Biodiversity, Carbon and Chocolate: Toward an Environmentally Friendly Cocoa Production System in Ghana

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Abstract

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Global demand of cocoa for chocolate moved the native cocoa production frontier from ancient Maya and Aztec to other favorable tropical locations around the world. Cocoa growing arrived in West Africa sometime by the late 1800s and was an instant success story. A massive investment in the form of expansion of lands under cultivation, intensification driven by improved varieties/systems and a plethora of farming incentives have led West Africa to supply more than half of the world's cocoa. Cocoa agroforestry provides a livelihood for many smallholder farmers and significant contribution to national economies; however, it also results in deforestation and land degradation. The traditional cocoa agroforestry system in highly forested tropical regions, utilized shade cocoa systems and require overhead canopy and favorable humidity to thrive. Thus, lands suitable for forest reserves or timber production, are also suitable for cocoa production. Land

conversion of biodiverse High Forests in Ghana, part of the global biodiversity hotspot of the West African Guinean forest landscape, have allowed Ghana to become the second largest global cocoa producing nation. Cocoa led deforestation dominates the reported 2% rate of deforestation. In order to curb cocoa-led deforestation, it is essential to understand the crucial social, economic and environmental underpinnings of cocoa production. This study focuses on determining land use change and deforestation in the Krokosua Hills Forest Reserve, one of the most important cocoa producing areas of Ghana. Land use types are regulated within the reserve and timber production and protected area inside the reserve were compared with areas immediately outside the forest reserve over a 17-year period using multispectral satellite images acquired from Landsat and Sentinel earth observatory programs. A two-step land use pattern of change was observed, with closed forest land changing to open forest, and open forests were converted to croplands. These changes were mostly observed in areas of the forest reserve which have been technically designated as a production zone for wood/timber harvesting and admitted farming, in comparison to the areas specifically maintained for forest protection. Tree species composition varied significantly among the two broad management zones in comparison to uncultivated land within the forest reserve. Classifying tree species into ecological guilds depicts a natural reference condition of shade tolerant species, with non-pioneer light demanders among natural regeneration encountered in uncultivated areas. In contrast with other areas of the reserve where cocoa farming is interspersed with forests, regeneration of shade tolerant species is rare, with a greater amount of species as non-pioneer light demanders and pioneer species. Species composition of adult trees also showed a pattern of higher proportions of economically valuable species on cocoa farms compared with natural forest areas that are more diverse and have species represented in all the economic valuation classes of trees. In essence, cocoa farming promotes deforestation and species compositional changes that unequivocally present a challenge for forest management, particularly where objectives of cocoa farming and forestry are both emphasized within a broad land use category. This study suggests timber production and cocoa production, two vital industries in Ghana are connected with initial cutting leading conversion to cocoa. Cocoa production is susceptible to climatic variations which may be mitigated by environmentally friendly shaded cocoa production which effectively reduce associated deforestation. However, once cocoa farms are established, reduction of shade trees increases forest degradation, as farmers seek to increase cocoa yields. Therefore, land use change and the physical environment are interconnected. Since cocoa cultivation is essential to many livelihoods in Ghana, a changing global climate is of concern to smallholder cocoa farmers. Understanding cocoa farmers' perceptions on topics of climate change and its impacts are thus necessary to assess the potential of recent economic incentives to enhance sustainable cocoa production. A social survey of farmers' perception/knowledge of climate change and its potential effect on cocoa production was conducted to assess beliefs. I examined the potential of economic incentives of a REDD+ climate mitigation strategy as an alternative income generating avenue to maintain lower intensity, shaded cocoa production. Farmers' perceptions of climate were not in agreement with empirical data. Although farmers recognize the need to protect trees to provide ecosystem benefits, the system of direct monetary benefits associated with tree protection/maintenance presents a challenge for the success of integrating climate change mitigation strategies (REDD+) into cocoa farming. Common farm/cultural practices of cocoa farmers (e.g. slash and burn) may also degrade land, reducing forest biodiversity and releasing carbon.

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Chapter 1. GENERAL INTRODUCTION

The array of confectionary chocolate brands has become overwhelming in recent times. Indeed, the popularity and preferred taste of chocolate are a delicacy and a staple in many homes particularly in the developed world. The labelling on many of these chocolate products suggests that it is made in Europe and North America; the largest global consumers of cocoa (*Theobroma cacao L.*) and chocolate (Leissle 2018). Chocolate consumption trends depict it is as luxury among the affluent area of the world. This almost disguises the fact that the largest consumers of chocolate do not grow any cocoa (Fountain and Hütz-Adams 2018). It is almost unavoidable not to get into a North-South conversation when it comes to cocoa production and chocolate, since the major global suppliers/producers of cocoa are in developing or undeveloped nations. Historical antecedents in ancient Aztec were similar to modern day, where chocolate produced from cocoa was consumed by the powerful and deemed “food of the gods”. Cote D’Ivoire and Ghana, the first and second largest global cocoa producers, together produce/supply more than half of the global demand for unprocessed cocoa (Robson 2010, Leissle 2018). Unsurprisingly, both Cote D’Ivoire and Ghana are developing nations exporting cocoa to developed countries. It is important to note that cocoa is exported mostly in its raw/unprocessed form (Boansi 2013). In Ghana, for instance, a lackluster cocoa processing industry coupled with a weak local market for processed cocoa products results in 80% of raw cocoa being exported (Essegbey and Ofori-Gyamfi 2012). The economic ramifications of this commodity trade is a missed opportunity to capture the added value that results from local cocoa processing (Amoro and Shen 2013).

The physiological requirements of cocoa restrict its cultivation to what has become known as the “cocoa belt”; a region located between 20° north and south of the equator, that receives the annual 1,000 – 2,500mm rainfall and the 21° – 23°C temperature range needed for optimum cocoa growth and yield (ITC, 2001). Cocoa is not native to Africa. Cocoa, once used as a currency among native growers in ancient Aztec regions (Coe and Coe 2007), has continued in this economic importance to become a mainstay among producers in Ghana and Cote D'Ivoire. Both West African nations have populations financially dependent on cocoa farming and related activities. Although cocoa farmers across West Africa utilize small holdings (i.e., small farm sizes), cocoa farm sizes are on average larger (4ha) in Cote D'Ivoire (Wessel and Quist-Wessel 2015) than in Ghana (2ha (Ameyaw et al. 2018)). Increasing cocoa production in both countries drives expansion of cocoa farms in forest lands, leading to widespread deforestation and land degradation (Wessel and Quist-Wessel 2015).

In Ghana, an estimated 800,000 small holder cocoa farmers have their livelihoods centered on cocoa production (Anim-Kwapong et al. 2008). The popular saying "Ghana is cocoa, and cocoa is Ghana" encapsulates the economic importance of the deeply entrenched cocoa industry. Cocoa originating from Ghana is unmatched in overall quality, an attribute enhanced by strict adherence to rigorous cocoa bean fermentation and drying processes (Leissle 2018). Licensed Buying Companies (LBCs), approved by the government agency responsible for all cocoa related activities in Ghana (i.e., COCOBOD – Ghana Cocoa Board), help ensure the quality of Ghana cocoa. COCOBOD is structured to streamline all aspects of the cocoa industry in Ghana from bean to bar as well as on international commodity markets.

Cocoa farming and production in Ghana have had success and failures since introduction in the late 19th century; a pattern that is epitomized by boom and bust cycles (Ruf and Siswoputranto 1995). These cycles are influenced by several factors, ranging from environmental/ecological (land availability), physiological attributes/responses (diseases and pests), social (farmer demography, governance) and economics (global/local market systems and policies) (Ruf and Siswoputranto 1995). The bust cycle between 1964 and 1982 was dramatic because prior to that period Ghana was the leading global producer of cocoa. A combination of low cocoa production attributed to ageing trees, changing climatic conditions, diseases associated with cocoa and subsequent local and global financial implications led to a near collapse of the cocoa sector in Ghana. Cocoa production in neighboring Cote D'Ivoire began to boom around this time. Since 1983, the Cocoa Rehabilitation Project under the Economic Recovery Program (ERP) in Ghana has provided the needed impetus to facilitate the recovery of the cocoa industry and maintain Ghana's global reputation as a major cocoa producer (Kolavalli and Vigneri 2011).

The need for sustainability, envisioned under the United Nation's Sustainable Development Goals (SDGs) (UN 2015) emphasizes the need for cocoa production to maintain biodiversity and provide additional ecosystem services within a well-regulated system. Despite the importance of the cocoa industry to Ghana, it may be unsustainable since it contributes to significant land use change. This change occurs in the hot and wet High Forest Zone (HFZ), an area suitable for traditionally shade grown cocoa. Deforestation and degradation in the HFZ is of global concern as this forest area is part of a global biodiversity hotspot known as the West African Guinean forest complex which contains an estimated 3,600 plant species (mostly angiosperms) and is home to approximately 225 mammalian species, 724 bird species and 221 amphibian and reptile species (MES 2002). Land conversion in the HFZ has created an anthropogenic conflict between the goals of conservation and human development/livelihoods (Malhi et al. 2014). Agriculture (including cocoa production) has historically caused about one-third of deforestation (Hall 1987) although more recent research suggests that it now accounts for more than 50% of deforestation in Ghana (Rainforest Alliance 2018). Ghana currently has an annual deforestation rate of 2%, one of the highest global deforestation rates (PWC 2015, Forestry Commission 2010).

Cocoa-led deforestation has been difficult to quantify due to problems with spectral similarities of cocoa trees and forest trees (Benefoh et al. 2018, Curtis et al. 2018). Additionally, national interventions and their influence on land use change/deforestation in Ghana have been poorly documented to date (Asibey et al. 2019).

To address cocoa-led deforestation, it is important to obtain accurate estimates of the land use change attributed to cocoa farming. Most work to determine land use change attributed to cocoa farming has been done through projections from the FAO's FAOSTAT, a database dedicated to agriculture. Various nations submit annual reports of crop harvest area to FAOSTAT. Despite the usability of this data platform, several challenges exist with regards to data quality/accuracy and gaps in annual national data (Numbisi et al. 2019). Spatial mapping presents a more reliable and accurate method for determining existing land use types in a given area. In the second chapter, I use spatial mapping to examine land use trends/land use change to estimate cocoa-led deforestation in a study area that is well known for cocoa farming in Ghana. I also investigate land use change associated with forest management/conservation within the framework of national interventions aimed towards natural resource management by analyzing Landsat and Sentinel Imagery of the study area between 2000 and 2017. Percent change of individual land use types within the study area were used to analyze land use trends.

Deforestation and land use change are known to have a strong negative correlation with plant species diversity (Dawoe et al. 2016, Tondoh et al. 2015). In addition, environmental conservation techniques and specifically forest management practices also influence plant species diversity. For instance, although forests in the off-reserve areas in Ghana are species rich and diverse, there are no strict protection protocols compared with reserved forests (Oduro et al. 2015). Cocoa agroforestry, a system which merges the objectives of forestry (i.e. sustainable forest resource management and utilization) and cocoa farming, is known to support plant species diversity although much less than intact forest reserves (Asigbaase et al. 2019, Norgrove and Beck 2016). Chapter 2 compares species richness and Shannon and Simpson's Diversity Indices among land use types determined by existing forest management practices and how variations in tree diversity vary with observed land use change.

The Forest Transition Theory (Mather 1992, Grainger 1995, Lambin and Meyfroidt 2010, Oduro et al. 2015) suggests that deforestation is a necessary evil for developing nations as a pathway to overall development and improvement in general well-being. In that sense, deforestation associated with cocoa and agriculture appear to be influenced by financial and cultural motives for increasing human prosperity. While the Forest Transition Theory helps explain patterns of deforestation and degradation in Ghana, it does not adequately account for the importance of cocoa farming in driving these dynamics. Cocoa farming can occur on a forest management gradient ranging from small gaps to open forest stands mixed with fruit and timber trees (i.e., traditional cocoa farming and also described as agroforestry), to open forest stands within degraded forests (i.e., non-specific selection or remnant trees post high-grading), to non-forested cocoa monocultures.

Zero-shade cocoa systems, where cocoa monoculture is encouraged with improved cocoa varieties for faster return on investment is quickly gaining momentum within the cocoa growing regions of Ghana (Obiri et al. 2007). To avert the detrimental impacts of zero-shade systems on forest conservation and forest ecosystems, it is imperative to make traditional cocoa farming/systems (agroforestry) financially attractive for farmers. Recent studies have suggested that cocoa monoculture systems are more susceptible to climate change and may render smallholder cocoa farmers worse off financially over an 80-year period (Obiri et al. 2007). Cocoa production systems that foster the goals of sustainability, referred to as “climate smart” (Asare 2014) are thus needed to maintain livelihoods and foster environmental protection. Global emphasis on sustainability (of both livelihoods and natural resource management) and environmental protection has spawned several programs including Reducing Emissions from Deforestation and Forest Degradation (REDD+), Clean Development Mechanism (CDM), and Modified Taungya System (MTS) which are mostly implemented in tropical biodiversity hotspots like Ghana. Studies have found that such climate sensitive programs achieve the goals of sustainability and environmental protection only when farmers’ perceptions of climatic changes are in line with the overarching objectives of such programs (Ogalley et al. 2012, Atkins and Eastin 2012).

In Chapter 3, which has been published in the journal, *Forests*, a social survey was used to investigate cocoa farmers’ perceptions on the practicability of including a popular climate change mitigation strategy, REDD+, in cocoa farming. Farmers’ views on climatic variables that have changed over the past twenty years were also compared and verified with empirical weather data.

Chapter 4 provides a synthesis of the dissertation. Chapter specific conclusions are provided in addition to inferences and recommendations (in some instances) as well as a logical textual framework to combine preceding chapters to engender coherency and ease of understanding of the results of the research. It was discovered that cocoa farming, and zero-shade cocoa systems in particular, promote deforestation and influence tree species composition. Farmers generally welcome the potential economic opportunities associated with climate change projects but are skeptical on the mechanisms of income disbursement. Lastly, a concept/model *TeoTimber*, presents a pathway to rehabilitation of degraded or deforested forest lands using cocoa agroforestry.

