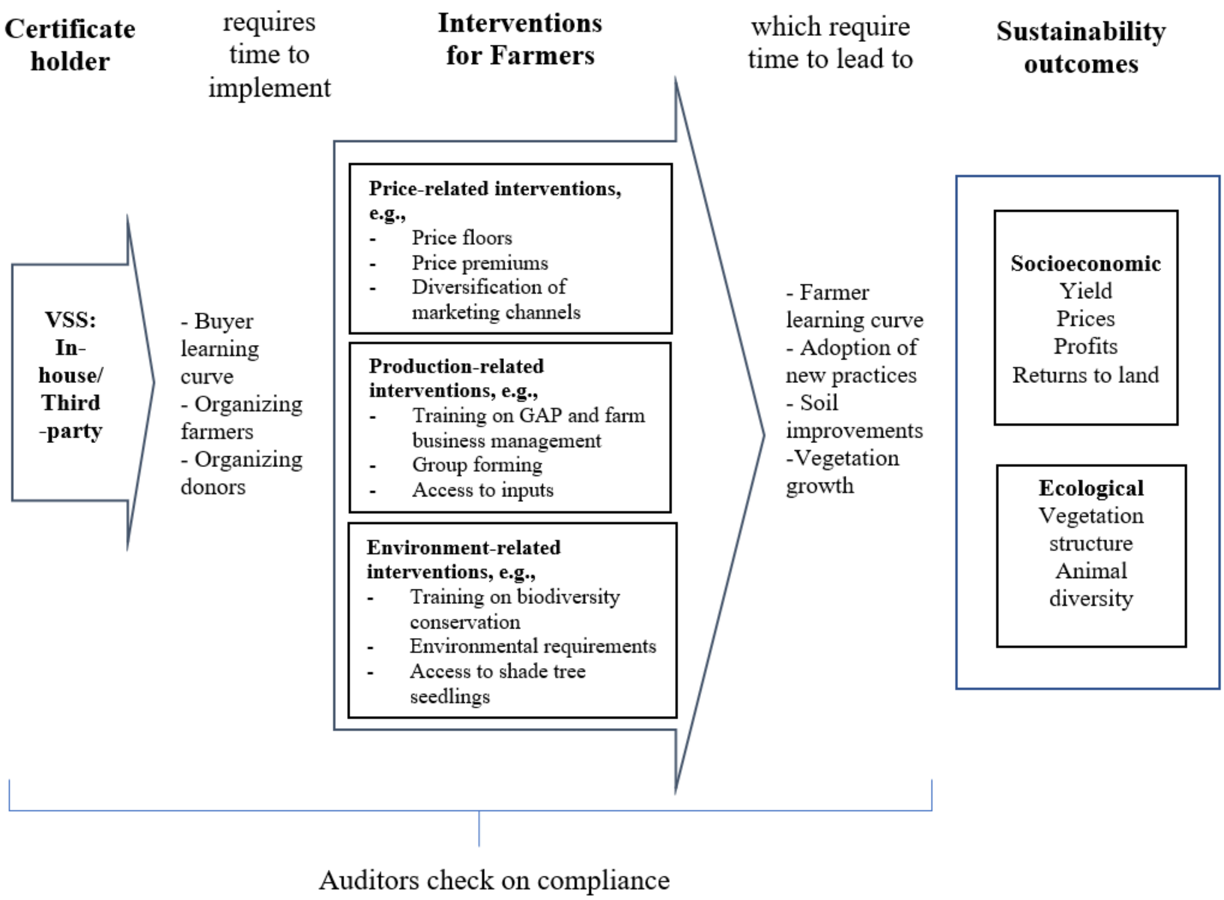

Figure 1: Conceptual framework describing how VSS influence sustainability outcomes over time.

3) Study context

The Rwandan coffee sector

Our study takes place in Rwanda which is characterized by hilly landscapes and fertile volcanic soils. Its agroecological conditions, particularly in the western and southern regions, are highly suitable for the cultivation of high-quality Arabica coffee, especially the "bourbon" variety (NAEB 2024). Introduced by German colonialists in the early 1900s, coffee has since become a key cash crop, accounting for approximately 20% of Rwanda's total agricultural export value (Agrilogic 2018). The sector is dominated by smallholder farmers, who on average cultivate 0.26 hectares of coffee (ICO 2024). Around 400,000 farmers, representing 80% of Rwanda's agricultural households, depend on coffee for their livelihoods (NAEB 2024). Despite its economic importance, the coffee sector continues to struggle with low productivity, driven by aging trees, limited access to technology and knowledge on sustainable farming practices, and inadequate extension services (ICO 2024).

The coffee production sector in Rwanda is organized around coffee washing stations (CWSs) These are the first formal buyers of fresh coffee cherries from farmers. CWSs are responsible for processing the cherries after purchase, removing the skin and pulp, fermenting and drying the beans. CWSs are typically owned by cooperatives, private individuals, or companies and they differ in size, human capital, and institutional capacity (Macchiavello and Morjaria 2021).

CWSs play an important role in the coffee sector. For instance, they support the government in activities such as distributing subsidized agrochemicals and collecting coffee-related census data within their zones. A zone is an administrative boundary that defines the area of operation of a CWS. In addition, CWSs often provide farmers with services that are aimed to improve productivity such as training or the distribution of coffee tree seedlings (Macchiavello and Morjaria 2021; Gerard et al. 2022).

From 2016 to 2023, the Rwandan coffee sector was governed by a zoning policy, which required farmers to sell their coffee to a designated CWS in the zone where they were producing their coffee. The purpose of the zoning policy was to improve the relationship between farmers and CWSs, enhance traceability, and improve coffee quality by reducing travel time between harvest and processing (Gerard et al. 2022). However, the zoning policy was repealed shortly after the harvest season in June 2023 because it had inadvertently hampered market efficiencies by weakening competitive incentives such as prices among CWSs (ICO 2024).

Voluntary sustainability standards

VSS have been present in Rwanda since the early 2000s, with a range of third-party certifications such as Rainforest Alliance, Fairtrade, 4C (Common Code for the Coffee Community) and Organic, as well as company in-house certifications such as C.A.F.E. Practices (Paz et al. 2025). As of 2019, 32% of Rwandan coffee was certified (IISD 2019). CWSs serve as the certificate holders, with their farmer suppliers certified under their name. CWSs are therefore responsible for implementing the VSS interventions. Despite the high costs associated with obtaining and maintaining certification, they often regard it as essential for accessing European markets (Agrilogic 2018).

4) Methods

4.1) Sampling and data collection

A major contribution of this study is that we use three waves of panel household and ecological data for our analysis. The data was collected across five major coffee-producing districts located in Rwanda’s coffee belt (see Figure 2), between November 2022 and February 2023 (Wave 1), November 2023 and February 2024 (Wave 2), and October 2024 and January 2025 (Wave 3).

Our sample is based on a stratified random sampling approach (Paz et al. 2025). Within each district, CWSs were randomly selected from lists provided by the government. Subsequently, households were randomly chosen from farmers lists compiled by the managers of each selected CWS. In Wave 1, a total of 844 households from 39 CWSs were included in the study. In Wave 2, 834 of these households were re-interviewed, and in Wave 3, 839 households from the original sample were re-interviewed. Reasons for attrition were death and relocation (including migration or extended travel outside the study area). After removing households with unreliable data, the final sample comprises an unbalanced panel consisting of 844 households in Wave 1, 831 in Wave 2, and 833 in Wave 3 (see Table 1).

Of the originally sampled CWSs, in Wave 1, 14 CWSs were non-certified and 25 CWSs were certified (5 in-house only, 14 third-party only and 6 both in-house and third-party). By Wave 3, one additional CWS had obtained third-party certification. As mentioned in Chapter 3, the zoning policy remained in place until the end of the 2023 harvest season, after which farmers were permitted to switch CWSs. Accordingly, the coffee seasons corresponding to Waves 1 and 2 were under the zoning policy, whereas Wave 3 occurred after the policy had been repealed. Between Wave 2 and 3, a total of 63 farmers switched CWSs. We consider farmers to have changed their certification status if they switched from a certified to a non-certified CWS (or vice versa). Altogether between Wave 2 and 3, 26 farmers changed their certification status.[2]

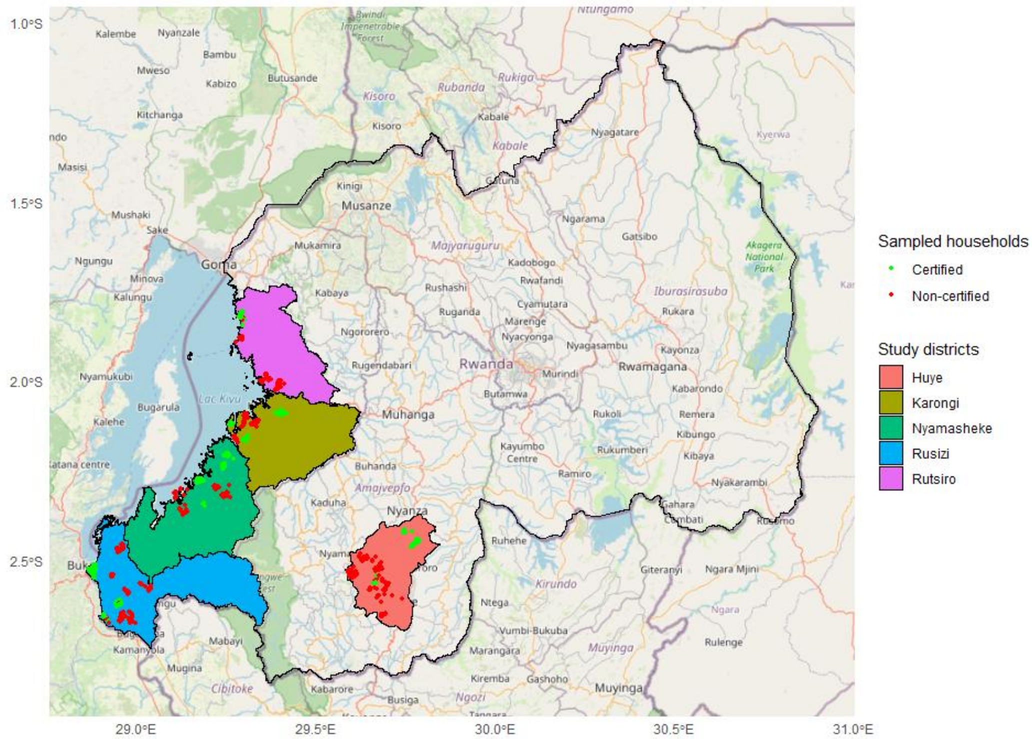

Figure 2: Map of Rwanda and five selected study districts. Green dots represent certified households and red dots represent non-certified households. Due to the former zoning policy, households are spatially clustered based on the certification status of the CWS in their respective zone.