The enormous contribution of the cocoa industry to the economy of Ghana has spearheaded a plethora of research efforts aimed at profit maximization as well as cocoa system optimization to enhance environmental protection and promotion of related and desirable social attributes. The inseparable association between cocoa farming and forestry reinforces the need for further research to foster a healthy co-existence between two vital industries in Ghana. Expectedly, numerous studies have made significant contributions towards determining options aimed at promoting the benefits of the cocoa and forest industries at the socio-economic and environmental scale. Some earlier efforts concentrated on determining tradeoffs between shaded and unshaded cocoa systems (Ahenkorah et al. 1974) and rehabilitation of old cocoa lands (Anim-Kwapong and Teklehaimanot 1995). More recent efforts have looked at the relationship between forest protection and cocoa farming (England 1993), influence of land use rights (tenure) on forest protection (Owubah et al. 2001) as well as shifts in cocoa farming systems and correlations with forest loss (Ruf 2011). More recently, studies have looked separately at the sustainability of cocoa and forestry in Ghana (Ofori-Boateng and Baba 2014, Hutchins et al. 2015, Ehiakpor et al. 2016, Wiah and Twumasi-Ankrah 2017). There is however a notable lack of literature on the intersection between forest management types/regime and cocoa farming. The present study specifically seeks to fill this gap by undertaking a unique biological/ecological, environmental, social and economic research inquiry into the topic of cocoa and forestry in Ghana, serving as a critique of forest management and cocoa farming in forest reserves. Current satellite imagery analysis techniques developed within the last two years (Benefoh et al. 2018 and Asubonteng et al. 2018) are utilized to estimate/visualize extent of cocoa farming and forest loss. The study also presents fresh insight into the perceptions of cocoa farmers on climate change and mitigation options as an alternative income generating option within a framework of fostering environmentally friendly cocoa farming systems. Finally, this study presents a unique practical and theoretical contribution into forest rehabilitation aimed specifically towards forest reserves that have been degraded as a result of cocoa farming. This approach advances theories of forest rehabilitation by showing realistic pathways of land use change within a forest-cocoa mosaic.

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Chapter 2. LAND USE TRENDS AND TREE DIVERSITY ASSESSMENT ALONG A FOREST RESERVE GRADIENT: A CASE OF COCOA AGROFORESTRY DRIVEN DEFORESTATION AND DEGRADATION IN GHANA

ABSTRACT

Despite the significant contribution of the cocoa industry to Ghana's economy, cocoa farming contributes to widespread deforestation and forest degradation. Deforestation also drives changes in plant communities and reduces tree species diversity. Since cocoa thrives in the moist forest zones of Ghana, institutional mechanisms have been adopted to assure forest protection, and manage cocoa farming intensification and expansion, especially in areas where conservation/protection and silviculture is performed in tandem with cocoa farming. This study used a combination of spatial analysis of 2000 and 2017 satellite imagery obtained from Landsat and Sentinel, respectively, to document land use change. It also used field data to document differences in economic and ecological guild classifications of tree species diversity in the Krokosua Hills Forest Reserve, a contiguous landscape where intact forest reserves are contrasted with forests where protection and wood/timber production are interspersed with cocoa farming. We document extensive land use changes mostly from closed forest to open forests (18,520ha) and open forests to croplands (12,614ha). This observation was prevalent in the off-reserve area, where about 6000 ha of closed forest was lost to other land use types. Zero-shade cocoa was also noted as the dominant land use type in the off-reserve area, representing almost half the off-reserve area. Zero-shade cocoa systems are used extensively within the reserve as well, with an area of about 8811.73 ha compared to 337.72 ha for shade grown cocoa. It was also observed that the difference in open forest area for reserve and off-reserve area was not as dramatic (9251.84 ha and 11176.58

ha respectively) as that of closed forest area (28517.86 ha for reserve area and 3030.65 ha for off-reserve area). Mature tree and juvenile naturally regenerated tree species showed significant compositional differences among land use types (p = 0.004 and p = 0.011 respectively). Differences here, however, appear to be dictated by observations made from intact forest areas where there are no cocoa farms. Indicator species analysis on the other hand, showed differences among tree species association with certain land use/reserve classifications, e.g. *Antiaris toxicaria* and *Entandrophragma cylindricum* are mostly associated with undisturbed forests. In addition, cocoa productivity significantly varied among land use types (p = 0.05 for pod counts). Specifically, cocoa production was greater in the most disturbed areas. That is, production was greatest in off-reserve areas than adjoining areas within the reserve. Similarly, production was greater in the timber production area than the protected area. Findings further reinforced disturbance theory by utilizing land use change and species diversity inference to conclude that, forest management regimes exert an influence on the direction of choice of trees/regeneration on cocoa farms in comparison with uncultivated areas. It was also revealed that protection is essential to preserve some tree species. This work highlights cocoa production's role in driving deforestation and the need for institutional mechanisms/strategies aimed specifically at developing restoration-oriented and protection-oriented silviculture systems and forest management pathways; particularly where cocoa is a dominant land use type situated within forest reserves with implications for adjoining off reserve areas.

Keywords: Cocoa, deforestation, land use, diversity, forest reserve, management, Ghana

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INTRODUCTION

Cocoa production in Ghana is a multi-billion-dollar industry and Ghana is the second largest cocoa producing nation in the world. Cocoa production and related activities support about 800,000 smallholder farmer households in Ghana (Anim-Kwapong and Frimpong 2004). The importance of the cocoa industry is significant, accounting for an estimated 7% of GDP in 2017 (The World Bank 2017), as well as approximately 20% of Ghana's total export earnings (Sulaiman and Boachie-Danquah 2017). Ghana's increasing cocoa production has resulted in a significant expansion of cocoa farm-lands. Since the physiological attributes of cocoa restricts it to the favorable climate of the forested High Forest Zone (HFZ) of Ghana (1,200 – 2,200mm of average annual precipitation), the cocoa boom has been entirely to the detriment of forested lands, making cocoa farming a significant cause of deforestation (UNEP 2008). The HFZ is known to accommodate about 3,600 plant species and a combined total of about 1,170 wildlife species (mammals, birds, amphibians and reptiles) (MES 2002), all of which are threatened by the expansion of cocoa farming.

The HFZ includes six forest types; Wet Evergreen, Moist Evergreen, Moist Semi-deciduous, Southern Marginal, Dry Semi-Deciduous Fire Zone and Dry Semi-Deciduous Inner Zone (Figure 1) (Hall and Swaine 1976). All these forest types are suitable for traditional shade grown cocoa. However, insecurities in tree tenure (i.e., a conglomerate of rights associated with tree ownership and use), especially in reserved forest areas, illegal harvesting of trees, and rising global demand for cocoa/chocolate, have led cocoa farmers to move from shade grown cocoa toward faster growing cocoa monocultures in the HFZ. Thus, traditional shade cocoa systems are being replaced by faster growing systems which require no shade (Ruf 2011, Obiri et al. 2007). In addition to cocoa farm expansion, which occurs primarily within previously logged areas and existing admitted farms in forest reserves, shifts in cocoa production systems have caused widespread deforestation and forest degradation in cocoa growing areas of Ghana (Kolavalli and Vigneri 2011, Ruf 2011, Gockowski 2007). Between 1955 and 1972 alone, cocoa production drove one-third of Ghana's deforestation (Hall, 1987). Ghana has averaged 2% deforestation (since 1990), with agriculture (including cocoa farming) accounting for about 50%, followed by timber harvesting (35%), population pressure (10%) and mining (5%) (PWC 2015, Forestry Commission 2010). Some authors have suggested that this trend of deforestation follows the Forest Transition Theory; where developing nations deplete their forest cover for economic reasons but regain the cover over time as forest management and silviculture techniques in the region mature (Mather 1992, Grainger 1995, Lambin and Meyfroidt 2010, Oduro et al. 2015).

"Cocoa-led deforestation" (Anglaaere et al. 2011), concomitantly promotes significant losses in plant species richness and diversity and results in increased soil degradation in cocoa agroforests. The impact of deforestation-related disturbance has significant impacts on species diversity in general (Wu et al. 2016, Borah et al. 2014, Bisseleua et al. 2008, Dale et al. 2000, Greenberg 1998, Phillips 1997, Denslow 1980). Increasing global demand and supply of cocoa generally triggers intensification and or expansion of cocoa farms which mostly involves a significant reduction of overhead canopy, and thus, a reduction in tree species diversity (Vaast and Somarriba 2014). Across the West African sub region, Dawoe et al. (2016) reported a significant decline in tree/timber species diversity on cocoa farms in the Western Region of Ghana. Cocoa farms and agroforestry systems generally have lower species diversity compared with primary and secondary forests and tend to follow a decreasing biodiversity trajectory as the system approaches a monoculture, as is the case with genetically improved and sun-tolerant cocoa varieties (Vaast and Somarriba 2014, Greco et al. 2012).

Shade tree diversity on cocoa farms may also be influenced according to the discretion of farm/landowners based on needs which are mostly financial in nature (Sonwa and Weise 2008, Richards and Asare 1999). Dawoe et al. (2016) noted that farmers tend to favor non-timber species (fruit bearing trees; e.g. *Musa spp*. and *Citrus spp*) on their cocoa farms to serve as a deterrent to illegal timber harvesters who target cocoa farms with high value timber species and in the process of harvesting timber, destroy cocoa trees. Farmers are generally not compensated for losses caused by illegal logging and often limit shade tree diversity to avoid future confrontations with timber harvesters (Asare and Ræbild 2016). Asigbaase et al. (2019) noted that farmers' choice of introduced and/or naturally regenerated tree species to plant/tend on cocoa farms often lead farmers to favor specific soil nutrient enhancing tree species (e.g. nitrogen fixing leguminous plants/trees like *Albizia ferruginea* and *Amphimas pterocarpoides*) that result in faster canopy growth, increased shade and promote a more nutrient rich growing environment for young cocoa trees and for other domestic uses. Regeneration of juvenile trees across the forestlands of West Africa generally appear to follow a shifting mosaic pattern where juveniles are spatially separate from the adult species they came from (Aubreville 1938, Swaine et al, 1987), perhaps in response to the Janzen-Connell hypothesis of tropical tree diversity (where natural enemies and or pest/diseases of plants prevent ecological dominance of a species in a particular area (Clark and Clark 1984)). Juvenile tree (natural and artificial) distribution and survivability is essential for present and future forest composition (Schiǿtz et al. 2006) and maintenance of forest biodiversity.

Tondoh et al. (2015) observed that forest land conversion to cocoa farms resulted in significant losses and decline in the diversity and richness of native tree species in Cote D'Ivoire. Benefoh et al. (2018) also reported a similar conversion of closed and open forests to cocoa farms in Ghana. Using Remote Sensing, GIS and stochastic models, Addo Koranteng et al. (2016)

investigated the amount, trend and location of land cover changes in Ghana's Western Region and suggested that the rate of change could lead to the elimination of primary/natural forest cover by 2020. Tsai et al. (2019) compared Landsat imagery from 1999 and 2018 and found that within a 9,800 km^2 mapping area in Southern Ghana (HFZ), about 625 km^2 of forest (in protected and off reserve areas) had been lost. The causal factors, they noted, were mostly due to agriculture as well as plantation development, illegal logging, and mining. They observed that the areas adjacent to forest reserves were the most degraded/deforested. Ruf (2011) noted that cocoa growing areas in Ghana are experiencing a significant shift in land use, first from forested lands to cocoa agroforests and more recently from forest lands and agroforestry to full sun cocoa farms (and in some cases, rubber, oil palm and teak).

The documentation of cocoa-led deforestation has remained elusive, as changes in timber tree cover have spectral attributes which are difficult to distinguish from cocoa trees (Sonwa et al. 2016). Despite this challenge, some studies have provided estimates of the land area dedicated to cocoa farming using spatial mapping. To overcome the spectral limitations, cocoa farms detected with Landsat imagery (30m resolution) were categorized as croplands (Ordway et al. 2017, Hackman et al. 2017, Tsai et al. 2019). With the advent of Sentinel-2 (an earth observatory satellite), it is now possible to accurately depict cocoa farms at a fine enough scale to distinguish cocoa systems (e.g. Asubonteng et al. 2018 and Benefoh et al. 2018). The topic of land use change associated with cocoa farming is closely associated with forest management in Ghana where lands suitable for forests/forestry are also suitable for cocoa growing as well. Forest management strategies have an impact on forest cover change and ultimately, species diversity. Although Tsai et al. (2019) suggest an association between forest protection/management status/regime and forest cover change factors (which includes agriculture), their study employed only qualitative procedures. In a related global study, Chaudhary et al. (2016) found forest management type/intensity/regime, is responsible for variations in biodiversity at both the spatial and temporal scales. The Krokosua Hills Forest Reserve provides a unique opportunity to evaluate the intersection between forest management regimes, cocoa agroforestry and land use change; providing a rich addition to the literature.

This study used spatial analysis of imagery obtained from Landsat and Sentinel earth observatory satellites to evaluate land use change/deforestation associated with cocoa farming along a gradient of land use types in a forest reserve situated in a major cocoa growing area in Ghana. Among the land use types/gradient, field-based inventory data was also used to investigate differences in shade tree and natural regeneration tree species composition, ecological guilds and economic value and diversity. The study area represented a gradient of land use in a forest reserve which has a strictly protected area as well as an area which permits logging and their adjacent off-reserve (OFR) areas. Thus, forest management in these gradients are different and directed mainly towards protection/conservation, timber production and cocoa farming. In view of that, this study tested the hypotheses that: 1) forest management type/regime exerts an influence on tree species diversity/composition as well as cocoa farming intensity; 2) forest management type/regime influences the level of observed deforestation/degradation (i.e. transition from closed/open forest to other land use types and increasing crop land area); and 3) zero-shade cocoa systems are more prevalent in off-reserve areas and timber production areas than protected areas. The objectives of this study were to: 1) evaluate categorical forest cover, to measure the effectiveness of management zonation and land use changes associated with cocoa farming in the Krokosua Hills Forest Reserve; 2) investigate the differences in adult and juvenile shade tree diversity with respect to management zonation and existing cocoa farms; 3) determine variations in species valuation of adult trees and ecological guilds of juvenile tree species in response to management zonation; and 4) assess variations in productivity of cocoa farms based on management zonation and existing shade tree species.