[2] From the 26 farmers whose statuses changed, 12 farmers' certification statuses changed because the CWS became certified, 11 farmers switched from a non-certified to a certified CWS and 3 farmers switched from a certified to a non-certified CWS.

Local enumerators, most of whom participated across all data collection waves and were trained by the research team, collected household-level data by conducting interviews with either the household head or a designated representative using tablet-based computer-assisted personal interviewing (CAPI). The structured questionnaire comprised detailed modules on household composition, coffee production and marketing (with a focus on the most productive coffee plot), other agricultural and income-generating activities, and various aspects of household well-being.

In addition, during Wave 3 (2024), we conducted face-to-face interviews with the managers of the sampled CWSs, in order to collect information related to the manager's background and CWS characteristics. For information corresponding to Waves 1 and 2, managers responded to recall questions. We use this information to derive control variables to account for some potential selection bias at the CWS level (Sellare et al. 2020). Additionally, since the certification status is decided at the CWS level, meeting the managers was important in order to understand each CWS' certification status and the date of first certification. Asking the farmers during the interview was insufficient because farmers are typically unaware of their formal certification status.

As mentioned above, altogether 63 farmers had switched CWS between Wave 2 and 3. While some remained within our original pool of CWSs, others joined CWSs that were not included in the initial sample. To capture information from these new CWSs, we conducted additional interviews with their managers. In total, we interviewed managers of 9 new CWSs, increasing our sample from 39 to 48 CWSs. However, we were unable to interview the managers of 4 CWSs, to which 6 farmers had switched after Wave 2. Furthermore, 10 farmers reported not knowing the name of their new CWS. Consequently, we lack information on the certification status and CWS characteristics of 16 farmers in Wave 3. Excluding their data from that wave's analysis results in a final household sample of 2,492.

We collected ecological data through detailed coffee plot inventories from a subsample of 102 plots. After cleaning the data and removing unreliable observations, we retained 92 plots in Wave 1, 95 in Wave 2 and 102 in Wave 3. We selected the subsample by randomly selecting farmers whose plots contained at least 100 coffee trees. Hence the plots were large enough to reduce the recording of sounds from outside the plot. We collected data on the number and species of shade trees as indicators of vegetation complexity in the crop (Clough et al. 2011; Tscharntke et al. 2011), conducted sentinel artificial caterpillar predation experiments, with abundance and diversity of bite marks serving as proxies of pest predation ecosystem services (Howe et al. 2009), and deployed sound recorders to indirectly evaluate animal diversity through soundscape analyses (Hill et al. 2018). A complete explanation of how we conducted the plot inventories is in Appendix A.1. Table 1 presents the final number of CWSs, households and plots for each survey wave used in the analysis.

Table 1: Distribution of certified and non-certified CWSs, households and plots from the subsample across the three survey waves.

Wave 1 (2022)		Wave 2 (2023)		Wave 3 (2024)	
CWS sample (N = 39)		**CWS sample (N = 39)**		**CWS sample (N = 48)**	
Non-certified	Certified	Non-certified	Non-certified	Non-certified	Non-certified
14	25 (IH = 11 TP = 20)	13	26 (IH = 11 TP = 21)	17	31 (IH = 12 TP = 26)
HH sample (N=844)		**HH sample (N=831)**		**HH sample (N=817*)**	
Non-certified	Non-certified	Non-certified	Non-certified	Non-certified	Non-certified
312	532 (IH = 247 TP= 413)	295	536 (IH = 241 TP = 419)	282	535 (IH = 247 TP = 416)
Ecological subsample (N= 92)		**Ecological subsample (N= 95)**		**Ecological subsample (N= 102)**	
Non-certified	Non-certified	Non-certified	Non-certified	Non-certified	Non-certified
38	54 (IH = 29 TP = 43)	36	59 (IH = 35 TP = 45)	38	64 (IH = 36 TP = 49)

**excludes the 16 farmers whose CWS and certification status we could not trace back. IH refers to in-house certified, while TP to third-party certified. Note that their status is not mutually exclusive.*

4.2) Main variables

Treatment variables

To address our first research question, we define two dummy treatment variables. Each variable takes the value 1, if a household is certified under either an in-house or a third-party scheme, and 0 if otherwise. Because CWSs often pursue multiple certifications to meet different exporter requirements, in-house and third-party certification are not mutually exclusive, and some farmers fall under both types. In our sample, in-house certification refers to C.A.F.E. Practices, while third-party certification includes Fairtrade, the Rainforest Alliance, 4C, and Organic.

For our second research question, we examine whether a longer certification participation duration is associated with higher sustainability outcomes. We use two continuous treatment variables: the number of years a household has been in-house certified and the number of years a household has been third-party certified. We assume that farmers have supplied their respective CWS since the beginning of the certification period. Following the introduction of zoning regulations in 2016, all farmers supplying a CWS that became certified thereafter can reasonably be regarded as automatically included in certification. For CWSs that obtained certification prior to zoning, we assume that the farmers in our sample were already supplying them at the time of certification. This assumption is plausible, as farmers typically supply their cherries to the nearest CWS since delivering to a more distant one would risk quality losses and consequently lower prices. Figure 3 illustrates the distribution of certification duration: in-house certification spans 3 to 10 years, while third-party certification ranges from 1 to 21 years.

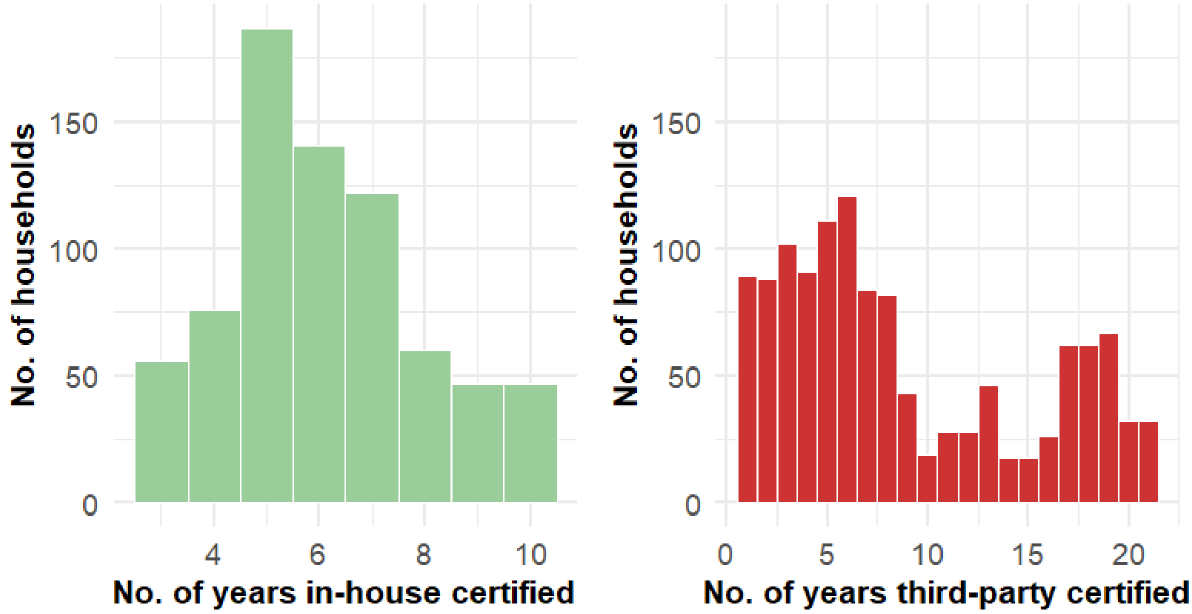

Figure 3: Distribution of certification duration in years for households under in-house and third-party certification, conditional on certification.

Socioeconomic outcomes variables

We use a set of different outcome variables to measure the socioeconomic outcomes on the household's most productive coffee plot: We categorize our outcome variables into yield outcomes, price outcomes, and profit-related outcomes.

Yield outcomes relate to coffee yield per tree and per area. Increasing coffee yield is a key objective of certification since it can improve household income and livelihoods (Hörner and Wollni 2021; Khonje et al. 2018). *Coffee yield per tree* is measured by the number of kilograms of fresh coffee cherries harvested per coffee tree in the harvest season preceding the survey. To calculate this variable, we asked farmers how many kilograms of coffee they had harvested in the previous season and how many coffee trees are on their plot. If the farmer was unsure of the number of trees, the enumerator counted them. Similarly, we calculate the kilograms of *coffee yield per are* (each "are" being 10m x 10m). We use "are" instead of "hectare" as the unit of measurement, because most farmers' plots fall well below one hectare. At the time of data collection, farmers were asked to report the size of their plot using their preferred unit of measurement. If the farmer did not know the area, the enumerator estimated it by counting the number of steps along each side of the plot.