MATERIALS AND METHODS

Study Area

The study was conducted in the Krokosua Hills Forest Reserve (KHFR), and the adjoining off reserve areas to the West and East of KHFR (Figure 1). KHFR is situated in the Juaboso District of the Western Region of Ghana; an area renowned as a cocoa production hub (Asare 2014). Apart from being a major forest reserve, KHFR has a distinct feature of being comprised of two major land use or management units (i.e. timber production and protected forest) interspersed with cocoa farms. The reserve has a similar area dedicated to timber harvesting (production area – 23,639ha) and protection (24,521ha); the protected area restricts all commercial wood harvesting. Within the protection zone, there are intact patches of secondary forests that have considerable biodiversity value which are designated as Globally Significant Biodiversity Areas (GSBA) (FC 2010).

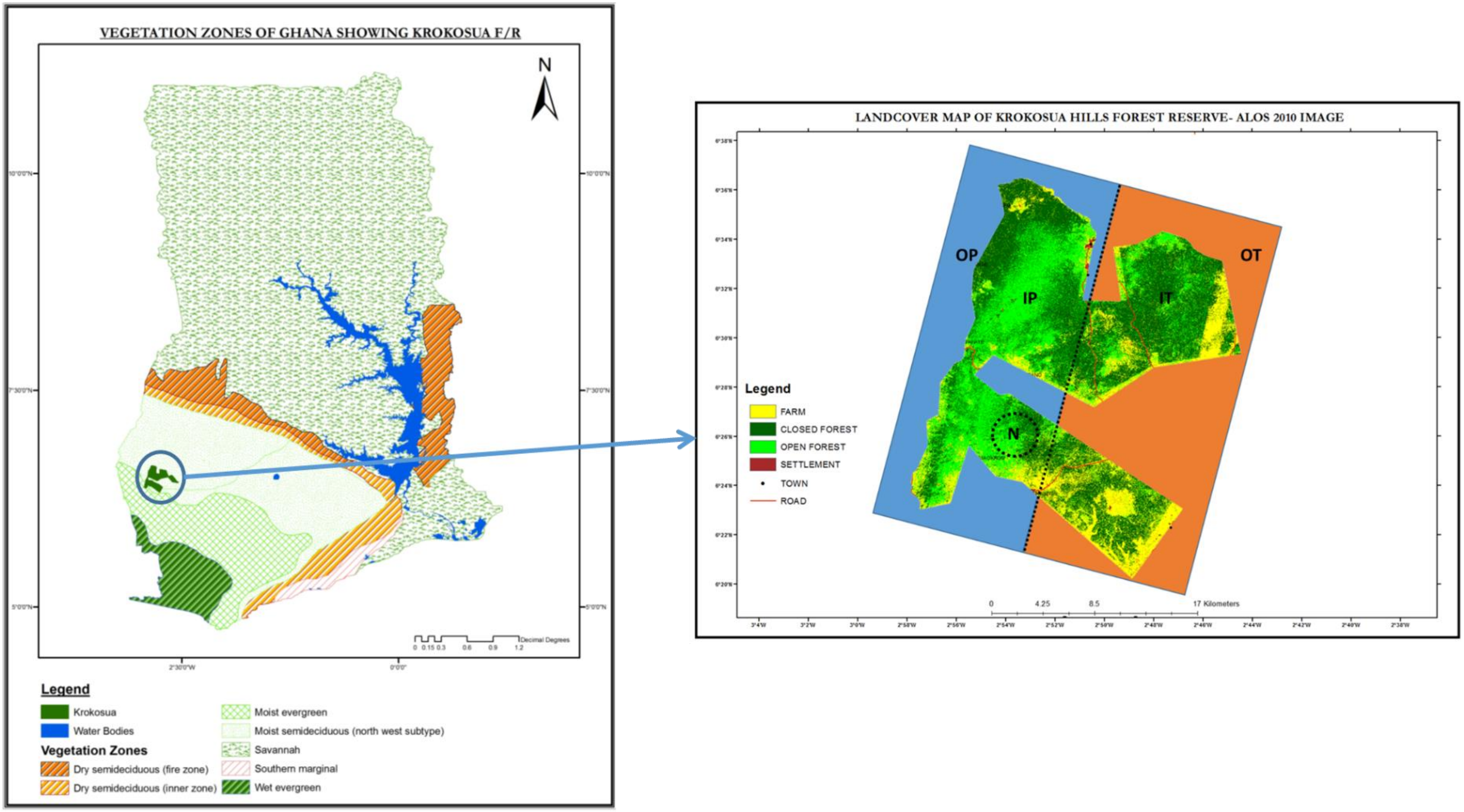

Figure 1. Vegetation zones/map of Ghana showing the study location (Krokosua Hills Forest Reserve) and the 5 management zones utilized as blocks for the study. Natural Area (N) refers to the intact portion of the reserve with no cocoa farms. Inside Timber Area (IT) is inside the reserve, managed for timber production with interspersed cocoa farms. Outside Timber Area (OT) is the area outside the reserve but immediately adjoining Inside Timber Area (IT) having interspersed cocoa farms. Inside Protection Area (IP) is inside the reserve but managed primarily for protective purposes, with an imposed logging ban but interspersed with cocoa farms. Outside Protection Area (OP) is the area outside the reserve immediately adjoining Inside Protection Area (IP) and also has interspersed cocoa farms.

The land use gradients used for the study are manifestations of institutionally streamlined forest management regimes that characterize protected and demarcated areas as forest reserves. Other areas falling outside these demarcated areas are termed off-reserve (OFR). Timber harvesting in forest reserves is done mostly through a selection system (appears to be an iteration of high grading, with stock taking of trees at or above 67cm in diameter which are removed in a rotational cycle which incorporates a 40-year rotation to allow for recovery of management units and ultimately, tree development (Oduro et al. 2015)). Off-reserve areas are mostly dedicated to agricultural use. Since most of these areas are adjacent to reserves, they are important and officially managed forest repositories, albeit with different management objectives (FC 2010). Pfeifer et al. (2012) has shown that areas adjoining protected areas are more likely to be affected by forest cover loss or deforestation, a phenomenon described as leakage. Leakage occurs when deforestation or forest degradation is averted in one area (in this case forest reserves) but leads to deforestation and degradation in a different area (such as off-reserve forests) (FC 2016). Leakage is often directly associated with the level of success of protection of the land area in question – more protected lands often show greater harvesting outside of the protected areas. A similar observation was also made by DeFries et al. (2005) but with the additional observation that areas surrounding protected forests (buffers) serve as protection for the overall biodiversity. Ameyaw et al. (2018) provided more details of human use in the study area.

Land use change imagery acquisition, processing and analysis

In this study, we acquired satellite imagery of the study area from Landsat 8 and Sentinel-2 earth observatory programs to better determine land use. Both programs provide downloadable images; United States Geological Survey (USGS) Global Visualization Viewer (GLOVIS) website (https://glovis.usgs.gov/) and the European Space Agency (ESA) Copernicus portal (https://scihub.copernicus.eu), respectively. Image-fusion was then applied to combine images from multiple years to determine forest cover changes. Specifically, the product of image-fusion is a thorough digitized capture of landscape level information in a single imagery. Image classification (using ERDAS Imagine 2016) via machine learning and maximum likelihood was then trained by sampled on-ground points in the study area. This resulted in distinct ranges of pixels being associated with 7 land use types (closed forest, open forest, cocoa agroforest, full-sun cocoa (mono cocoa), croplands, grasslands and settlement (Table 1). Errors were subsequently accounted for by conducting an accuracy assessment using a set of random points from ground truth/on-field data in comparison with data from classified imagery. The on-field data was collected using Global Positioning System (GPS) coordinates representative of existing land use types. A trend analysis using percentage change between land use types from 2000 and 2017 determined land use change associated with the identified land use types. Landsat imagery was used for the 2000 to 2017 comparison and did not provide enough resolution to assist in distinguishing cocoa farms from actual forest lands. However, a 2017 image of the study area acquired from the Sentinel program was used to determine current land use types and area allocations.

Table 1. Land use categories and descriptions for Landsat and Sentinel imagery analysis from Benefoh et al. (2018).

Land-Use Category	Definition
Closed Forest	Land with woody vegetation of at least 1m mapping unit having more than 60% crown canopy cover and with 5m height.
Open Forest	These lands are forests with crown canopy cover between 15% and 60%. Their low crown-cover is a sign of degradation resulting from planned or unplanned logging and mining activities.
Cocoa Agroforest	This type of land is incorporated with natural or planted trees that define a double-story canopy cover. It is usually established by thinning existing natural forest (closed forest) or open-forest to provide an overstory tree canopy that shades the cocoa trees.
Zero-shade Cocoa (Mono Cocoa)	This type is of land is considered to be monoculture cocoa farms with widely scattered trees or no natural or planted trees within. It occurs when a farmer decides to shift from cocoa agroforests to sun-tolerant hybrid species of cocoa and removes forest trees from within the farm.
Grassland	Lands dedicated to sustenance agriculture and patches of grass areas.
Settlement	Non-vegetated parts of the landscape including human-settlement, bare areas, mined-out areas, etc.
Cropland	This type are lands considered to be in CAF, FSC and sustenance agriculture for the Landsat imagery analysis.

On the ground plot layout and data collection

A stratified sample of the management units/land use gradients in and adjacent to KHFR was used to install vegetation plots in 5 different zones: 1) natural forest (reference stands with least disturbance; approaching natural reference [Natural Area]), 2) cocoa farms inside the area zoned for timber production (inside timber zone [Inside Timber Area]), 3) cocoa farms off-reserve adjacent to the timber production zoned area (outside timber zone [Outside Timber Area]), 4) admitted cocoa farms in the area zoned as protected from timber harvesting (inside protected zone [Inside Protection Area]) and 5) cocoa farms just off-reserve of the area zoned for protection from timber harvesting (outside protected zone [Outside Protection Area]) (Figure 1). A more detailed description of communities surrounding the forest reserve can be found in Ameyaw et al. 2018. For this study, we chose farms that were between 13 - 15 years old. According to Obiri et al. (2007), this range falls between the optimum productivity age (8 – 28 years) for cocoa.

In each management zone, four 25 m radius, 1962.5 m^2 circular plots (main plots), at least 100 m apart, were established, a total of 20 plots. A Haglof Vertex IV Hypsometer was used to demarcate plots by placing the monopod and a transponder at random locations on cocoa farms to serve as plot center. The Vertex receiver was then used to measure 25m in each cardinal direction and the perimeter of a circular plot was flagged.

The diameter of all trees (1.3 m aboveground; using a diameter tape) and regeneration surveys were measured in the main plot. Tree/sapling/seedling names (local names) were identified by two knowledgeable crew members of the Forestry Commission in Juaboso. Corresponding scientific and family names were added after field work. Diameter and heights of all cocoa trees were measured within a 10 m radius subplot (i.e. within the main plot using the same plot center)

(314 m^2). Heights of forest trees and cocoa trees (to the nearest meter) were measured with a TruPulse 360° Rangefinder.

The Ghana Forestry Commission's Wood Tracking System Database was used to group species into a decreasing economic order of value of Class 1, 2 and 3. Classes denote the quality of wood/timber which represents certain characteristics as wood workability (processing/usage), and local/foreign trade value. That is, Class 1 species have high economic value and are heavily sought after and exploited. Class 2 follows in value. Class 3 species may have some future potential for usage but are not harvested/exploited as Class 1 and 2. Tree regeneration was grouped based on physiological response to light needed for growth and development into three ecological guilds (Hawthorne et al. 2012, Hawthorne 1995); pioneers (P) which need open areas/gaps for growth and development, non-pioneer light-demanders (NPLD) which are intermediate light demanders and may require some shade for initial establishment but require higher levels of light as the tree grow, and lastly, shade tolerant (ST) which grow and develop in shaded areas. Duah-Gyamfi et al. (2014), Kariuki et al. (2006) and Foli (2005) all used a similar approach to organize tree species into ecological preferences. Ecological guilds or species groups provide a simpler way of categorizing species for the purposes of studying the structure and composition of a forest (Marshall and Hawthorne 2012). The categorization by guilds is particularly useful in ecosystems where species richness is high, and abundance is relatively low for individual species (Swaine and Whitmore 1988).

At each plot, soil pH (pH meter), soil temperature (soil thermometer probe), and volumetric water content (HydroSense) were collected. Five measurements were taken per plot using the positions at the plot edge of the cardinal directions (North, South, East and West) and the plot center. One Hygrochron temperature and humidity data logger was installed per plot to observe hourly temperature and humidity over a one-month period to characterize the physical environment. Leaf chlorophyll of cocoa trees was estimated using a Konica Minolta Chlorophyll Meter (a.k.a SPAD). SPAD offers a non-destructive means of measuring leaf chlorophyll content which is an indicator of plant health. Five cocoa trees were measured per plot whereas three readings were taken and averaged per cocoa tree. Cocoa pod counts were used as proxies to estimate average potential yield per harvest (Gateau-Rey et al. 2018). Pod counts were taken towards the middle of the main crop season (September – March) when pod harvesting is highest. Pod counts were collected in November, when some harvesting had already begun. Pods with no defects and greater than 10cm in length were counted. To obtain kg/ha estimates of yield (i.e., pod counts), the 1962.5 m^2 circular plots were scaled to one hectare following the protocol of Gateau-Rey et al. (2018). Ameyaw et al. (2018) indicated that farm sizes in the area were mostly between 0.4 – 2 hectares. The upper bound was used for calculating cocoa yield. As a reference, a bag of cocoa weighs 62.5kg (COCOBOD 2019). The average net weight of hybrid cocoa pods (which is the dominant cocoa variety, according to Ameyaw et al. 2018) was taken as 0.48kg (Adzimah and Asiam 2010).

Data analysis

Plot-level data was summarized and species richness and evenness (Shannon Weiner – *H'* and Simpson's – *D* indices) were calculated using the *vegan* package in R (Oksanen et al. 2019). These measures of diversity were specifically chosen because they are widely used, have moderate discriminant abilities and moderate and low sensitivity to sample size respectively (Magurran, 2004, Whittaker 1972). The Shannon Weiner diversity index (*H')* provides diversity estimates based on species richness and abundance, with common ranges between 1.5 – 3.5 and rarely more than 4. Shannon Weiner diversity index (*H')* was calculated:

$$H' = -\sum_{i=1}^{N} P_i InP_{i;}$$

Where P_i is the proportion of individuals found in the *i*th species; *Ln* is the natural logarithm; and *N* is the total number of species in the community. A zero was recorded where there is only one species in the sample (Magurran 2004, Shannon 1948). Simpson's Diversity index (*D*) works similarly, but specifically estimates the probability of arriving at the same individuals when random sampling is done. Simpson's Diversity index (*D*) was calculated:

$$D = 1 - \left(\sum \frac{n_i(n_i - 1)}{N(N-1)}\right);$$

Where n_i is the number of individuals representing each species and *N* is the total number of species in the entire sample.

Statistical tests and significance were determined using a one-way ANOVA. A Levene's test was used to test for homoscedasticity. In cases of violation, a Kruskal Wallis test was used. Where differences among means were observed, a Tukey test (HSD) was used to assess differences among land use types.

To test the effects of forest management regime/land use type (as independent variable) on abundance/composition of adult and juvenile (regeneration) species (as dependent variable), we used non-parametric permutational multivariate analysis of variance (PERMANOVA); via the *adonis* function in R (McArdle and Anderson, 2001). A Bray Curtis dissimilarity measure was used, and 999 permutations were run. Pairwise comparisons of land use types were performed using the *pairwise.perm.manova* function in the *RVAideMemoire* package in R (Herve 2019). We conducted an indicator species analysis (ISA) to determine species specificity/exclusivity to land use types. We used a direct approach (presence/absence count) and the *indicspecies* package in R to analyze indicator species. This package assigns scores (*IndVal.g* – Dufrêne and Legendre 1997) based on species abundance and frequency using the *multipatt* function. Both measures are useful in ISA (Bakker 2008). Direct counts were done to complement/supplement ISA, which may be prone to interpretational difficulties (Lindenmayer and Likers 2011). Microsoft excel was used to sort and count data where necessary. All remaining analysis were done in R v 3.5.1 (R Core Team, 2018).

RESULTS

Environmental Variables

Temperature and humidity are essential to the growth of cocoa, and I tested differences in the growth environment as a potential driver of cocoa production. Field measurements made at inventory plots showed no significant differences among land use types. However, the trend observed indicated a decreasing order from high to low: Inside Timber Area, Outside Timber Area, Outside Protection Area, Inside Protection Area and Natural Area for overall temperature. A decreasing order of Natural Area, Inside Timber Area, Inside Protection Area, Outside Protection Area and Outside Timber Area was also observed for humidity (Figure 2). Recordings for soil pH were not statistically different and showed that soils in the KHFR and outlying areas are acidic (between a range of 4 – 5.5 – Table 2).

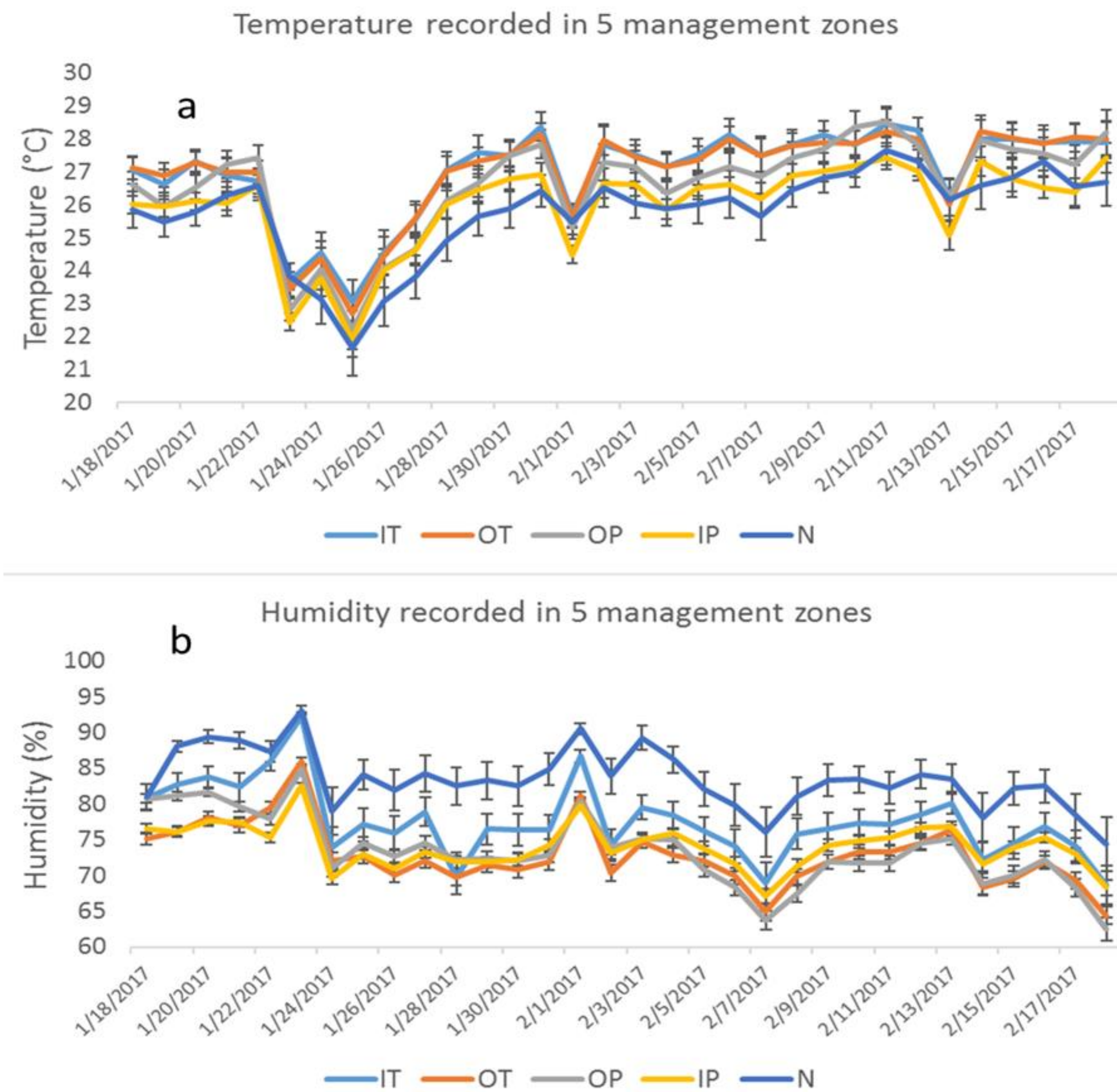

Figure 2. Trends in temperature (a) and humidity (b) for Inside Timber Area (IT), Outside Timber Area (OT), Outside Protection Area (OP), Inside Protection Area (IP) and Natural Area (N) within the month of data collection. Trends showed no significant differences among the various land use types.

Land use change/trend analysis

Landsat imagery showed a conversion of the dominant land use to more human dominated use between 2000 and 2017 (Figure 3). The largest change in cover between 2000 and 2017 was observed in the closed forest area. More than 18,000ha of closed forest area has been lost within the reserve area and immediately outside it (Figure 3a). Loss of closed forests consistently accounted for the largest land use change in all the zones of the study area (Table 3 a, b, c, d, and e). With regards to area categorized as closed forest in the year 2000, the sharpest change was observed in the off-reserve areas (i.e. Outside Timber Area and Outside Protection Areas). Specifically, a closed forest area of more than 6000ha within the 2km buffer around the forest reserve was lost. The second largest change observed over the period was the increase in the area of croplands or more specifically, cocoa farming (since the majority of croplands in the area are dedicated to cocoa farming). Within all the zones, cropland/cocoa farming areas increased by more than 30% (i.e. between an area of 3000ha to 5100ha – Table 3 c, d and e). Open forested areas also increased between 2000 and 2017. This accounted for about 6% of all land use change (4,652ha – Table 3.a). Although this trend was consistent in both areas inside the reserve, area allocated to settlements was the third largest overall land use change for the areas outside the forest reserve (2% – Table 3.c). In general, deforestation and forest degradation were prevalent in the timber production zones (Figure 3.b).

The analysis of the Sentinel-2 imagery of the study area acquired from 2017 showed that, within the KHFR, the dominant land use type is closed forest (60.3%), followed by open forest (19.6%), zero-shade cocoa (18.6%), cocoa agroforestry (0.7%), grassland (0.5%), and settlement (0.3%) (Figure 4). With the addition of a 2km off-reserve buffer around KHFR, the dominant land use is still closed forest, but represents 39.8% of land use (31548.51ha). Interestingly, zero-shade cocoa is next, representing 29.5% of the area (23402.39ha) (Figure 5). Open forest follows closely with 25.8% (20428.42ha). In the off-reserve area however, zero-shade cocoa is the dominant land use type (45.7%); almost half the area, followed by open forest (35%), closed forest (9.5%), grassland (6.6%) (Table 4).

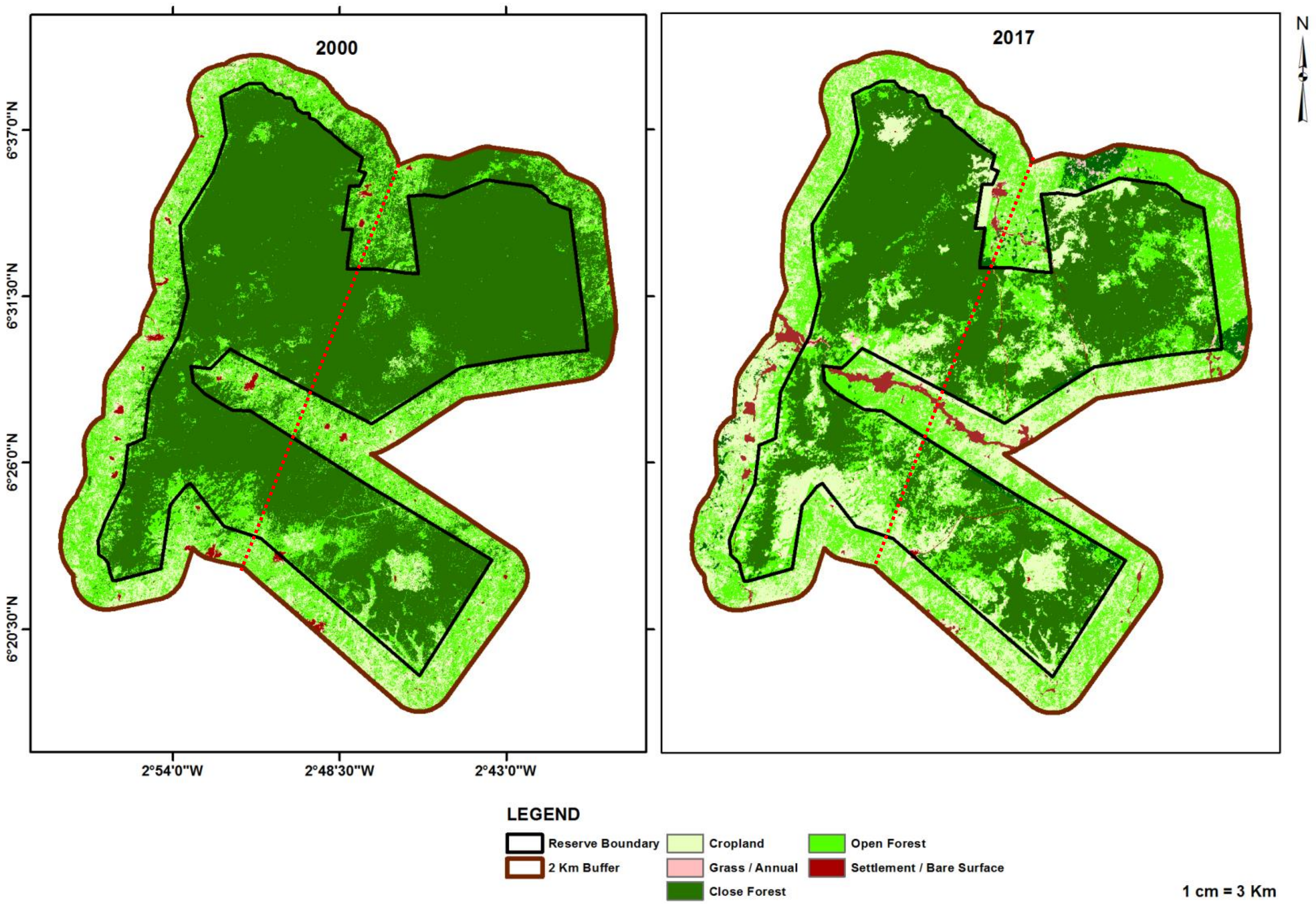

Figure 3.a. Landsat images captured for KHFR in 2000 and 2017 comparing landuse types, area allocated and changes within the period. Landuse types are defined in Table 1. Left of the broken line is the protected area and the right is the timber production area.