We include coffee price per kilogram as an additional outcome variable because we expect certified farmers to receive higher prices, not only from additional price premiums, but also from quality improvements resulting from trainings[3]. This variable is defined as the *average price per kilogram* that the farmer received, including any premiums.

An increase in yield and prices should lead to higher coffee profits, provided that costs do not exceed revenue. *Coffee profit per are* is calculated as coffee revenue per are (yield per are multiplied by the price) minus costs per are. Costs include expenses related to labor and organic fertilizers, such as manure and compost. Agrochemicals are primarily supplied by the government, with costs covered through revenues collected via the export levy on coffee. We therefore exclude agrochemical-related input costs from our main calculations, as farmers do not directly pay for them. As a robustness check, we also estimate profits including these agrochemical costs, which we calculate by multiplying reported input quantities by standardized government prices.

In addition to profit from coffee sales, farmers also generate revenue from a variety of intercrops such as bananas, pumpkins, and other fruits and vegetables, as well as from timber harvested from shade trees. Crop diversification on coffee plots not only contributes to farmers' resilience against shocks (Arslan et al. 2018) but also plays an important role in supporting on-farm biodiversity (Jones et al. 2023). Therefore, we include the variable *returns to land per are*, which combines coffee profit per are with the additional revenue per are derived from intercrops and shade trees on the coffee plot. To reduce the influence of outliers, we estimate the models using winsorized samples, excluding observations at the 1% extremes of the outcome distributions. This does not apply to price, as there are no outliers. As a robustness check, estimation results based on the full (non-winsorized) sample are provided in the appendix.

Ecological outcome variables

We use five outcome variables to measure the ecological effects of sustainability standards. We distinguish between variables related to the plot's vegetation structure and those related to animal diversity. Outcome variables that relate to the vegetation structure are shade tree density and shade tree richness. We choose shade tree density and richness because VSS promote the planting of shade trees to improve the biodiversity in the plot (Rainforest Alliance 2023; Fairtrade 2025; C.A.F.E. Practices 2024). We define *shade tree density* as the number of shade trees per are and *shade tree richness* as the number of distinct shade tree species present on the plot.

A more diverse and dense vegetation structure is expected to increase the animal diversity on the plot (Clough et al. 2011; Tscharntke et al. 2011). To assess animal diversity, we use arthropod predation rate and predator richness as proxies for pest-control ecosystem service availability (Howe et al. 2009).

[3] Typically, coffee is categorized into two price categories based on quality: one for high-quality and another for low-quality coffee. This classification is often determined using the coffee floating test, in which coffee cherries are placed in water tanks; denser, higher-quality cherries sink while lower-quality cherries float.

We define *predation rate* as the percentage of the artificial caterpillars deployed on each coffee plot that were bitten by insects, birds, small mammals or reptiles. *Predator richness* refers to the number of distinct bite marks found on the artificial caterpillars in the plot, serving as an indicator of the diversity of potential arthropod predators. Last but not least, the *Bioacoustic Index* reflects the overall acoustic diversity and intensity, as a reflection of animal diversity which we calculate based on dawn chorus (06:00-08:00) sound recordings using Audiomoths deployed in the coffee plots (Boelman et al. 2007; Bradfer-Lawrence et al. 2020). A detailed description of these variables and how they are calculated can be found in the Appendix A3.1.

4.3) Estimation strategy

To answer our first research question, we estimate the average association between in-house and third-party certification and socioeconomic and ecological outcomes. We use the following model:

$$Y_{icdt} = \beta_1 IH_{cd} + \beta_2 TP_{cd} + \beta_3 X_{icdt} + \beta_4 CWS_{cdt} + \mu_d + \gamma_t + a_i + \epsilon_{icdt} \quad (1)$$

where Y_{icdt} represents the socioeconomic and ecological outcome for household i, supplier to CWS c, in district d, in year t. IH_{cd} and TP_{cd} are the main treatment variables, taking a value of 1 if the CWS that the household supplies to is in-house or third-party certified, respectively, and 0 otherwise. X_{icdt} is a vector of household-level control variables, CWS_{cdt} denotes CWS-level control variables, μ_d a set of district dummies, γ_t year dummies, a_i captures household-specific fixed effects, and ϵ_{icdt} is the error term.

For our socioeconomic estimations, we control for a set of characteristics that we expect to be associated with our socioeconomic outcomes. At the household level, we control for a set of household characteristics, as well as a set of characteristics related to the household's location and the coffee plot. We derive these variables from our household survey. Household characteristics include the household head's literacy status, gender, age, years of experience in coffee farming, the household's dependency ratio and whether any household member has experienced an illness that severely affected their coffee production in the previous season. Characteristics related to the household's location include the reported condition of the road leading to the homestead, reported availability of electricity in the area, and the reported distance to the nearest agricultural input store. To account for characteristics of the coffee plot, we control for the reported distance between the coffee plot and the homestead, the reported age of the coffee trees, the reported quality of the soil, and the reported experience of a pest or disease outbreak in the previous harvest season.

At the CWS level, we control for CWS characteristics that may influence the likelihood of CWS certification as well as the implementation of VSS interventions and related outcomes (Sellare et al. 2020). We derive these variables from our CWS survey. They include the CWS size, measured by the number of farmer members and the maximum capacity of coffee cherries that the CWS can wash daily. Additionally, we control for the number of coffee farmers living in the zone[4] where the CWS operates. As mentioned earlier, during the zoning policy (2016-2023) CWSs were only allowed to source coffee from farmers living in their zone. Zones with a higher number of coffee farmers therefore provided CWSs with greater access to coffee, thereby increasing their revenue potential and potentially enabling them to offer more interventions to farmers. Moreover, we consider the CWS manager's gender, age, whether the manager has obtained a university degree, the manager's experience in coffee farming, and the duration of managing the CWS.

For our ecological estimations, we include a reduced[5] set of household-, and plot-level control variables that we derive from our household survey and that we expect to most likely affect our ecological outcomes. Additionally, we include the area and the altitude of the plot, measured with a GPS device, the surrounding tree cover in square kilometers within a 2 km radius and the distance to the nearest primary forest[6] measured in kilmeters. We expect that plots at higher altitudes have less anthropogenic activity due to their remoteness which would lead to more undisturbed habitat availability for animals (Kunc and Schmidt 2019). Additionally, we expect increasing distance to forest to negatively effect in-plot biodiversity, since birds, potential pollinators and other animals species that primarily use forests may "spillover" into agroforestry areas of suitable quality (Estavillo et al. 2013).

Our second research question investigates how the duration of certification is associated with socioeconomic and ecological outcomes. To address this research question, we follow (Maggio et al. 2022), and our model takes the following form:

$$Y_{icdt} = \beta_1 IH\ no\ of\ yrs_{cdt} + \beta_2 TP\ no\ of\ yrs_{cdt} + \beta_3 X_{icdt} + \beta_4 CWS_{cdt} + \mu_d + \gamma_t + a_i + \epsilon_{icdt} \quad (2)$$

where all variables are defined as in equation 1, except that $IH\ no\ of\ yrs_{cdt}$ represents the number of years that the household is in-house certified and $TP\ no\ of\ yrs_{cdt}$ represents the number of years that the household is third-party certified up to year *t*.

The nature of our data allows us to employ panel data methods, which can either be implemented using a random or fixed effects estimator (Wooldridge 2010). Using a fixed effects estimator which measures changes within households between the years and thereby controls for unobserved heterogeneity,

[4] This variable differs from the number of CWS farmer members, as not all farmers within a zone are formal members of the CWS. In particular, cooperatives typically operate with a limited number of membership shares, meaning that only a subset of farmers in the zone are registered members.
[5] This reduction is necessary because the ecological sample is smaller than the socioeconomic sample, and including a larger number of covariates could compromise statistical power. We therefore prioritize variables that are most likely to affect ecological outcomes based on theoretical relevance and previous empirical studies (Wätzold et al. 2025).
[6] The distance to the nearest primary forest was mapped in QGIS using Google Earth Imagery 2023).

requires substantial variation within our treatment variables. However, as discussed in Chapter 4.1, no farmers changed their certification status between Waves 1 and 2, and only 26 did so between Waves 2 and 3. This limited variation restricts the applicability of the fixed effects estimator.

A potential issue with using the random effects estimator is that it relies on the assumption of zero correlation between observable and unobservable variables. This assumption is unlikely to hold when the treatment (in our case certification) is voluntary. To address this concern of potential endogeneity, we employ the correlated random effects (CRE) model (Mundlak 1978). The CRE model is computationally like the random effects model but it includes the means of time-varying variables $\overline{HH_{icdt}}$ and $\overline{CWS_{cdt}}$ as pseudo-fixed effects to control for unobserved time-invariant heterogeneity. The CRE has been widely applied in impact studies in the field of agricultural economics (Preusse et al. 2024; Sibhatu et al. 2025; Abay et al. 2022).

The main limitation in our context is the absence of pre-certification data, which prevents us from fully accounting for baseline differences and leaves the possibility of reverse causality which may bias our estimates. Reverse causality could occur, for instance, if CWSs decide to pursue certification because their supplying farmers already achieve higher yields. Thus, certification becomes more profitable as it generates greater revenues from exporters. Similarly, CWSs that are located in areas with a higher proportion of farmers cultivating agroforestry systems may have a higher likelihood of joining certification since it will be easier to meet shade tree-related requirements. An instrumental variable approach would be ideal for addressing bias resulting from reverse causality. However, since we could not find a valid instrument, we refrain from making causal claims and rather interpret our estimates as associations between the certification and outcome variables.

5.) Results

5.1) Descriptive results

In this section, we present descriptive statistics for the variables used in the analyses, as well as the households' participation in VSS interventions. Table 2 reports descriptive statistics on the outcome and control variables, pooled across the 2022, 2023, and 2024 survey waves.