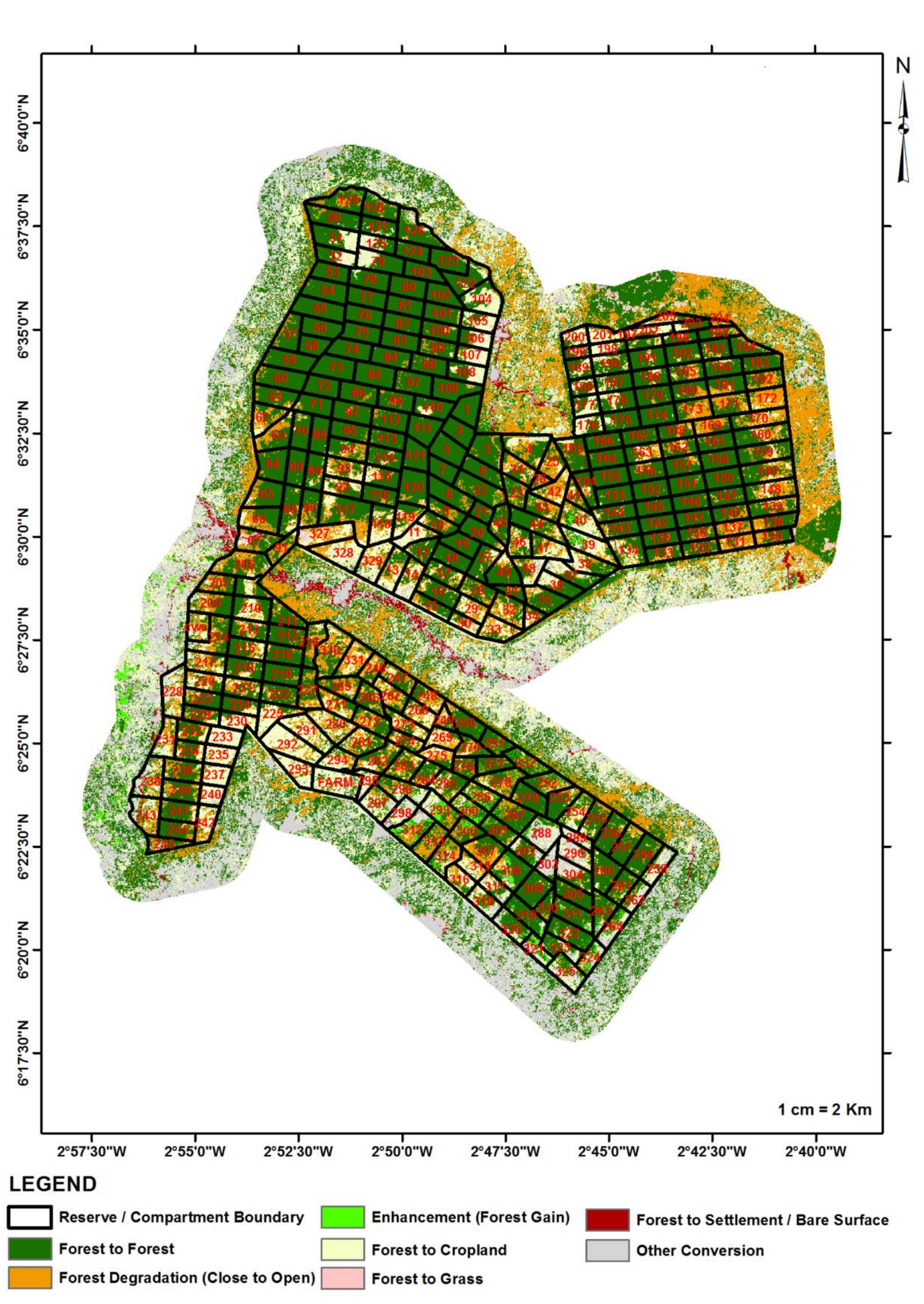

Figure 3.b. Combined Landsat images captured for KHFR in 2000 and 2017 comparing landuse types, area allocated and changes within the period. Landuse types are defined in Table 1.

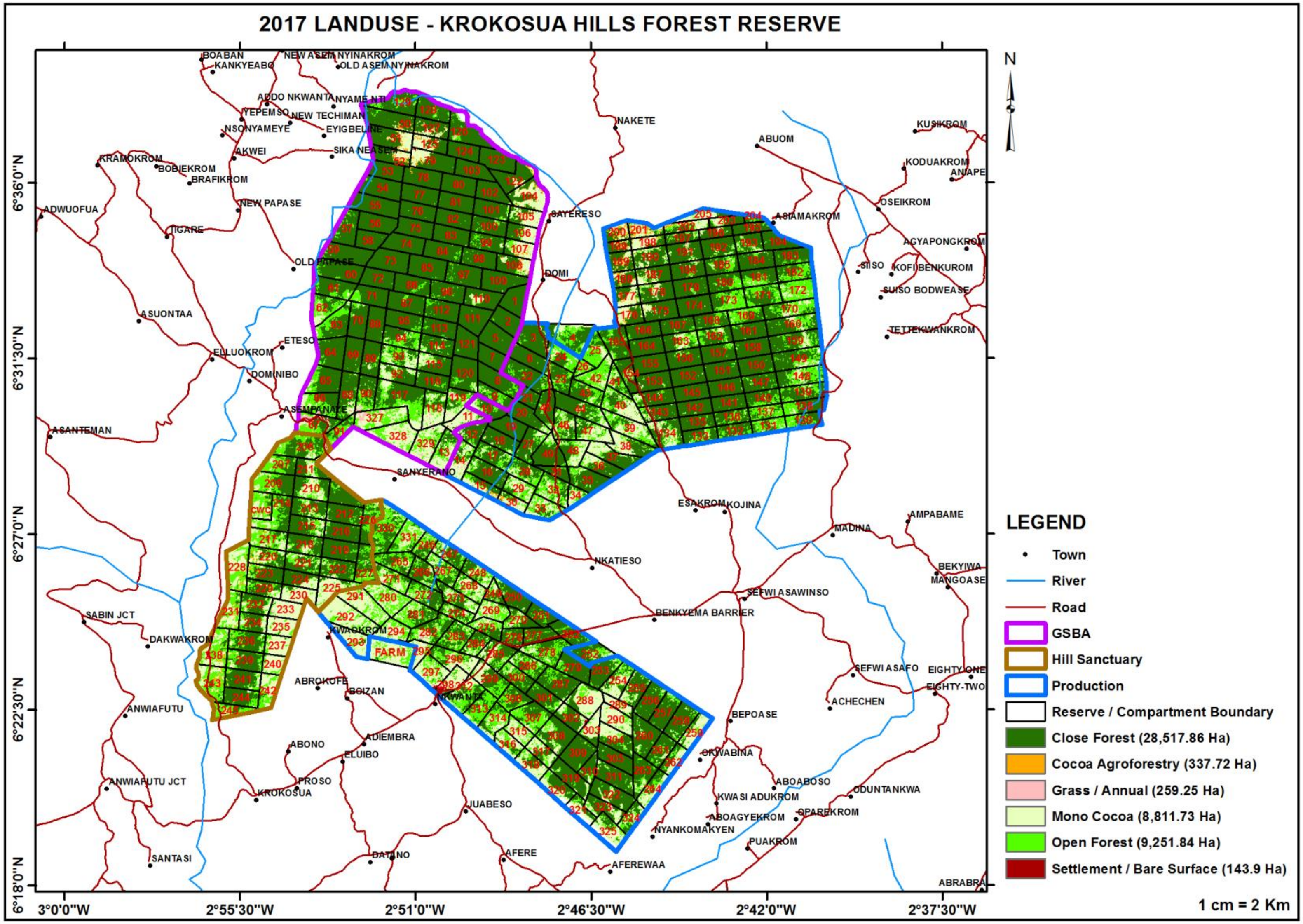

Figure 4. Sentinel-2 image captured for KHFR in 2017 showing landuse types and area allocated. Landuse types are defined in Table 1. Numbers within blocks are compartments serving as individual management unit for specific management interventions or silvicultural treatments (in areas where timber harvesting is allowed). For timber harvesting areas, a rotation of 40 years is used.

Figure 5. Sentinel-2 image captured for KHFR and a 2km area buffer in 2017 showing landuse types and area. Landuse types are defined in Table 1. Numbers within blocks are compartments serving as individual management units for specific management interventions or silvicultural treatments (in areas where timber harvesting is allowed). For timber harvesting areas, a rotation of 40 years is used.

Table 2. Environmental variables measured in the study area. Ranges fall within favorable conditions needed for growth of cocoa. The International Cocoa Organization recommends a maximum temperature range of 30 – 32ºC and a minimum between 18 - 21ºC. Recommended pH is 5.0 – 7.5; although growth is not impaired with higher acidity levels provided soil nutrient level is high.

Variable	Inside Timber Area	Outside Timber Area	Outside Protection Area	Inside Protection Area	Natural Area
Temperature (ºC)	27	26.98	26.6	26	25.8
Humidity (%)	77.7	72.83	73.45	74.05	83.5
pH	4.89	4.42	4.37	4.58	5.25
Elevation (m)	200.25	198.75	257.5	380.5	199.75

Table 3. a. Land use types and detailed area allocation for the time period between 2000 and 2017 for the KHFR acquired from Landsat. Area shown for 2000 and 2017 is the **area of reserve and off-reserve, i.e. Inside Timber Area + Outside Timber Area + Inside Protection Area + Outside Protection Area)**. Land use types have been defined in Table 1.

Land use	2000	2017	Change (ha)	% Land Use Type Change	% Total Changed Area
Closed Forest	48,882.33	30,361.95	-18,520.38	-37.89	-23.42
Open Forest	19,690.47	24,342.21	4,651.74	19.11	5.88
Cropland	9,463.95	22,078.26	12,614.31	57.13	15.95
Grass	561.51	922.68	361.17	39.14	0.46
Settlement / Bare Surface	470.07	1,363.23	893.16	65.52	1.13
Total	79,068.33	79,068.33			

Table 3. b. Land use types and detailed area allocation for the time period between 2000 and 2017 for the KHFR acquired from Landsat. Area shown for 2000 and 2017 is the **area of protection and timber production only (forest reserve area; does not include the 2km buffer around the reserve, i.e. Inside Timber Area + Inside Protection Area)**. Land use types have been defined in Table 1.

Land use	2000	2017	Change (ha)	% Land Use Type Change	% Total Changed Area
Closed Forest	40,703.76	28,322.64	-12381.12	-30.42	-26.40
Open Forest	4,710.42	9,190.44	4,480.02	48.75	9.55
Cropland	1,431.00	8,980.20	7,549.20	84.06	16.10
Grass	34.38	263.07	228.69	86.93	0.49
Settlement / Bare Surface	21.60	144.81	123.21	85.08	0.26
Total	46,901.16	46,901.16			

Table 3. c. Land use types and detailed area allocation for the time period between 2000 and 2017 for the KHFR acquired from Landsat. Area shown for 2000 and 2017 is the **area of the 2km buffer around the reserve (i.e. Outside Production Area + Outside Protection Area)**. Land use types have been defined in Table 1.

Land use	2000	2017	Change (ha)	% Land Use Type Change	% Total Changed Area
Closed Forest	8,178.57	2,039.31	-6,139.26	-75.07	-19.09
Open Forest	14,980.05	15,151.77	171.72	1.13	0.53
Cropland	8,032.95	13,098.06	5,065.11	38.67	15.75
Grass	527.13	659.61	132.48	20.08	0.41
Settlement / Bare Surface	448.47	1,218.42	769.95	63.19	2.39
Total	32,167.17	32,167.17			

Table 3. d. Land use types and detailed area allocation for the time period between 2000 and 2017 for the KHFR acquired from Landsat. Area shown for 2000 and 2017 is the **area of protection only (i.e. Inside Protection Area)**. Land use types have been defined in Table 1.

Land use	2000	2017	Change (ha)	% Land Use Type Change	% Total Changed Area
Closed Forest	17,969.49	13,249.53	-4,719.96	-26.27	-23.46
Open Forest	1,740.78	3,247.83	1,507.05	46.40	7.49
Cropland	396.90	3,441.51	3,044.61	88.47	15.13
Grass	9.63	140.40	130.77	93.14	0.65
Settlement / Bare Surface	1.98	39.51	37.53	94.99	0.19
Total	20,118.78	20,118.78			

Table 3. e. Land use types and detailed area allocation for the time period between 2000 and 2017 for the KHFR acquired from Landsat. Area shown for 2000 and 2017 is the **area of timber production only (i.e. Inside Production Area)**. Land use types have been defined in Table 1.

Land use	**2000**	**2017**	**Change (ha)**	**% Land Use Type Change**	**% Total Changed Area**
Closed Forest	22,734.27	15,073.11	-7,661.16	33.70	-28.61
Open Forest	2,969.64	5,942.61	2,972.97	50.03	11.10
Cropland	1,034.10	5,538.69	4,504.59	81.33	16.82
Grass	24.75	122.67	97.92	79.82	0.37
Settlement / Bare Surface	19.62	105.30	85.68	81.37	0.32
Total	26,782.38	26,782.38			

Table 4. Land use types and detailed area allocation for 2017 for the KHFR acquired from Sentinel-2. Land use types have been defined in Table 1. FR is Forest Reserve and OFR is Off-Reserve.

Land Use	Within Reserve	% Land Use within FR	With 2km Buffer	% Land Use (FR + OFR)	OFR Area	% OFR in Land Use
Closed Forest	28517.86	60.3	31548.51	39.8	3030.65	9.5
Cocoa Agroforestry	337.72	0.7	337.72	0.4	0	0.0
Grass/Annual	259.25	0.5	2354.31	3.0	2095.06	6.6
Mono Cocoa	8811.73	18.6	23402.39	29.5	14590.66	45.7
Open Forest	9251.84	19.6	20428.42	25.8	11176.58	35.0
Settlement	143.9	0.3	1190.8	1.5	1046.9	3.3
Total	47322.3	100	79262.15	100	31939.85	100.0

Species composition, distribution and diversity

One hundred and sixty-one shade trees were recorded across all field plots. *Newbouldia laevis*, *Celtis mildbraedii* and *Terminalia superba*, were the most common trees, representing approximately 15, 11 and 7 percent respectively. A total of 21 families were recorded with the most common being *Bignoniaceae*, *Ulmaceae*, and *Sterculiaceae* (representing approximately 15, 14 and 11 percent). Variations among sites at the higher taxonomical scale of family occurrence was less compared with variation at the species level. For instance, 18 species were found exclusively in the Natural Area. *Trema orientalis* and *Ficus exasperata*, are pioneer species in heavily disturbed forests, but were found only in the Inside Protection Area. *Amphimas pterocarpoides* (*Caesalpiniaceae*), mostly associated with old-growth forests, was recorded only in the reserve land use classifications (i.e. Natural Area, Inside Timber Area and Inside Protection Area). Indicator species analysis showed that 11 out of the reported 18 tree species are significantly associated with the Natural Area ($p \leq 0.05$ – Table 5). Similarly, 6 natural regeneration species (out of 18 in the Natural Area) are significantly associated with Natural Area ($p \leq 0.03$ – Table 6). *Ceiba pentandra*, a pioneer species mostly occurring in secondary forests, was the only natural regeneration species with a significant preference to Outside Protection Area and Outside Timber Area ($p = 0.02$ – Table 6). Additionally, tree and natural regeneration species composition differed by management zones ($p = 0.004$ and $p = 0.011$, respectively – Table 7). Pairwise comparison of management zones showed that Outside Timber Area and Outside Protection Area were statistically different from each other ($p = 0.043$ – Table 7) in terms of species composition. Outside Protection Area and Natural Area as well as Outside Timber Area and Natural Area were marginally significant from each other ($p = 0.067$ – Table 7). Differences could be attributed to proportions of species encountered. For instance, *Celtis mildbraedii*, which occurred frequently had higher counts of adult tree species in the Natural Area (17) which in turn contributed more to the vegetation in the Natural Area than to the vegetation in Outside Timber Area (1) where it also occurred. On the other hand, Outside Timber Area and Inside Timber Area were statistically different in terms of natural regeneration species observed ($p = 0.051$); and a marginal statistical difference was found between Outside Timber Area and Natural Area ($p = 0.067$ – Table 8). Individual species had flushes of regeneration which increased individual species counts and could be the explanation behind compositional differences among zones. As an example, *Nesogordonia papaverifera* had 48 regeneration counts in the Natural Area compared with 12 counts Outside Timber Area. This means that the species contributed more to overall species composition in the former area than the latter.