Table 2 shows that in both certification groups, households are on average certified under more than two schemes, with Rainforest Alliance being the most common VSS. With respect to the socioeconomic outcome variables, both in-house and third-party certified households achieve significantly higher coffee yields, receive higher prices, and exhibit larger profits and returns to land compared to non-certified households. With respect to the ecological outcome variables, both in-house and third-party certification are associated with significantly higher shade tree density and shade tree richness. However, households from both schemes exhibit significantly lower predation rates, and in-house certified households have significantly lower predator richness on their plots. For the Bioacoustics

Index, no significant differences are observed between non-certified and certified households from either scheme.

In terms of household and household location-related characteristics, third-party certified and non-certified households are relatively similar. In contrast, in-house certified households differ significantly from non-certified ones in several aspects although the differences are small in magnitude. For instance, in-house certified household heads are significantly younger and have significantly fewer years of coffee-growing experience. At the same time, in-house certified households cultivate almost half a coffee plot more, possess significantly younger trees, and report soil conditions that are significantly better.

Characteristics at the CWS level differ significantly between certified and non-certified households, indicating potential selection into certification at the CWS level. Compared to non-certified farmers, both in-house and third-party certified farmers supply to larger CWSs and supply to CWSs that are located in zones with significantly larger coffee farmer populations. Moreover, a significantly lower share of both in-house and third-party certified farmers supply to CWSs managed by a woman and by a manager with experience in coffee farming. In addition, a larger proportion of third-party certified farmers supply to a CWS managed by a university graduate.

Table 2: Descriptive statistics of all variables (pooled across 2022, 2023, 2024).

Variable	Non-certified HH mean (SD)	In-house certified HH mean (SD)	Third-party certified HH mean (SD)
Socioeconomic outcome variables			
Coffee yield (kg/tree)	2.12 (1.79)	2.60 (2.58)***	2.40 (4.45)*
Coffee yield (kg/are)	59.59 (54.93)	68.31 (67.92)***	64.15 (64.74)*
Coffee price (RWF/kg)	547.15 (113.96)	568.25 (120.65)***	573.15 (112.29)***
Profit (RWF/are)	28,921.75 (29,034.17)	35,595.01 (40,430.92)***	33,441.81 (37,757.12)***
Returns to land (RWF/are)	29,627.73 (29,533.08)	36,677.42 (40,670.22)***	34,439.05 (38,058.06)***
Ecological outcome variables			
Shade tree density (are)	1.55 (1.76)	2.64 (2.32)***	2.82 (2.98)***
Shade tree richness	3.47 (1.66)	3.94 (1.61)**	4.10 (1.88)***
Predation rate	0.21 (0.12)	0.17 (0.10)***	0.17 (0.10)***
Predator richness	5.66 (1.51)	5.14 (1.66)**	5.40 (1.57)
Bioacoustic Index†	72.00 (20.11)	68.88 (20.88)	69.76 (20.01)
HH control variables			
HH head can read/write	0.78	0.82**	0.79
Gender of HH head (male=1)	0.75	0.78	0.73
Age of HH head	56.40 (13.99)	54.19*** (12.51)	56.83 (12.10)
Household size	4.80 (2.13)	5.05** (2.16)	4.77 (2.17)
Dependency ratio	0.64 (0.28)	0.67** (0.25)	0.64 (0.27)
Years growing coffee	29.64 (16.22)	27.68** (14.35)	29.77 (14.65)
No. of coffee plots	2.38 (1.97)	2.67*** (2.15)	2.46 (2.05)
Serious illness in HH	0.27	0.21***	0.24
Distance to plot (km)	8.63 (73.54)	5.13 (48.33)	4.68 (47.43)
Coffee plot experienced disease	0.27	0.25	0.25
Average age of trees	29.28 (16.49)	26.98*** (15.38)	27.19*** (15.55)
Soil condition (1-5)	4.14 (0.82)	4.23** (0.80)	4.21** (0.80)
Condition of road (good/bad)	0.22	0.18	0.24
Access to electricity (yes/no)	0.89	0.91	0.92
Distance to input market (km)	7.52 (42.95)	5.14 (25.50)	6.12 (35.04)
Household observations	889	735	1248

*Note: Standard deviations are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively, for differences in means compared to non-certified households. †55 Bioacoustic Index values had to be deleted either because the audio file was corrupted or because heavy rain caused excessive background noise, which biases the sound calculations.*

Table 2: Continued

Variable	Non-certified HH mean (SD)	In-house certified HH mean (SD)	Third-party certified HH mean (SD)
CWS control variables			
No. of registered farmers	676.22 (378.44)	1120.79*** (413.69)	823.07*** (393.47)
Max washing capacity (t)	14.37 (7.76)	27.90*** (11.77)	20.09*** (9.99)
No. of farmers in zone	790.17 (509.65)	1195.20*** (399.95)	911.64*** (425.51)
Manager is woman	0.24	0.15***	0.09***
Manager yrs. at CWS	5.35 (3.24)	5.75** (3.91)	5.20 (4.12)
Manager age	37.99 (4.79)	41.05*** (11.41)	37.29** (9.68)
Manager is university graduate	0.59	0.52***	0.83***
Manager produces coffee	0.89	0.79***	0.83***
Control variables only used in the ecological analysis			
Plot altitude (m)	1629.68 (213.65)	2522.86 (8462.01)	1688.09 (158.78)**
Tree cover (km² within 2km radius)	1.55 (0.71)	1.61 (0.98)	1.54 (0.84)
Distance to primary forest (km)	12.50 (7.98)	7.97 (6.17)***	11.51 (7.98)
Plot size (are) measured with GPS	14.89 (16.67)	8.84 (8.83)***	10.47 (10.19)**
Districts dummies			
Rusizi	0.19	0.21	0.36***
Nyamasheke	0.24	0.38***	0.13***
Karongi	0.24	0.08***	0.15***
Rutsiro	0.19	0.15**	0.11***
Huye	0.14	0.18**	0.25***
VSS type			
C.A.F.E. Practices		1.00***	0.30***
Organic		0.08***	0.20***
Rainforest Alliance		0.52***	0.55***
Fairtrade		0.00	0.52***
4C		0.08***	0.05***
No. of certificates		2.19 (1.27)***	2.62 (0.72)***
Plot sizes (not included as control variables)			
Coffee plot size (ha)	0.15 (0.32)	0.13 (0.21)	0.14 (0.20)
Coffee plot size (are)	15.49 (31.84)	13.34 (20.66)	14.43 (19.53)
Household observations	889	735	1248

*Note: Standard deviations are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively, for differences in means compared to non-certified households.*

As discussed in Chapter 2, VSS require the certificate holder (in our case the CWS) to implement a range of interventions. Table 3 presents descriptive statistics on households' reported participation in these interventions during the past coffee harvest season. On average, compared to non-certified households, a larger proportion of both in-house and third-party certified households report to participate in almost all interventions, suggesting that VSS contribute to the implementation of various support measures. However, the extent of household participation differs slightly between the two certification types. For instance, a significantly larger share of third-party certified households report to have received premiums. This is likely due to the fact that premium distribution is not mandatory under C.A.F.E Practices but is so under Fairtrade and The Rainforest Alliance (C.A.F.E. Practices 2024; Fairtrade 2024; Rainforest Alliance 2021). A higher proportion of third-party certified households also report to have received loans and insurances, whereas in-house certified households more frequently report to receive spraying services.

On average, compared to non-certified households, a higher share of both in-house and third-party certified households report to have participated in environment-related interventions such as training on IPM or on how to improve the biodiversity, as well as report to have received shade tree seedlings. The share of households receiving audits is similar across in-house and third-party certification, although a slightly higher proportion of third-party certified farmers report to have received audits on agrochemical use. While the certificate holder, in this case the CWS, is audited annually to tri-annually depending on the scheme, only a small subset of farmers is typically selected for inspection (Rainforest Alliance 2023). In our sample, the reported audit rate of 11-15% of certified farmers is substantially lower than in the study of Bemelmans and Maertens (2025), who find that 60% of certified Rainforest Alliance cocoa farmers in Indonesia reported at least one annual audit.

Table 3: Descriptive statistics of participation in interventions within the past coffee harvest season (pooled across 2022, 2023, 2024)

Intervention	Non-certified HH mean	In-house certified HH mean	Third-party certified HH mean
Price-related interventions			
Received premium	0.11	0.18***	0.27***
Production-related interventions			
Received training (on any topic)	0.38	0.67***	0.61***
Participated in farmer group	0.30	0.64***	0.63***
Received loan	0.10	0.14**	0.24***
Received insurance	0.03	0.02**	0.09***
Received spraying services	0.77	0.88***	0.83***
Received compost for free	0.04	0.10***	0.10***
Received free coffee tree seedlings	0.27	0.32**	0.35***
Received in-kind support	0.05	0.07	0.11***
Environment-related interventions			
Received shade tree seedlings	0.26	0.34***	0.34***
Received training on biodiversity conservation	0.16	0.33***	0.33***
Received training on IPM	0.16	0.37***	0.35***
Had audit on agrochemical use	0.07	0.11	0.13**
Had audit on shade tree requirements	0.04	0.08*	0.08**
Had audit on agricultural practices compliance	0.08	0.15***	0.15***
Household observations	889	735	1248

*Note: Standard deviations are shown in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively, for differences in means compared to non-certified households.*

3.2) Regression results

Results on the average association between in-house and third-party certification and socioeconomic and ecological outcomes

In this section, we present the CRE model results on the average associations obtained using the CRE model with the data from all three survey waves (Table 4). Regarding the socioeconomic outcomes in Panel A, both in-house and third-party certification are positively associated with all socioeconomic outcome variables, however, the associations are only significant for third-party certification.

Turning to the ecological outcomes in Panel B, the results are less conclusive. None of the associations are statistically significant, although both certification types are positively associated with shade tree density and third-party certification is positively associated with shade tree species richness. With regard to animal diversity, neither certification type shows significant associations, and some coefficients are negative.

Table 4: CRE results on the association between in-house and third-party certification and socioeconomic and ecological outcomes

Outcome	In-house certified coefficient (SE)	Third-party certified coefficient (SE)
Panel A: Socioeconomic outcomes		
Coffee yield (kg/tree)	0.16 (0.13)	0.21** (0.09)
Coffee yield (kg/are)	3.02 (3.66)	4.49* (2.63)
Price (RWF/kg)	2.57 (6.13)	29.81*** (3.66)
Profit (RWF/are)	2804.32 (2107.01)	3984.59*** (1464.65)
Returns (RWF/are)	3240.99 (2110.59)	4234.28*** (1458.31)
Panel B: Ecological outcomes		
Shade tree density	0.50 (0.48)	0.75 (0.49)
Species tree richness	0.00 (0.42)	0.52 (0.32)
Predation rate	0.00 (0.02)	–0.02 (0.01)
Predator class richness	–0.44 (0.29)	–0.12 (0.21)
Bioacoustic Index†	–2.22 (5.14)	–0.70 (3.34)

*Robust standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1. Socioeconomic outcome variables are winsorized at the 1% level (except for price, which has no outliers). Coffee yield (kg/tree): N = 2,468; Coffee yield (kg/are): N = 2,469; Price: N = 2,492; Profit: N = 2,468; Returns: N = 2,467. The ecological subsample includes 289 observations, except for the Bioacoustic Index (N = 234), as 55 observations are excluded due to corrupted audio files or heavy rain. Control variables and means of time-varying controls are included but not shown for brevity. Full estimation results are provided in Appendix Tables A.1 and A.2.*

We further explore the associations between certification and the outcomes separately for each survey wave. Table A.3 presents the results of the analyses, estimated using OLS for socioeconomic outcomes and generalized linear mixed effects models[7] for ecological outcomes. The results reveal that third-party certification is relatively consistently associated with significantly higher yields, prices, profits, and returns to land across the three waves, whereas for in-house certification, significant positive associations are mostly only in Wave 3. Regarding the ecological shade tree-related results, in some years, certification is significantly positively associated with shade tree richness, while in others there is no association. Regarding the animal diversity-related results, in some years, certification is significantly negatively associated with predation rates, predator richness, and the Bioacoustic Index, while in others there is no association. The variation observed in our cross-sectional results, and in particular the ecological results, highlights the fact that relying on a single survey wave may lead to

[7] We choose generalized linear mixed effects models because they are more suitable when analyzing for ecological data since they account for non-linear outcome distributions, as well as account for similar environmental characteristics that plots in the same area share (Vanderhaegen et al. 2018).

misleading conclusions and underscores the importance of using panel data sets.

Regression results on the association between the in-house and third-party certification duration and socioeconomic and ecological outcomes

Our second research objective is to examine how certification duration is associated with socioeconomic and ecological outcomes. The CRE results in Table 5 indicate a positive and significant association between certification duration and all socioeconomic outcomes for both in-house and third-party certification. On average, the longer the household is certified, the higher the socioeconomic outcome.

In contrast, the ecological results show that longer in-house certification duration shows a negative association with the shade tree outcomes, albeit the associations are not significant. Longer in-house certification duration is also associated with significantly lower levels of predator richness and lower levels of the Bioacoustics Index, albeit the latter association is not significant. In contrast, longer third-party certification duration is significantly positively associated with higher values for shade tree density. Third-party certification duration shows no significant associations with predation outcomes and a negative, albeit non-significant association with the Bioacoustic Index.

Table 5: Association between in-house and third-party certification duration and socioeconomic and ecological outcomes

Outcome	No. of years in-house certified coeff (SE)	No. of years third-party certified coeff (SE)
Panel A: Socioeconomic outcomes (N = 2,492)		
Coffee (kg/tree)	0.04** (0.02)	0.02** (0.01)
Coffee (kg/are)	1.17** (0.53)	0.51** (0.21)
Price (RWF/kg)	1.49* (0.83)	2.25*** (0.33)
Profit (RWF/are)	843.56*** (313.65)	398.06*** (114.26)
Returns (RWF/are)	957.1*** (315.35)	388.8*** (114.22)
Panel B: Ecological outcomes (N = 289)		
Shade tree density	–0.04 (0.07)	0.09* (0.05)
Shade tree richness	–0.01 (0.06)	0.05 (0.03)
Predation rate	0.00 (0.00)	0.00 (0.00)
Predator richness	–0.08** (0.04)	0.00 (0.02)
Bioacoustic Index†	–0.47 (0.66)	–0.20 (0.33)

*Robust standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1. Socioeconomic outcome variables are winsorized at the 1% level (except for price, which has no outliers). Coffee yield (kg/tree): N = 2,468; Coffee yield (kg/are): N = 2,469; Price: N = 2,494; Profit: N = 2,468; Returns: N = 2,467. The ecological subsample includes 289 observations, except for the Bioacoustic Index (N = 234), as 55 observations are excluded due to corrupted audio files or heavy rain. Control variables and means of time-varying controls are included but not shown for brevity.*

As discussed in Chapter 4.2, the longest in-house certification duration in our sample is 10 years. However, a significant proportion of households have been third-party certifications since 11 to 21 years. To account for this difference and explore potential heterogeneous associations depending on certification duration (short-, medium-, and long-term), we re-estimate the model using cut-offs that group farmers by certification duration. We define the groups to ensure roughly comparable certification-duration intervals across the schemes. For in-house certification, the groups relate to 3 to 4 years, 5 to 8 years, and 9 to 10 years. As for third-party certification, they relate to 1 to 4 years, 5 to 8 years, 9 to 10 years, and a fourth group covering 11 to 21 years, given the longer durations observed. Each of these groups is represented by a dummy variable that takes on 1 if the household falls into the specific category.

The results in Table 6 indicate that the magnitude of the associations between certification and socioeconomic outcomes increases with a longer certification time period. For in-house certification, only farmers certified for 9 to 10 years show significant positive associations with yields, profits, and returns, while shorter certification periods show no significant associations. Third-party certification follows a similar pattern. This finding may also explain why significant positive associations for in-house certification are observed mostly only by Wave 3 (Table A.1). It is likely that a proportion of households started to experience the benefits of certification only in Wave 3. The price associations, however, differ between the two schemes. None of the in-house certification groups show significant price associations, whereas third-party certification consistently shows higher prices across all duration groups, with larger magnitudes for longer certification periods.

The ecological outcomes also show heterogeneous associations across different certification durations. For in-house certification, shorter durations are significantly and positively associated with higher shade tree density and richness, whereas longer durations display negative, though not statistically significant, associations. For third-party certification, significant positive associations with shade tree outcomes are evident only among households certified for more than 11 years. Across both certification schemes and all duration groups, predation rates and the Bioacoustic Index show no significant associations. Predator richness is negatively and significantly associated with farmers in-house certified for 9 to 10 years, likely reflecting lower shade tree values.

Table 6: Association between different in-house and third-party certification durations and socioeconomic and ecological outcomes.

Outcome	IH 3–4 yrs	IH 5–8 yrs	IH 9–10 yrs	TP 1–4 yrs	TP 5–8 yrs	TP 9–10 yrs	TP 11–21 yrs
Panel A: Socioeconomic outcomes							
Coffee	0.14	0.12	0.52*	0.18	0.06	0.39	0.37***
(kg/tree)	(0.24)	(0.14)	(0.27)	(0.13)	(0.14)	(0.27)	(0.13)
Coffee	–0.03	1.54	15.43*	–0.32	2.35	11.75	9.70**
(kg/are)	(6.27)	(4.00)	(8.71)	(3.68)	(3.90)	(8.69)	(3.86)
Price	10.48	1.96	–11.83	29.63***	17.26***	65.81***	45.27***
(RWF/kg)	(10.42)	(6.91)	(10.89)	(5.55)	(5.73)	(12.24)	(6.04)
Profit	799.20	1806.95	9229.66**	1158.18	2871.47	10196.05**	7175.26***
(RWF/are)	(3428.49)	(2302.81)	(4704.16)	(2065.68)	(2202.32)	(4851.50)	(2171.55)
Returns	976.07	2089.5	10666.74**	1489.43	3190.68	9875.5**	6936.02***
(RWF/are)	(3425.28)	(2310.55)	(4819.28)	(2088.19)	(2212.3)	(4949.99)	(2181.45)
B: Ecological outcomes							
Shade tree	2.16***	1.12**	–0.54	0.22	0.15	–0.59	2.07**
density	(0.68)	(0.50)	(0.76)	(0.74)	(0.53)	(1.11)	(0.91)
Shade tree	0.50	0.23	–0.60	–0.02	0.21	–0.50	1.06*
richness	(0.50)	(0.50)	(0.79)	(0.48)	(0.51)	(1.13)	(0.63)
Predation	0.02	–0.01	–0.01	–0.02	–0.01	0.04	–0.02
rate	(0.04)	(0.02)	(0.03)	(0.02)	(0.02)	(0.05)	(0.02)
Predator	–0.11	–0.33	–0.90*	0.06	–0.27	0.19	0.06
richness	(0.61)	(0.40)	(0.48)	(0.35)	(0.39)	(0.86)	(0.41)
Bioacoustic	7.79	0.31	–11.77	–0.52	0.04	–4.53	2.74
Index†	(9.07)	(5.82)	(7.70)	(4.81)	(5.45)	(9.89)	(5.85)

*Robust standard errors are in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1. Socioeconomic outcome variables are winsorized at the 1% level (except for price, which has no outliers). Coffee yield (kg/tree): N = 2,468; Coffee yield (kg/are): N = 2,469; Price: N = 2,494; Profit: N = 2,468; Returns: N = 2,467. The ecological subsample includes 289 observations, except for the Bioacoustic Index (N = 234), as 55 observations are excluded due to corrupted audio files or heavy rain. Control variables and means of time-varying controls are included but not shown for brevity.*

As a robustness check, we re-run all main socioeconomic estimations using the full (non-winsorized) sample (Tables A.4, A.5, and A.6 in the appendix). The results remain similar, except for two notable changes. The first change relates to the average in-house certification associations (Table A.4): the previously non-significant associations between in-house certification and profits and returns to land gain statistically significance once households with the highest 1% of outcome values are included. However, this suggests that the positive significant associations in the non-winsorized results are driven by a small number of high-performing in-house certified farmers rather than reflecting systematic differences across the broader sample.