Table 5. Indicator species analysis (ISA) of shade/adult tree species with significant associations among land use types: Natural Area (Natural/secondary forest with no cocoa. Inside Timber Area, Outside Timber Area, Outside Protection Area and Inside Protection Area are explained where they appear. A total of 11 species characterize Natural Area.

Species	**Land Use Type**	**IndVal.g**	***p*-value**	
Blighia sapida	Natural Area	1.00	0.0078	**
Celtis adolfi-friderici	Natural Area	1.00	0.0078	**
Chrysophyllum perpulchrum	Natural Area	1.00	0.0078	**
Celtis zenkeri	Natural Area	1.00	0.0078	**
Guibourtia ehie	Natural Area	1.00	0.0078	**
Piptadeniastrum africanum	Natural Area	1.00	0.0078	**
Celtis mildbraedii	Natural Area	0.986	0.0084	**
Nesogordonia papaverifera	Natural Area	0.949	0.012	*
Triplochiton scleroxylon	Natural Area	0.943	0.0134	*
Entandrophragma cylindricum	Natural Area	0.866	0.044	*
Antiaris toxicaria	Natural Area	0.816	0.0476	*

Table 6. Indicator species analysis of natural regeneration/juvenile tree species with significant associations with land use types. Natural Area (Natural/secondary forest with no cocoa. Outside Protection Area is outside forest reserve but on the protection side where cocoa is cultivated but timber harvesting is not allowed. Outside Timber Area is outside forest reserve where cocoa is cultivated and timber harvesting is allowed. A total of 6 species characterize Natural Area whereas only 1 species characterizes Outside Protection Area and Outside Timber Area in terms of observed natural regeneration.

Species	**Land Use Type**	**IndVal.g**	***p*-value**	
Daniellia ogea	Natural Area	1.00	0.025	*
Mansonia altissima	Natural Area	1.00	0.025	*
Pterygota macrocarpa	Natural Area	1.00	0.025	*
Sterculia rhinopetala	Natural Area	1.00	0.025	*
Triplochiton scleroxylon	Natural Area	1.00	0.025	*
Celtis mildbraedii	Natural Area	0.998	0.0124	*
Ceiba pentandra	Outside Protection Area + Outside Timber Area	0.964	0.0164	*

Table 7. Results from PERMANOVA (Bray-Curtis dissimilarities) to determine effects of land use types (Blocks: Natural Area, Inside Timber Area, Outside Timber Area, Outside Protection Area, Inside Protection Area) on species composition. 52 species were observed. P-value is based on 999 permutations. Pairwise comparison using the *pairwise.perm.manova* function in the *RVAideMemoire* package showed that Outside Timber Area and Outside Protection Area were different in tree species composition (p = 0.043), Outside Protection Area and Natural Area as well as Outside Timber Area and Natural Area were marginally significant (p = 0.067). ** denotes significant results.

	DF	**Sums of Squares**	**Mean Squares**	**F.Model**	**R^2**	***p*-value**	
Block	4	2.3252	0.58131	1.6965	0.38154	0.004	**
Residuals	11	3.7691	0.34264		0.61846		
Total	15	6.0943			1.00000		

Table 8. Results from PERMANOVA (Bray-Curtis dissimilarities) to determine effects of land use types (Blocks: Natural Area, Inside Timber Area, Outside Timber Area, Outside Protection Area, Inside Protection Area) on natural regeneration/ juvenile species composition. 18 species were observed. P-value is based on 999 permutations. Pairwise comparison using the *pairwise.perm.manova* function in the *RVAideMemoire* package showed that OutsideTimberArea and InsideTimberArea were different in natural regeneration species composition (p = 0.051). OutsideTimberArea and Natural Area were marginally significant (p = 0.067). * denotes significant results.

	DF	**Sums of Squares**	**Mean Squares**	**F.Model**	**R^2**	***p*-value**	
Block	4	2.3713	0.59282	1.676	0.4269	0.011	*
Residuals	9	3.1834	0.35371		0.5731		
Total	13	5.5546			1.00000		

Diversity indices did not differ statistically among management zones but showed a consistent trend of increasing diversity from lowest to highest: Inside Timber Area, Outside Timber Area, Outside Protection Area, Inside Protection Area and Natural Area. In both cases (*H'* and *D*), Inside Timber Area showed the least diversity. Diversity among the management zones was generally higher in Inside Protection Area and Outside Protection Area than Inside Timber Area and Outside Timber Area. Species richness was comparable among all sites, except Natural Area. Variations with tree abundance was however more pronounced among sites. For dendrometric measurements, tree heights in Natural Area and Outside Timber Area were within a similar range whereas those in Outside Protection Area were comparatively lower. Stem diameter did not entirely follow the trend of height. Generally, tree stem diameters were higher in all zones (except Inside Protection Area) than Natural Area (Table 9). Diversity associated with regeneration showed a different trend in comparison to adult tree species. Apart from Natural Area being consistently higher in diversity, there was a complete flip with Inside Timber Area and Outside Timber Area being higher in diversity than Inside Protection Area and Outside Protection Area. Although the highest abundance was recorded in Outside Timber Area, this did not necessarily apply to richness (Table 9 and 10 shows a breakdown of variables measured).

Table 9. Table showing all diversity measurements and indices used for the study. TPH is trees per hectare (estimated).

Management Zone	Tree Abundance	TPH	Species Richness	Mean Tree Height (m)	Mean Stem Diameter (cm)	Shannon Diversity Index (H)	Simpson Diversity Index (D)
Inside Timber Area	30 ± 3.79	51 ± 19.3	13 ± 0.79	14.5 ± 2.80	50.3 ±12.70	1.97 ± 0.23	0.78 ± 0.10
Outside Timber Area	24 ± 0.82	31 ± 4.2	12 ± 0.17	19.4 ± 2.20	49.9 ± 2.80	2.18 ± 0.22	0.82 ± 0.08
Outside Protection Area	17 ± 1.22	20.4 ± 6.2	11 ± 0.23	11.8 ± 7.00	43.1 ± 16.10	2.26 ± 0.16	0.88 ± 0.06
Inside Protection Area	19 ± 1.86	32 ± 9.5	11 ± 0.08	8.0 ± 0.20	23.8 ± 2.80	2.55 ± 0.22	0.91 ± 0.04
Natural Area	71 ± 10.5	181 ± 53.5	29 ± 0.33	20.3 ± 0.80	42.2 ± 0.90	2.99 ± 0.50	0.92 ± 0.05

Table 10. Table showing diversity measurements and indices measured for regeneration species.

Management Zone	Abundance	Species Richness	Shannon Diversity Index (H)	Simpson Diversity Index (D)
Inside Timber Area	17 ± 1.75	4 ± 0.41	1.10 ± 0.14	0.66 ± 0.09
Outside Timber Area	334 ± 21.25	12 ± 0.41	1.33 ± 0.13	0.70 ± 0.09
Outside Protection Area	26 ± 4.37	5 ± 0.63	0.52 ± 0.16	0.27 ± 0.09
Inside Protection Area	19 ± 2.93	2 ± 0.29	0.66 ± 0.00	0.47 ± 0.00
Natural Area	306 ± 54.45	18 ± 2.59	1.81 ± 0.46	0.77 ± 0.21

Commercial value of trees and ecological guilds of natural regeneration

The majority (79%) of tree species encountered were Class 1, the most valuable timber species. The Natural Area, unsurprisingly, accounted for the greater proportion of Class 1 species occurrence (25 species). Trees within the *Sterculiaceae* family were the most frequent. The Natural Area was the only management zone with species represented in all classes (i.e. Class 1, 2 and 3). Inside Timber Area, Outside Timber Area and Inside Protection Area were all comparable in terms of Class 1 species occurrence (10 species). Outside Protection Area recorded the lowest occurrence of Class 1 species. Among 41 Class 1 species, only *Entandrophragma angolense* occurred in all management zones. Class 2 species; *Blighia sapida* and *Cola gigantea*, were found only in Natural Area. The only exotic species encountered, *Persea Americana* (avocado), a Class 3 species, and a fruit tree, was found only in zones outside of the reserve, Outside Timber Area and Outside Protection Area. *Tetrapleura tetraptera*, another popular fruit/medicinal tree, in Class 3 was found only in Natural Area. The most frequently observed Class 3 species was *Newbouldia laevis*, which was found in all management zones, except Natural Area. The rarest Class 3 species was *Buchholzia coriacea*, found only in Inside Timber Area. Apart from *Morinda lucida*, which was found in Inside Timber Area and Outside Protection Area, all other Class 3 species are lesser utilized tree species which are not considered economically valuable tree species. Table 11 details the location and abundance of tree species observed.

Table 11. Shade tree species details. Natural Area, Inside Timber Area, Outside Timber Area, Inside Protection Area and Outside Protection Area are described in Figure 2. Class refers to the economic value assigned to individual tree species via Ghana Forestry Commissions Wood Tracking System Database with 1 as the highest assignable value. The lowest value, 3, is usually assigned to lesser used species or species with relatively lower economic value. ** are trees that are of significant value especially as fruit trees or usage for medicinal purposes.

Species	Local Name	Family/Subfamily	Location					Tree Count	Local/Exotic	Class
			IT	OT	OP	IP	N			
Albizia ferruginea	Awiemfosamina	Mimosaceae	×	×	✓	×	×	3	Local	1
Alstonia boonei	Nyamedua	Apocynaceae	×	✓	✓	×	✓	4	Local	1
Amphimas pterocarpoides	Yaya	Caesalpiniaceae	✓	×	×	×	×	7	Local	1
Aningeria robusta	Asamfena	Sapotaceae	✓	✓	×	×	×	11	Local	1
Antiaris toxicaria	Kyenkyen	Moraceae	×	×	✓	×	✓	9	Local	1
Blighia sapida	Akye	Sapindaceae	×	×	×	×	✓	2	Local	2
Buchholzia coriacea**	Konini	Carpparaceae	✓	×	×	×	×	1	Local	3
Ceiba pentandra	Ceiba	Bombaceae	×	×	×	×	✓	4	Local	1
Celtis adolfi-friderici	Esakosua	Ulmaceae	×	×	×	×	✓	24	Local	1
Celtis mildbraedii	Esafufuo	Ulmaceae	×	✓	×	×	✓	*	Local	1
Celtis zenkeri	Esakokoo	Ulmaceae	×	×	×	×	✓	*	Local	1
Chrysophyllum albidum	Akasaa	Sapotaceae	×	×	×	×	✓	*	Local	1
Chrysophyllum perpulchrum	Ataben	Sapotaceae	×	×	×	×	✓	*	Local	1
Cola gigantea	Watapuo	Sterculiaceae	×	×	×	×	✓	18	Local	2
Corynanthe pachyceras	Pamprama	Rubiaceae	×	×	×	×	✓	8	Local	1
Dialium aubrevillei	Dua Bankye	Caesalpiniaceae	×	×	×	×	✓	*	Local	1
Discoglypremna caloneura	Fetefre	Euphorbiaceae	✓	×	×	✓	×	7	Local	1
Entandrophragma angolense	Edinam	Meliaceae	✓	✓	✓	✓	✓	8	Local	1

Entandrophragma candollei	Candoli/Penkwa akoa	Meliaceae	×	×	×	✓	×	*	Local	1
Entandrophragma cylindricum	Sapele/Penkwa	Meliaceae	×	×	×	×	✓	*	Local	1
Erythrophleun ivorense	Potrodom	Caesalpiniaceae	×	×	×	✓	×	*	Local	1
Ficus exasperata	Nyankyerene	Moraceae	×	×	×	✓	×	*	Local	1
Ficus sur	Kotreamfo/Domini	Moraceae	✓	×	✓	×	×	*	Local	1
Glyphaea brevis**	Foto	Tiliaceae	×	×	×	✓	×	2	Local	3
Guibourtia ehie	Anokyehyedua	Caesalpiniaceae	×	×	×	×	✓	*	Local	1
Holoptelea grandis	Nakwa	Ulmaceae	×	×	×	×	✓	*	Local	1
Hymenostegia afzelii**	Takorowa	Caesalpiniaceae	×	×	×	×	✓	*	Local	3
Khaya ivorensis	Mahogany/Dubini	Meliaceae	×	×	×	×	×	*	Local	1
Lannea welwitschii	Kumanini	Anacardiaceae	×	✓	×	×	✓	3	Local	1
Mansonia altissima	Mansonia/Pronoo	Sterculiaceae	×	×	×	×	✓	*	Local	1
Margaritaria discoidea	Pepea	Euphorbiaceae	×	×	✓	×	×	*	Local	1
Morinda lucida	Konkroma	Rubiaceae	✓	×	✓	×	×	*	Local	3
Musanga cecropioides**	Odwuma	Moraceae	×	×	×	✓	✓	*	Local	3
Nesogordonia papaverifera	Danta	Sterculiaceae	×	×	×	✓	✓	*	Local	1
Newbouldia laevis**	Sasramasa/Sesemasa	Bignoniaceae	✓	✓	✓	✓	×	25	Local	3
Persea americana**	Avocado	Lauraceae	×	✓	✓	×	×	4	Exotic	3
Piptadeniastrum africanum	Dahoma	Mimosaceae	×	×	×	×	✓	*	Local	1
Pterygota macrocarpa	Koto	Sterculiaceae	×	×	×	×	✓	*	Local	1
Pycnanthus angolensis	Otie	Myristicaceae	✓	×	×	×	×	1	Local	1
Rhodognaphalon buonopozence	Akata	Bombaceae	✓	×	×	✓	✓	*	Local	1
Ricinodendron heudelotii	Wama	Euphorbiaceae	×	×	×	×	✓	*	Local	1
Spathodea campanulata	Krokoanisuo/Akuakuonisuo	Bignoniaceae	×	×	×	✓	×	*	Local	1

Sterculia oblonga	Ohaa	Sterculiaceae	×	×	×	×	✓	*	Local	1
Sterculia rhinopetala	Wawabima	Sterculiaceae	✓	×	×	×	✓	*	Local	1
Strombosia glaucascens	Afena	Olacaceae	✓	✓	×	✓	✓	6	Local	1
Terminalia ivorensis	Emire	Combretaceae	×	✓	×	×	×	*	Local	1
Terminalia superba	Ofram	Combretaceae	✓	✓	✓	×	×	12	Local	1
Tetrapleura tetraptera**	Prekese	Mimosaceae	×	×	×	×	✓	*	Local	3
Tieghemella heckelii	Makore	Sapotaceae	×	×	✓	×	×	*	Local	1
Trema orientalis**	Sesea	Ulmaceae	×	×	×	✓	×	*	Local	3
Triplochiton scleroxylon	Wawa	Sterculiaceae	×	✓	×	×	✓	*	Local	1
Zanthoxylum leprieurii	Oyaa	Rutaceae	×	✓	×	✓	×	2	Local	1

In terms of ecological guilds, natural regeneration species varied with management zones. Pioneer species represented 29 percent whereas shade tolerant species made up the remaining 25 percent of ecological guild classification. Interestingly, there were no shade tolerant tree regeneration species observed in Outside Protection Area and Inside Protection Area. *Mansonia altissima*, the most frequently occurring shade tolerant species, was found only in the Natural Area. Counts of *Terminalia superba*, a pioneer species were the second most frequently occurring, found only in Outside Timber Area, Outside Protection Area and Inside Protection Area. The highest proportion of pioneers were observed in Outside Timber Area (Table 12). The NPLD were mostly non-responsive to forest management zonation, about half (46 percent) the species counted were NPLD belonging to the *Sterculiaceae* family. However, more than half the species recorded in Natural Area were also NPLD belonging to the *Sterculiaceae* family.

Table 12. Natural regeneration tree species details. Natural Area, InsideTimberArea, OutsideTimberArea, InsideProtectionArea and OutsideProtectionArea are described in figure 2. Guild refers to the ecological requirement of the tree. Three categories are used; NPLD – Non-pioneer light demander, P – Pioneer and ST – shade tolerant (Hawthorne et al. 2012, Hawthorne 1995)

Species	Local Name	Family/Subfamily	Location					Count	Local/ Exotic	Guild
			IT	OT	OP	IP	N			
Antiaris toxicaria	Kyenkyen	Moraceae	✓	×	×	×	✓	9	Local	NPLD
Ceiba pentandra	Ceiba	Bombaceae	✓	✓	✓	×	✓	85	Local	P
Celtis mildbraedii	Esafufuo	Ulmaceae	×	✓	×	×	✓	126	Local	NPLD
Chrysophyllum albidum	Akasaa	Sapotaceae	×	×	×	×	✓	17	Local	ST
Chrysophyllum perpulchrum	Ataben	Sapotaceae	×	×	×	×	✓	*	Local	NPLD
Daniellia ogea	Hyedua	Caesalpiniaceae	×	×	×	×	✓	9	Local	NPLD
Entandrophragma angolense	Edinam	Meliaceae	×	✓	×	✓	×	49	Local	NPLD
Khaya ivorensis	Mahogany/Dubini	Meliaceae	×	×	×	×	✓	*	Local	NPLD
Mansonia altissima	Mansonia/Pronoo	Sterculiaceae	×	×	×	×	✓	158	Local	NPLD
Nesogordonia papaverifera	Danta	Sterculiaceae	✓	×	×	×	✓	*	Local	ST
Piptadeniastrum africanum	Dahoma	Mimosaceae	×	×	×	×	✓	2	Local	NPLD
Pterygota macrocarpa	Koto	Sterculiaceae	×	×	×	×	✓	*	Local	NPLD
Ricinodendron heudelotii	Wama	Euphorbiaceae	×	✓	×	×	×	4	Local	P
Sterculia rhinopetala	Wawabima	Sterculiaceae	×	×	×	×	✓	*	Local	NPLD
Strombosia glaucascens	Afena	Olacaceae	×	✓	×	×	×	90	Local	ST
Terminalia superba	Ofram	Combretaceae	×	✓	✓	✓	×	153	Local	P
Tieghemella heckelii	Makore	Sapotaceae	×	×	✓	×	×	*	Local	NPLD
Triplochiton scleroxylon	Wawa	Sterculiaceae	×	×	×	×	✓	*	Local	NPLD

Characteristics of cocoa trees

Cocoa pod counts were statistically different among cocoa farms located in the different management zones ($p = 0.03$). Cocoa pod counts suggest that cocoa production and management intensity is higher in and adjacent to the timber zones than the protected zones and greater in the off-reserve areas when compared with their respective reserved areas. Outside Timber Area had the highest yield; 71 (± 22) kg/ha, followed by Inside Timber Area 58 kg/ha (± 13), then Outside Protection Area 21 kg/ha (± 6) and lastly Inside Protection Area 15 kg/ha (± 2). The highest difference was observed between Outside Timber Area and Inside Protection Area ($p = 0.05$). Interestingly, cocoa leaf chlorophyll content (SPAD), diameter and height followed the same trend (an increasing trend of Inside Protection Area, Outside Protection Area, Inside Timber Area and Outside Timber Area). Although SPAD readings were not significant among the management zones ($p = 0.363$), cocoa tree diameters (Inside Protection Area, Outside Protection Area, Inside Timber Area and Outside Timber Area) and height (Inside Protection Area, Outside Protection Area, Inside Timber Area and Outside Timber Area) were significantly different ($p = 0.004$ and $p = 0.05$, respectively) among management zones. For diameters, Outside Timber Area – Inside Protection Area were the most different ($p = 0.005$), followed by Outside Timber Area – Outside Protection Area ($p = 0.02$) and lastly, Inside Timber Area – Inside Protection Area ($p = 0.05$). Cocoa heights unsurprisingly followed a similar trend ($p = 0.05$) with Outside Timber Area – Inside Protection Area being the most different ($p = 0.06$), followed by Outside Timber Area – Outside Protection Area ($p = 0.09$).

DISCUSSION

Land use change associated with management units/zones

I hypothesized that land use change will be greatest in areas where commercial timber logging activities are permitted in KHFR (i.e. Inside Timber Area and Outside Timber Area) compared with the protected area (Outside Protection Area and Inside Protection Area). Our results supported this hypothesis. The opening-up of closed forests as a result of timber harvesting presents a favorable option for cocoa farming because farmers do not need to remove much overhead canopy to obtain favorable levels of shade for cocoa growth and development. Overhead shade removal, especially in the reserve area (i.e. Natural Area, Inside Timber Area and Inside Protection Area) has legal implications if the due process is not followed. The legal process may be serving as a deterrent to farmers because of its lengthy nature and time investment. Additionally, overhead canopy removal for cocoa farming is labor intensive. Gaps created by timber harvesting operations therefore present ideal conditions for cocoa farming. The bulk of land use changes seemed to have happened in the production side of the reserve where timber harvesting is permitted. This supports the idea that management designation (i.e., timber or protection) of an area influences the tendency of cocoa farmers to utilize lands for cocoa farming. A forest canopy that has been opened through logging is more readily utilized by farmers for agricultural purposes, with completely cleared canopies fostering no-shade agricultural activities, e.g. zero-shade cocoa (Ruff 2011). This analysis also documents the deficiencies in institutional efficiency of enforcing differences in forest management by land zoning (Oduro et al. 2015).

Species diversity, distribution and compositional differences across different land use gradients

Many studies have shown that tree species diversity in primary and secondary forests is generally higher than that found in agroforestry systems and follows a downward trend as forest cover changes into single species systems or monocultures (e.g. Tondoh et al. 2015, Greco et al. 2012, Vaast and Somarriba 2014, Greenberg 1998). Literature on how this trend manifests in protected areas (forest reserves) and adjoining lands (buffers or OFR areas) interspersed with other prominent land use types like cocoa agroforestry is rare. The study sought to investigate adult and juvenile tree species diversity measures along contiguous land area specifically demarcated as a forest reserve with streamlined managerial procedures which further segregate the reserve land into two distinct management units. The production area is managed for sustainable timber supply/harvesting while the remaining portion serves as a protected area, serving as an ecological reservoir of biological diversity (Figure 2). We found that both adult and regeneration tree species composition were significantly different among the land use types in the study area (Gerstner et al. 2014, Borah et al. 2014, Anglaaere et al. 2011). *Antiaris toxicaria*, which is found in Outside Protection Area and Natural Area is an indicator species of the Natural Area. The representation of the species in Outside Protection Area is not enough to warrant exclusiveness of the species to that area. Knowledge of species exclusivity helps determine species preferences and serves as a measure of disturbance. Regeneration surveys also followed the same species specificity observation. Remnants of old growth tree communities were more evident within the reserve than adjoining OFR areas. Along the continuum/gradient of land use types, we observed that species compositional differences were most pronounced among the outlying land use types; thus, differentiation in tree species composition is less observable among land use types within the forest reserve than adjoining and opposite OFR areas (Pfeifer et al. 2012).

Significant gaps and spacing of trees observed in OFR areas portrays less competition among trees and a tendency of tree allocation to both height and girth increment compared with uncultivated and less disturbed areas where competition for existing resources is markedly higher. Goals of forest management and specifically protection of forest reserves and agroforestry include maintenance of species diversity. Our study showed that species diversity was highest in the protected areas (Inside Timber Area, Inside Protection Area and Natural Area); a much-desired outcome for conservation efforts (Chaudhary et al. 2016, Pfeifer et al. 2012). There is also substantial evidence that OFR areas could serve as plausible options for maintenance of species diversity (Marshall and Hawthorne 2012) as evidenced in our observation of comparable species richness (for both adult and juvenile tree species) in OFR areas and adjoining reserve areas. Protection objectives are not always successful, due to managerial constraints or inadequacies (Oduro et al. 2015) and this could explain the relatively lower tree heights and girth observed in the protected forest. Our study reveals evidence that species associated with heavily disturbed forests were found only in the Inside Protection Area. Natural regeneration on the other hand presents a whole new trajectory compared with adult species (Oduro et al. 2015). The obvious observation of more regeneration success in uncultivated forest lands (Natural Area) (Table 9) was made in our study (Borah et al. 2014). However, cocoa farms in OFR (Outside Timber Area and Outside Protection Area) areas were generally higher in natural regeneration species richness than protected areas. Species diversity of natural regeneration seems higher in areas with less protection and higher disturbance. This observation could have an underlying relation with tree tenure; a systematically complicated benefit sharing scheme particularly for trees on cocoa farms within a forest reserve. Rigid enforcement of less than favorable tree tenure arrangements, particularly in forest reserves fosters a lack of motivation/willingness to protect naturally occurring trees within cocoa farms situated within the forest reserve compared with farms in OFR areas (Ameyaw et al. 2018, Richards and Asare, 1999). The evidence of dominant trees/regeneration belonging to the *Sterculiaceae* and *Bombacaceae* family could also have adverse long terms effects on cocoa production and yield as this family of trees is well noted to be excellent hosts of capsid pests (Gockowski et al. 2004, Manu and Tetteh 1987). In the same way, the occurrence of *Persea americana* in a supposed uncultivated area could indicate a future potential for land use change especially since it is an exotic fruit tree species that is intentionally planted.

Ecological distribution and economic valuation of species based on management/land use type

Human decisions on land management/land use (aka disturbance) have a profound effect on tree species distribution. Strict emphasis on forest protection compared with that of timber and or cocoa production will therefore go a long way to influence plant community and associations as well as the economic value assigned to wood/products from particular species by virtue of inherent ecological attributes. In an effort to curb illegal timber harvest in Ghana, the Forestry Commission launched the National Wood Tracking System as a mechanism to track timber along the chain of custody. The system provides a classification system which can be used to determine the economic value of timber species. Here, we investigate the ecological guilds and assigned economic values of adult and juvenile tree species in the different land use types studied.

Although Class 1 species were prominent in the uncultivated area (N), the presence of trees of all classes provides evidence of less disturbance and pronounced natural forest stand dynamics. Conversely, a marginal pattern can be seen with Class 3 species occurrence where protected areas (reserve and OFR) had more Class 3 species than timber production areas. Class 1 species (such as *Aningeria robusta* and *Terminalia superba*) were generally higher in occurrence on the timber production areas; signaling an effort towards profitability. In other words, farmers may be altering tree communities with a view to the potential monetary benefits when trees are eventually harvested. Protected areas may be less attractive in terms of maintenance of Class 1 species due to the comparatively higher restriction levels. Some other studies have however stated that although farmers maintain trees on their farms, such trees are generally of low economic value. This is done intentionally to avoid/prevent future confrontations with timber concessionaires/illegal loggers who are mostly interested in economically high value trees (Asigbaase et al (2019) and Dawoe et al. (2016)).