The second change relates to the heterogeneity duration analysis (Table A.6). The coefficient for third-party certification of 5 to 8 years increases in magnitude and gains statistical significance, while the third-party certification coefficient for 9 to 10 years decreases in magnitude and loses statistical significance. This pattern indicates that including extreme observations slightly shifts the pattern of associations across duration groups but does not alter the overall conclusion that benefits from certification tend to materialize over longer participation periods.

In addition, we re-estimate the models for profits and returns to land by including the costs of the agrochemicals that are subsidized by the government. The results (Tables A.7, A.8, and A.9 in the appendix) remain similar in magnitude and significance, indicating that our main findings are robust to this adjustment.

6) Discussion

The aim of this article is to examine how in-house and third-party certification, as well as their duration, are associated with both socioeconomic and ecological outcomes using household, ecological, and buyer panel data from Rwanda's coffee sector. We find that only third-party certification is significantly positively associated with coffee yields, prices, profits, and returns to land. Furthermore, we find that, both in-house and third-party certification duration is significantly positively associated with all socioeconomic outcomes.

These results are encouraging and consistent with our hypotheses. They suggest that once CWSs obtain certification, they are gradually able to improve farmers' access to interventions, such as agronomic training and, in the case of third-party certification, price premiums, which over time translate into higher socioeconomic outcomes. Indeed, a simple correlation analysis (Table A.10 in the appendix) shows that longer in-house and third-party certification duration is also significantly and positively correlated with higher farmer-reported participation in the VSS interventions.

In contrast, the ecological results are more mixed. While the average associations between both certification types and shade tree density and tree species richness are positive, they are not statistically significant. Additionally, we find no positive associations with animal diversity outcomes. The duration analysis highlights important differences between certification types. Third-party certification duration is significantly and positively associated with shade tree density and the heterogeneity analysis reveals that significantly higher shade tree outcomes are observed among households that have been certified for more than 11 years. This is consistent with the expectation that ecological outcomes require time to materialize and also reflects the continuous-improvement model applied by schemes such as the Rainforest Alliance. As discussed earlier, in these schemes, a specific shade tree level threshold is not required to enter certification. Instead, farmers are monitored on their progress toward higher shade levels over time. This helps explain why significant positive associations are evident mainly among those with the longest certification histories. However, while the shade tree results are promising, it is noteworthy to mention that they do not translate into positive associations for animal diversity indicators.

Conversely, for in-house certification, we find the opposite trend: households with shorter certification durations are associated with significant positive shade tree outcomes, whereas longer durations show negative, though non-significant, associations. This reverse trend is counterintuitive because both in-house and third-party certified households have the same level of access to shade tree seedlings (Table 2). However, an explanation for the absence of any positive associations could be the underlying point-based system that is used by the in-house scheme C.A.F.E. Practices. Under this system, households with higher shade tree cover gain additional points toward their overall evaluation score; however, shade tree cover is not a core requirement and is not monitored based on improvements over time. As a result, households may focus on adopting less costly practices that yield comparable point gains, such as primarily yield-enhancing practices, which could inadvertently have detrimental effects on animal diversity, such as reduced predator richness.

The absence of significant associations with animal diversity outcomes runs counter to our expectations. Table 3 shows that certified households from both schemes report attending significantly more training on IPM and biodiversity conservation, and Table A.10 shows that longer certification durations for both schemes are significantly positively correlated with such trainings. This suggests that while the necessary interventions are in place, they do not translate into measurable improvements in animal diversity. Moreover, although third-party certification and its duration are positively associated with shade tree outcomes, these do not lead to corresponding gains in animal diversity. One possible explanation is that positive shade tree effects are offset by other yield-enhancing practices. In addition, increases in plot-level shade tree cover alone may be insufficient to enhance animal diversity if the individual plots are relatively small (circa 0.14 hectare on average) and if other environmental factors, such as the surrounding habitat connectivity, are limited (Aycart-Lazo et al. 2025).

Our findings have several policy and research implications. First, the fact that most positive socioeconomic outcomes only become evident after nearly a decade of certification suggests that benefits may materialize too late to retain farmers. While this may have been less of a concern under Rwanda's former zoning policy (2016-2023) which restricted farmers to selling their coffee to the CWS in their zone, it could become a greater challenge in the current liberalized market where farmers can freely switch CWS. Compared to non-certified farmers, third-party certified farmers already receive higher prices across all duration groups. However, these prices are insufficient in the initial years to offset investment costs and generate higher profits. If certificate holders aim to sustain farmer participation, they should ensure that certification provides adequate short-term incentives. Offering higher and more stable farm-gate prices in the early years could help cover costs until yields increase. Since this may be financially challenging for the certificate holder, certification schemes could consider reducing the certification fee for the certificate holder in the initial years.

Second, the contrasting results related to shade tree outcomes between in-house and third-party schemes suggest the need for stricter environmental requirements for in-house certification. In particular, a point-based evaluation system may be insufficient for companies, such as Starbucks, to achieve the intended environmental outcomes if they aim to position their in-house VSS as environmentally sustainable. Finally, Ocampo-Ariza et al. (2024) and Aycart-Lazo et al. (2025) emphasize that improving animal diversity on coffee plots requires a combination of measures implemented both at the plot and landscape level. Hence, our findings suggest that forest restoration and the enhancement of ecological connectivity between agricultural and natural areas are critically needed to achieve overall ecological improvements.

With respect to research, our results emphasize the importance of using panel data that covers multiple survey rounds in order to obtain robust assessments. The variation in the significance of the in-house coefficients for both socioeconomic and ecological outcomes across the three survey years as well as the variation in the third-party coefficients for ecological outcomes, illustrates that single-round analyses provide only a snapshot and risk presenting a misleading picture.

Our findings also underscore the need to view certification as a long-term process rather than a short-term intervention. Evaluations that assess VSS effects within only the first few years of participation may fail to detect significant changes because it is too early for the benefits to develop. For future studies, this implies that particular attention should be paid to the timing of certification when selecting the certified sample. Moreover, examining the associations between certification duration and outcomes can yield valuable insights into whether there is progress toward the intended sustainability goal.

7) Conclusion

The aim of this article is to examine how in-house certification, third-party certification and their duration are associated with both socioeconomic and ecological outcomes in Rwanda's coffee sector. Whereas most previous studies focus on a single sustainability dimension or rely on cross-sectional data, our study contributes to the literature by combining household and ecological panel data to provide a more holistic understanding of VSS and its associations with different sustainability dimensions.

In summary, only third-party certification is significantly positively associated with all selected socioeconomic outcomes. Moreover, for both in-house and third-party certification we find that a longer certification duration is significantly associated with higher socioeconomic outcomes. For ecological outcomes, we only find significant positive associations with shade tree outcomes under long-term third-party certification, while in-house certification shows reverse trends. This suggests that third-party schemes with continuous improvement requirements are more effective in promoting ecological benefits than in-house schemes with less stringent environmental criteria.

Last but not least, it must be acknowledged that a limitation of our study is the small number of farmers who changed their certification status during the study period. This prevents us from estimating the effects within households over time. Future research tracking a larger sample of farmers who change certification status over longer time horizons would be costly but beneficial for allowing stronger causal inference.

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9) Appendix

A.9.1) Ecological data collection protocol

Shade tree density and richness

On each plot, we counted and identified the species of all non-coffee trees with a diameter at breast height (DBH) greater than 10 cm (Hoover and Smith 2020). In cases where species identification was uncertain, we photographed the tree for subsequent verification using tools such as PlantNet (Yang et al. 2022) and consultation with local experts. This procedure enabled the construction of a comprehensive dataset of tree species composition for each plot.

Bioacoustic Index

We collected audio data using two recorders per plot. Due to the steep slopes and limited plot sizes, we positioned the recorders mid-slope and oriented towards each other on opposite sides of each plot. This setup ensured a minimum distance of 20 meters between devices, minimized overlapping recording areas, and maintained placement within the plot interior. We placed the recorders no closer to the edge than the second-to-last row of coffee trees. We tied each device to a tree at 1.5 m height.

We used AudioMoth autonomous recorders developed by Open Acoustic Devices. We equipped devices with 64-gigabyte microSD cards and AudioMoth waterproof cases with acoustic vents. We configured device settings such as sample rate and recording schedule using AudioMoth configuration software (Open Acoustic Devices 2022). We ran all devices with firmware version 1.8.1, a sample rate of 48 kHz, and medium gain. A 48 kHz sample rate has a Nyquist value of 24 kHz, which is the highest frequency at which sounds can be analyzed using this sample rate (Meddins 2000). The devices operated continuously without a sleep cycle for a minimum of 24 hours on each plot. This setup provided a cost-effective yet high-quality solution for long-term acoustic monitoring (Hill et al. 2019).

We used the Bioacoustic Index (Boelman et al. 2007) to estimate the relative intensity and diversity of animal sounds as an indicator of animal diversity, rather than using time-consuming and costly species-level identification methods. The Bioacoustic Index is defined as the "product of the amplitude and the number of occupied frequency bands, relative to the quietest 1 kHz frequency band" (Bradfer-Lawrence et al. 2020). We band-pass filtered recordings between 0.5-24 kHz. This range excluded recorder self-noise, which typically occurs between 0-0.5 kHz (Bradfer-Lawrence et al. 2023). If both recordings from the plot were without error, we eliminated one and used the other for calculating the BI. We used Kaleidoscope Pro software version 5.7.0 to split recordings into one-minute segments and to calculate the Bioacoustic Index for each minute using a Fast Fourier Transform (FFT) size of 512 (Wildlife Acoustics Inc. 2025). We then calculated the median Bioacoustic Index during the dawn chorus from 06:00-08:00 for each plot, as this period reflects high biological activity (Burt and Vehrencamp 2025). 30 observations had to be deleted due to corrupted audio files in Wave 2. Additionally, we had to delete 25 of the total observations because heavy rain caused excessive background noise, which biases the sound calculations.

Arthropod predation rate and predator richness

We used experiments with sentinel artificial caterpillars to measure predation rates on arthropods as a proxy for biological control of insect pests (Howe et al. 2009). We used green plasticine (Pelikan Nakiplast®, Colour: 681/"green") and a mechanical clay extruder to make caterpillars of 35 x 5 mm, consistent with other studies in similar tropical contexts (Maas et al. 2015; Ocampo-Ariza et al. 2023; Wätzold et al. 2025). We prepared the caterpillar one day before deployment by cutting them to size, smoothing them with a thin plastic card, and storing them in insulated boxes to prevent damage or temperature-related alterations.

On plots with at least 100 coffee trees, we deployed 40 caterpillars per plot for a 24-hour period using a cluster plot design. Each plot included five clusters, one central and four at each cardinal point. Within each cluster, we placed the caterpillars on the coffee trees at different vertical strata (ground, trunk, branch, and leaf), ensuring at least 15 cm spacing between them. We attached ground-level caterpillars to sticks or local leaves, while we fixed those on the tree using a neutral-scent superglue at an average height of 1.5 meters.

After 24 hours, we inspected all caterpillars for predation bite marks. We documented bite marks using reference images (Schwab et al. 2021; Low et al. 2014) and validated them with test marks made by field-caught insects. For ambiguous impressions, we photographed the caterpillar and categorized these bites as "morphobites" for further analysis. Using this information, we calculated arthropod predation rates as the proportion of predated caterpillars in each plot. We defined predator richness as the number of distinct bite types (morphobites) identified on the caterpillars. We assume that this number reflects the number of predator groups, such as birds, squirrels, and multiple arthropod groups, that attacked the caterpillars.

A.9.2) Regression tables

Table A.1: CRE full estimation results on the association between in-house and third-party certification and socioeconomic outcomes

	(1) Coffee yield (kg/tree)	(2) Coffee yield (kg/are)	(3) Price (RWF/kg)	(4) Profit (RWF/are)	(5) Returns (RWF/are)
In-house certified	.16	3.02	2.57	2804.32	3240.99
	(.13)	(3.66)	(6.13)	(2107.01)	(2110.59)
Third-party certified	.21**	4.49*	29.81***	3984.59***	4234.28***
	(.09)	(2.63)	(3.66)	(1464.65)	(1458.31)
HH head can read and write	-.01	4.6	7.07	3964.22	4170.88
	(.15)	(4.35)	(9.45)	(2637.39)	(2714.11)
Gender of HH head	-.18	-4.51	5.27	-1732.54	-1995.95
	(.23)	(6.36)	(10.83)	(3981.24)	(4032.1)
Age of HH head	-.02	-.54*	.3	-280.85	-269.48
	(.01)	(.29)	(.53)	(173.6)	(174.41)
Dependency ratio in HH	-.26	-3.47	-.42	-2711.78	-1895.19
	(.23)	(8.18)	(14.32)	(4423.99)	(4454.97)
Years HH head has been growing coffee	0	.12	-.37	47.42	22.31
	(0)	(.14)	(.28)	(78.92)	(75.6)
No. of coffee plots	-.02	-.69	1.53	-548.89	-575.78*
	(.02)	(.57)	(1.02)	(353.07)	(336.17)
HH has person with serious illness	-.1	-2.48	5.43	-1155.14	-1419.41
	(.08)	(2.55)	(4.86)	(1531.14)	(1531.69)
Distance to plot (km)	0	.02	.01	9.52	9.52
	(0)	(.02)	(.02)	(9.54)	(9.46)
Coffee plot experienced disease	.03	-1.93	5.5	507.27	464.08
	(.08)	(2.7)	(4.54)	(1497.76)	(1512.71)
Average age of coffee trees on plot	0	-.02	-.05	16.91	51.97
	(0)	(.11)	(.2)	(67.36)	(66.07)
Soil condition	.02	.89	-1.44	567.88	495.43
	(.04)	(1.39)	(2.82)	(811.33)	(809.7)
Good road condition	.19	8.26	-1.35	4952.01	1599.44
	(.26)	(12.46)	(11.26)	(5865.27)	(5015.31)
Village has electricity	.36**	15.61***	-3.14	9874.04***	10833.83***
	(.18)	(5.83)	(15.2)	(3718.05)	(3808.88)
Distance to input market (km)	0	-.01	-.01	5.67	6.81
	(0)	(.02)	(.05)	(14.2)	(14.28)
No. of farmers in zone	0	0	.01**	.22	.32
	(0)	(0)	(.01)	(2.01)	(2.02)
Manager is woman	.88**	19.94*	29.23	3409.59	3482.71
	(.35)	(11.55)	(19.84)	(5129.73)	(5087.55)
Years as a manager at this CWS	.02	-.16	-9.99***	192.07	270.06
	(.03)	(1.37)	(1.62)	(518.61)	(522.17)
Manager age	-.04*	-.87	-.54	-321.37	-337.71
	(.02)	(.64)	(.96)	(353.56)	(364.6)
Manager is university graduate	-.23	-2.5	-5.15	-6000.07	-6117.31
	(.44)	(13.34)	(16.58)	(6272.12)	(6575.99)
Manager has or is producing coffee	.75	4.03	45.8	5394.73	7275.14
	(.58)	(16.49)	(42.14)	(9602.09)	(9102.05)
No. of registered farmers	0	.01	0	.41	-.44
	(0)	(.01)	(.01)	(3.4)	(3.45)
Maximum washing capacity (kg)	-.03**	-1.27**	-.78	-554.33*	-571.01*
	(.02)	(.61)	(1.14)	(308.99)	(312.77)
District fixed effects	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES
Means of time-varying variables	YES	YES	YES	YES	YES
Constant	-.29	12.77	568.94***	17385.4**	19583.17**
	(.48)	(13.96)	(24.31)	(7961.02)	(7978.35)
Observations	2468	2469	2492	2468	2467

*Robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1, Socioeconomic outcome variables are winsorized at the 1% level to limit the influence of extreme values (except price, which has no outliers).*

Table A.2: CRE full estimation results on the association between in-house and third-party certification and ecological outcomes

	(1) Shade tree density	(2) Shade tree richness	(3) Predation rate	(4) Predator richness	(5) Bioacoustic Index†
In-house certified	.5	0	0	-.44	-2.22
	(.48)	(.42)	(.02)	(.29)	(5.14)
Third-party certified	.75	.52	-.02	-.12	-.7
	(.49)	(.32)	(.01)	(.21)	(3.34)
HH head can read and write	-.13	.46	.04	-.42	8.67
	(.69)	(.36)	(.02)	(.35)	(10.87)
Gender of HH head	-1.17***	-.17	.05**	-.92**	-3.33
	(.45)	(.49)	(.02)	(.43)	(8.89)
Age of HH head	-.07**	-.03	0	0	-.57***
	(.03)	(.02)	(0)	(.02)	(.2)
Years HH head has been growing coffee	.01	.01	0	-.02	.11
	(.02)	(.01)	(0)	(.02)	(.22)
No. of coffee plots	.11	.06	0	.05	.33
	(.12)	(.04)	(0)	(.09)	(1)
HH has person with serious illness	.02	.01	.02	.06	3.86
	(.52)	(.3)	(.02)	(.29)	(4)
Distance to plot (km)	0	0	0	0***	-.02**
	(0)	(0)	(0)	(0)	(.01)
Plot altitude (m)	0	0	0***	0	0
	(0)	(0)	(0)	(0)	(0)
Good road condition	1.69	-1.7**	.09	1.16	8.75
	(1.48)	(.69)	(.13)	(1.46)	(31.26)
Manager is woman	.51	-3.99	.53***	3.62	46.96
	(5.79)	(3.52)	(.19)	(3.14)	(50.36)
Manager age	-.26	-.48	.06**	.12	8.69
	(.79)	(.46)	(.02)	(.38)	(6.85)
Manager is university graduate	.27	4.67	-.72***	2.18	-23.2
	(7.88)	(4.74)	(.25)	(4.11)	(75.62)
Manager has or is producing coffee	.51	1.17	-.21***	-1.98***	2.65
	(1.94)	(1)	(.05)	(.69)	(14.48)
Years as a manager at this CWS	.23	.7	-.11***	-.23	-10.05
	(1.25)	(.75)	(.04)	(.63)	(10.98)
No. of registered farmers	0	0	0	0	0
	(0)	(0)	(0)	(0)	(.01)
Maximum washing capacity (kg)	-.13	-.31	.05**	.21	5.39
	(.58)	(.34)	(.02)	(.3)	(4.99)
No. of farmers in zone	0	0	0*	0	0
	(0)	(0)	(0)	(0)	(.01)
Size of plot in m2 (measured with GPS device)		0	0	0***	-.01***
		(0)	(0)	(0)	(0)
Tree cover in m2 within 2km radius			0	0*	0
			(0)	(0)	(0)
Distance to primary forest(km)			0**	0	-.45
			(0)	(.03)	(.56)
District fixed effects	YES	YES	YES	YES	YES
Year fixed effects	YES	YES	YES	YES	YES
Means of time-varying variables	YES	YES	YES	YES	YES
Constant	3.94**	2.7**	-.02	4.04***	64.67***
	(1.99)	(1.33)	(.06)	(1.13)	(24.7)
Observations	289	289	289	289	234

*Robust standard errors are in parentheses, *** p<.01, ** p<.05, * p<.1 †55 values had to be deleted either because the audio file was corrupted or because heavy rain caused excessive background noise, which biases the sound calculations.*

Table A.3: Associations between in-house and third-party certification and socioeconomic and ecological outcomes in each survey wave.

Outcome	Wave 1[8]		Wave 2		Wave 3	
	In-house certification	Third-party certification	In-house certification	Third-party certification	In-house certification	Third-party certification
Socioeconomic Outcomes	N = 844		N = 831		N = 817	
Coffee yield (kg/tree)	0.25 (0.22)	0.36*** (0.14)	–0.03 (0.35)	0.88* (0.53)	0.39** (0.19)	0.16 (0.16)
Coffee yield (kg/are)	0.36 (7.56)	10.97** (4.86)	–0.45 (7.59)	7.49 (4.73)	11.58** (5.89)	9.14** (4.17)
Price (RWF/kg)	18.84* (9.61)	15.55** (6.18)	1.4 5 (9.06)	28.49*** (5.80)	–2.93 (9.92)	41.26*** (7.15)
Profit (RWF/are)	4,360.74 (4,175.53)	7,326.75*** (2,756.36)	301.43 (3,484.19)	5,698.78** (2,280.19)	9,886.29** (3,885.98)	7,315.02*** (2,629.50)
Returns to land (RWF/are)	4,666.29 (4,177.51)	7,507.53*** (2,785.83)	812.61 (3,512.54)	5,509.69** (2,317.58)	10,874.89*** (3,908.16)	7,077.58*** (2,716.26)
Ecological Outcomes	N = 92		N= 95		N = 102	
Shade tree density	1.01 (0.91)	0.36 (0.34)	0.05 (1.00)	0.46 (0.76)	1.15 (1.17)	0.93 (1.26)
Shade tree richness	0.05 (0.13)	0.21** (0.09)	–0.04 (0.12)	0.07* (0.04)	0.04 (0.13)	0.07 (0.09)
Predation rate	0.03 (0.08)	–0.12 (0.08)	–0.02 (0.13)	–0.12 (0.07)	–0.20* (0.11)	–0.03 (0.10)
Predator class richness	–0.01 (0.05)	0.03 (0.04)	–0.03 (0.07)	–0.09*** (0.03)	–0.24*** (0.08)	0.07 (0.06)
Bioacoustic Index†	–0.03 (0.08)	0.05 (0.06)	–0.56*** (0.18)	0.14 (0.11)	0.00 (0.08)	–0.07 (0.05)

*Robust standard errors are in parentheses*** p<.01, ** p<.05, * p<.1, †55 Bioacoustic Index values had to be deleted either because the audio file was corrupted or because heavy rain caused excessive background noise, which biases the sound calculations. Control variables are included but not shown for brevity.*

[8] Ecological results in Wave 1 differ slightly from Paz et al. (2024), who use the same Wave 1 dataset. This is because a few shade tree species that were not classified as trees in Waves 2 and 3 and therefore not recorded were excluded from our analysis. In addition, the analysis by Paz et al. (2024) did not control for CWS characteristics, as these variables were only generated during Wave 3.

Table A.4: CRE results on the association between in-house and third-party certification and socioeconomic and ecological outcomes before winsorizing observations

Outcome	In-house certified coeff (SE)	Third-party certified coeff (SE)
Coffee (kg/tree)	0.23 (0.17)	0.43** (0.20)
Coffee (kg/are)	4.61 (4.59)	8.08*** (3.11)
Price (RWF/kg)	2.57 (6.13)	29.81*** (3.66)
Profit (RWF/are)	4990.03* (2552.30)	6400.52*** (1715.81)
Returns (RWF/are)	5562.89** (2556.46)	6368.55*** (1740.82)

*Robust standard errors are in parentheses*** p<.01, ** p<.05, * p<.1, N = 2492, Control variables and means of time-varying control variables are included but not shown for brevity.*

Table A.5: Association between in-house and third-party certification duration and socioeconomic outcomes before winsorizing observations

Outcome	No. of years in-house certified coeff (SE)	No. of years third-party certified coeff (SE)
Coffee (kg/tree)	0.06** (0.03)	0.03** (0.01)
Coffee (kg/are)	1.95** (0.77)	0.78*** (0.25)
Price (RWF/kg)	1.49* (0.83)	2.25*** (0.33)
Profit (RWF/are)	1510.64*** (449.09)	587.31*** (143.30)
Returns (RWF/are)	1626.93*** (449.33)	551.62*** (145.68)

*Robust standard errors are in parentheses*** p<.01, ** p<.05, * p<.1, N = 2492, Control variables and means of time-varying control variables are included but not shown for brevity.*

Table A.6: Association between different lengths of in-house and third-party certification and socioeconomic outcomes before winsorizing observations

Outcome	IH 3–4 yrs	IH 5–8 yrs	IH 9–10 yrs	TP 1–4 yrs	TP 5–8 yrs	TP 9–10 yrs	TP 11–21 yrs
Coffee (kg/tree)	0.07	0.04	1.15**	0.06	0.68	0.32	0.43**
	(0.30)	(0.20)	(0.57)	(0.20)	(0.58)	(0.51)	(0.17)
Coffee (kg/are)	0.84	0.10	39.67**	2.48	5.10	–1.01	13.86***
	(7.67)	(4.60)	(18.15)	(4.33)	(4.18)	(12.92)	(4.43)
Price (RWF/kg)	10.48	1.96	–11.83	29.63***	17.26***	65.81***	45.27***
	(10.42)	(6.91)	(10.89)	(5.55)	(5.73)	(12.24)	(6.04)
Profit (RWF/are)	2853.56	2831.12	22050.17**	2453.79	4644.97*	3878.01	10831.92***
	(4361.67)	(2632.17)	(10845.78)	(2363.27)	(2424.03)	(7752.79)	(2540.63)
Returns (RWF/are)	3320.39	3245.07	23693.45**	2669.77	4673.97*	2979.88	10233.64***
	(4419.61)	(2638.96)	(10830.16)	(2399.96)	(2460.64)	(7808.21)	(2579.36)

*Robust standard errors are in parentheses*** p<.01, ** p<.05, * p<.1, N = 2492, Control variables and means of time-varying control variables are included but not shown for brevity.*

Table A.7: Association between different lengths of in-house and third-party certification and profit-related outcomes after including agrochemical-related costs based on standardized government prices

Outcome	In-house certified coeff (SE)	Third-party certified coeff (SE)
Profit (RWF/are)	3121.74 (2074.69)	4108.18*** (1445.31)
Returns (RWF/are)	3551.25* (2078.94)	4360.32*** (1438.61)

*Robust standard errors are in parentheses*** p<.01, ** p<.05, * p<.1, Profit: N = 2,468; Returns: N = 2,467, Control variables and means of time-varying control variables are included but not shown for brevity.*

Table A.8: Association between in-house and third-party duration certification and profit-related outcomes after including agrochemical-related costs based on standardized government prices

Outcome	No. of years in-house certified coeff (SE)	No. of years third-party certified coeff (SE)
Profit (RWF/are)	873.45*** (311.68)	403.05*** (112.98)
Returns (RWF/are)	985.89*** (313.43)	394.01*** (112.95)

*Robust standard errors are in parentheses*** p<.01, ** p<.05, * p<.1, Profit: N = 2,468; Returns: N = 2,467, Control variables and means of time-varying control variables are included but not shown for brevity.*

Table A.9: Association between different lengths of in-house and third-party certification and profit-related outcomes after including agrochemical-related costs based on standardized government prices

Outcome	IH 3–4 yrs	IH 5–8 yrs	IH 9–10 yrs	TP 1–4 yrs	TP 5–8 yrs	TP 9–10 yrs	TP 11–21 yrs
Profit (RWF/are)	1363.07 (3397.72)	2192.60 (2267.97)	9275.05** (4729.40)	1535.54 (2045.22)	2741.05 (2170.39)	10067.91** (4850.20)	7405.00*** (2143.90)
Returns (RWF/are)	1532.67 (3395.57)	2466.36 (2275.52)	10708.46** (4842.68)	1870.21 (2068.11)	3061.60 (2180.02)	9751.23** (4948.06)	7168.15*** (2154.15)

*Robust standard errors are in parentheses*** p<.01, ** p<.05, * p<.1, Profit: N = 2,468; Returns: N = 2,467, Control variables and means of time-varying control variables are included but not shown for brevity.*

Table A.10: Pairwise correlations between in-house and third-party certification duration and reported participation in VSS interventions (pooled across 2022, 2023, 2024)

Interventions	No. of years in-house certified	No. of years third-party certified
Received premium	0.02	0.28***
Received training (on any topic)	0.18***	0.21***
Participated in farmer group	0.13***	0.21***
Received loan	-0.02	0.28***
Received insurance	-0.11***	0.14***
Received spraying services	0.09***	0.07***
Received compost for free	0.14***	0.17***
Received free coffee tree seedlings	0.00	0.09***
Received in-kind support	0.02	0.20***
Received shade tree seedlings	0.01	0.10***
Received training on biodiversity	0.07***	0.15***
Received training on IPM	0.11***	0.15***
Had audit on agrochemical use	0.00	0.12***
Had audit on shade tree requirements	0.00	0.13***
Had audit on agricultural practices compliance	0.02	0.18***

**** p<.01, ** p<.05, * p<.1, N = 2492*