Disturbance has a significant effect on presence and absence of specific forest ecological guilds (Dale et al. 2000). The expectation is that, high levels of disturbances (e.g. deforestation and land conversion/land use change) will result in tree communities dominated by pioneer species (Foli 2005). Within the uncultivated area of the forest reserve (i.e. Natural Area), the observation of NPLD dominance along with some ST species signifies an absence of any recent major disturbances. In contrast, the dominance of pioneers in the OFR areas consequently points to more pronounced disturbances in that area or as described in the management plan, a sign of recovery from past disturbances (FC 2010). This may be the underlying reason why there were no shade tolerant natural regeneration species recorded in the protected zones where cocoa is cultivated in both the area within and outside the forest reserve.

Evidence of variation in management intensity of cocoa farms in different land use gradients and emerging trends in cocoa agroforestry systems

All measures made on cocoa farms points towards increasing cocoa farming intensity in areas with lesser protective restrictions (Outside Timber Area and Outside Protection Area). Thus, it was expected and confirmed by findings that cocoa production in general was higher in Outside Timber Area and Inside Timber Area (i.e., timber production area and adjoining off reserve area) than

Outside Protection Area and Inside Protection Area (protection area and adjoining off reserve area). We also expected productivity of cocoa to be higher in Outside Timber Area and Outside Protection Area compared to their adjacent reserved Inside Timber Area and Inside Protection Area. A concurrent study by Ameyaw et al. (2018) explained this observation. It was observed that the governing agency, Forestry Commission is spearheading a drive to curb encroachment of cocoa farms into the reserve with specific emphasis on the protected side; the area with a ban on logging (Inside Protection Area). The trend of increased cocoa yield is mostly as a result of cocoa farm expansion in Ghana. This in effect suggests that areas with comparatively lesser protection and institutional oversight are more favorable for cocoa farming. Considering that the entire reserve is or should be under institutional oversight, this suggests institutional deficiencies or failures in fostering management and protection of forest resources (Oduro et al. 2015). Outlying lands adjacent to reserve areas are often the most degraded as shown in this study which is generally confirmed also by Tsai et al. (2019).

CONCLUSIONS

Cocoa growing presents a challenge for forest management especially where cocoa is interspersed with management goals within forest reserve areas. The challenge is escalated when one reserve, although having an overarching forest protection goal also has multiple land use types; protection and timber production goals mixed with cocoa production. Compositional differences in plant/tree communities differ based on the management strategy or land use type and show a marked distinction in species diversity and numbers compared with uncultivated areas. Off-reserve areas synonymously follow species patterns and distribution of the immediately adjoining reserve area and land use type. Using uncultivated areas as a reference, ecological guilds of natural regeneration and economic value of trees follow a trend of concentration of pioneer species in the off-reserve areas compared with the reserve areas. The area of the reserve utilized for wood production generally had a higher level of pioneer species compared with the strictly protected zone. This tallies with patterns observed in land use change over a period of 17 years, with the highest disturbance and land use change observed in the off-reserve areas and more in the timber production zone than the protection zone. In essence, the management strategy imposed in a forest reserve has leakage effects on adjoining areas and generally influences tree species composition and intensity of cocoa farming. Since land use change has been observed to be progressive and directed towards deforestation and degradation even in a forest reserve, it is imperative to redefine forest management at the forest reserve level to adequately encapsulate the objectives of cocoa farming with a view to promoting the objectives of the two vital industries.

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Chapter 3. COCOA AND CLIMATE CHANGE: INSIGHTS FROM SMALLHOLDER COCOA PRODUCERS IN GHANA REGARDING CHALLENGES IN IMPLEMENTING CLIMATE CHANGE MITIGATION STRATEGIES

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ABSTRACT

This study investigates the knowledge and perception of smallholder cocoa farmers on the potential impacts of climate change on cocoa production in the Krokosua Hills Forest Reserve in Ghana. It addresses opinions on the inclusion of climate mitigation and adaptation strategies (Reducing Emissions from Deforestation and Degradation - REDD+) into cocoa production, potential obstacles and roles of stakeholders in ensuring community acceptance of such strategies. Farmers' perceptions of changes in climate did not always match historic weather data, but accurately described increases in temperature and drought which are linked to agriculture production. Farmers appreciate the importance of tree maintenance for ecosystem services but were skeptical of financially rewarding climate change strategies which favor tree protection. Cultural practices associated with cocoa production encourage carbon release and may pose a threat to the objectives of REDD+. Farmers experience on the land, interactions with other

farmers, government extension agents and cocoa buyers all influence cocoa agroforestry practices in the area, and messaging through existing entities (particularly extension agents) presents a pathway to community acceptance of climate change projects. The study recommends reforms in REDD+ strategies to adopt flexible and participatory frameworks to facilitate adoption and acceptability due to pronounced heterogeneity in community perceptions and knowledge of climate change and related issues.

INTRODUCTION

Cocoa (*Theobroma cacao*) cultivated under the shade of forest trees, in combination with annual food crops (i.e., cocoa agroforestry) on the same piece of land, is common for smallholder farmers across the cocoa-forest mosaic of tropical Ghana. Currently, Ghana is the world's second largest cocoa producing nation (behind Côte d'Ivoire). The cocoa industry employs about 3.2 million people along its commodity chain and accounts for 25% of foreign exchange earnings (Essegbey and Ofori-Gyamfi 2012). It is estimated that 800,000 smallholder cocoa farmers in Ghana derive between 70-100% of their yearly income solely from cocoa production (Anim-Kwapong and Frimpong 2008). Benefits from cocoa agroforestry are multifaceted providing: greater biodiversity than monocultures, and societal and economic benefits of continuous food supply (food crops/staples), annual income from cocoa, and long-term financial reserves in timber.

Cocoa generally requires high temperatures, precipitation and humidity to achieve optimum productivity and cultivation is restricted to the "cocoa belt" (20ºN and 20ºS of the Equator). Specifically, cocoa trees need temperatures between 21-23°C and rainfall between 1,000-2,500 mm annually to achieve optimum yield. Cocoa production is sensitive to precipitation and is reduced by drought which may increase in Ghana under climatic changes. A temperature increase of about 2°C and a 1% decrease in precipitation (1467mm to 1455mm) is projected by 2050 in Ghana with potential decreases in cocoa cultivation (Schroth et al. 2016), particularly in areas bordering the cocoa growing suitability area to the north and south respectively (Schroth et al. 2016, Läderach et al. 2013). Long-term trends in precipitation are lacking due to high variability along both inter-annual and inter-decadal timescales (McSweeney et al. 2010). The impacts of the severe El Niño years of the early 1980's on cocoa yield in the entire West African sub region (Ruf et al. 2015), provides a reference point for potential future impacts of increased drought under climate change projections.

A "climate-smart" (Asare 2014) approach is needed to counter the potential impacts of climate change on global cocoa production. Non-governmental organizations (NGOs) have made significant efforts in developing sustainable practices related to cocoa production and climate change across the West African sub region and other developing nations in the cocoa belt. However, the development of cocoa varieties with tolerance for higher temperatures and low precipitation is needed (Wiah and Twumasi-Ankrah 2017), particularly in Ghana, where strategic climate adaptation strategies are essential to the sustenance of cocoa production (Hutchins et al. 2015). Current and emerging climatic trends could render smallholder cocoa farmers vulnerable and pose a significant threat to livelihoods centered on cocoa production (Rainforest Alliance 2017).

In 1995 Ghana ratified the United Nations Framework Convention on Climate Change—UNFCCC global alliance to reduce carbon emissions (Awetori 2009) and in 2008 adopted the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program to foster carbon goals (Asare and Kwakye 2014). REDD+ aims to create financial value and incentive for activities which lead to sustainable natural resource management in developing nations (Agyei et al. 2014). REDD+ reinforces conservation, sustainable management of forests and enhancement of forest carbon stocks. Potential benefits envisaged include conservation of biodiversity, water and soil regulation, and direct human benefits including enhancing opportunities for participatory natural resource management. Ghana has made significant strides toward a national scale implementation of REDD+ and submitted its Readiness Preparation Proposal (RPP) to the World Bank's Forest Carbon Partnership Facility (FCPF) in 2010 (FC 2016). The National Forest and

Wildlife Policy (2012) and National Climate Policy (2013) were passed by Ghana to offer a favorable policy pathway for climate change strategies, including REDD+. The integration of cocoa agroforestry within REDD+ (Cocoa Forest REDD+ program, (FC 2016)) aims at improving net carbon gains through the integration of trees on crop lands and subsequently providing an opportunity toward climate change mitigation. REDD+ funding differs from mainstream project funding where funds are provided before the initiation of a project. REDD+ is rather performance based with a built-in component of demonstrating the impact(s) of the project before funds are released (Asare and Kwakye 2014). REDD+ has a strict set of criteria which are essential to its implementation. Although Ghana's REDD+ pathway has received accolades, globally applicable issues pertaining to tree and land tenure, benefit sharing mechanisms, technical capacity and governance (Asare and Kwakye 2014, Thompson et al. 2011, Vatn and Vedeld 2013, Chhatre et al. 2012) are yet to be fully resolved.

Numerous studies have examined the perceptions of farmers on such topics as the impact of climate change on cocoa yields (Wiah and Twumasi-Ankrah 2017, Hutchins et al. 2015, Ehiakpor et al. 2016, Ofori-Boateng and Baba 2014), smallholder choice of cocoa production systems (Denkyirah et al. 2017, Gyau et al. 2014, Codjoe et al. 2013), the potential benefits of cocoa agroforestry (Asare et al. 2014, Cerda et al. 2014) and advantages of REDD+ in cocoa production (Agyei et al. 2014, Baruah 2017). There is however, limited information on how farmers perceive the inclusion of climate change mitigation strategies into their land/farm management objectives. Since agroforestry emphasizes "people" as one of its key elements (Huxley 1999), understanding cocoa farmers' perceptions of issues such as tree planting, and local/indigenous knowledge on the role of climate on sustainable forest management and environmental conservation is important in answering questions on land use, land-use change (deforestation) and cocoa production. This suggests that, agroforestry is not just about the cocoa and associated shade trees (Jerneck and Olsson 2013), as there is a strong linkage between farmers' perception and management decisions on tree retention on cocoa farms in Ghana; positive perceptions of shade trees increase the probability that a farmer will retain trees on cocoa farms (Atkins and Eastin 2012). The importance of stakeholder perceptions on the success of conservation projects has been previously demonstrated; for example, in Kenya, stakeholder perceptions influenced adoption of new and improved strategies (Wiesmann 1998).

Smallholders perceptions also take into account interaction between their farming activities and changes in microclimate, and their perceptions may determine whether mitigation/adaptation strategies are implemented (Ogalley et al. 2012). In fact, the social acceptability of the agroforestry system at the individual farmer level, is influenced by: community heterogeneity, perceptions towards trees, land and tree tenure arrangements, gender and other socio-cultural factors like age, education, labor and cultural habits (Atangana et al. 2014). Remarkably, a strong correlation between climate change, the level of concern for associated implications, and ultimately, farmers' decision to subscribe to climate change mitigation policies and projects exists, irrespective of the accuracy of farmers' experience with regards to individual perceptions of climate change and actual historical climatic trends (Niles and Mueller 2016). For instance, people who believed that climatic changes were occurring and that changes were a result of human activities were more likely to perceive temperature increases despite inconsistencies with available climate records. In the end, perceptions about climate patterns effectively influence actions of farmers irrespective of patterns determined through analysis of empirical climate data (Meze-Hausken 2004).

Based on previous studies, there is empirical reason to suggest that the aforementioned demographic profiles have an impact on perceptions of climate change, and consequently, actions to be taken. In Ghana, for instance, smallholder farmers (both men and women) in different communities hold specific views of climate change which ultimately influences their coping strategies (Derkyi et al. 2018). Elsewhere, farmer age is a significant determinant of overall farming and climate experience (Debela et al. 2015, Deressa et al. 2011). Differences in access to information on climate change also correlates with climate change perceptions among male- and female-headed households, with the former more likely to be educated on climate-related issues (Asfaw and Admassie 2004). Women, on the other hand are considered more susceptible to the impacts of climate change because they are generally less informed (FAO 2011). This suggests that education in general influences how farmers perceive climate change (Denkyirah et al. 2017, Mustapha et al. 2012). Additionally, the accumulation of knowledge and experience with both farming and climate makes farmer age an important factor in climatic change perception inquiry (Juana et al. 2013). In Ghana, marital status among smallholder cocoa farmers influences access to information on climate change and ultimately, how individuals perceive climate change and adaptation strategies (Denkyirah et al. 2017). Lastly, comparisons between indigenous and migrant farmers, indicate that the former have a higher tendency to subscribe to long-term climate ameliorating programs and strategies. Lack of property rights is highlighted as a significant cause of this observation (Antwi-Agyei et al. 2015).

This study reports on findings of a survey conducted in smallholder cocoa communities in a major cocoa-producing area of Ghana. A semi-structured questionnaire was employed to collect demographic profiles, relevant information and opinions of individual farmers. In consonance with the study objectives, it is expected that different communities, and the gender, age, educational status, migrant status, and family/household status within communities will be tied to farmers' perceptions of climatic changes, potential causes, receptiveness to climate change mitigation projects and general opinions about climate change.

This paper investigates the perceptions of smallholder cocoa farmers on the inclusion of climate change mitigation strategies and payment for ecosystem services into land/farm management objectives. Specifically, this study:

1. Examines cocoa farmers' knowledge and perceptions of climate change in contrast with climate data and potential impacts of climate change on cocoa production;
2. Investigates the perceptions of smallholder farmers on the feasibility of including climate change mitigation projects in cocoa farming;
3. Explores the roles of scientific and non-scientific actors (cocoa farmers and non-cocoa farmers) in promoting the implementation of climate change mitigation strategies in combination with cocoa production; and
4. Examines potential obstacles to incorporating climate change mitigation strategies into cocoa production. materials and methods

MATERIALS AND METHODS

Study Area

The study was carried out in the Krokosua Hills Forest Reserve (KHFR), in the Juaboso District of the Western Region of Ghana (Figure 6). Specifically, the study was conducted among smallholder cocoa farmers resident in communities that fringe KHFR, one of the major forest

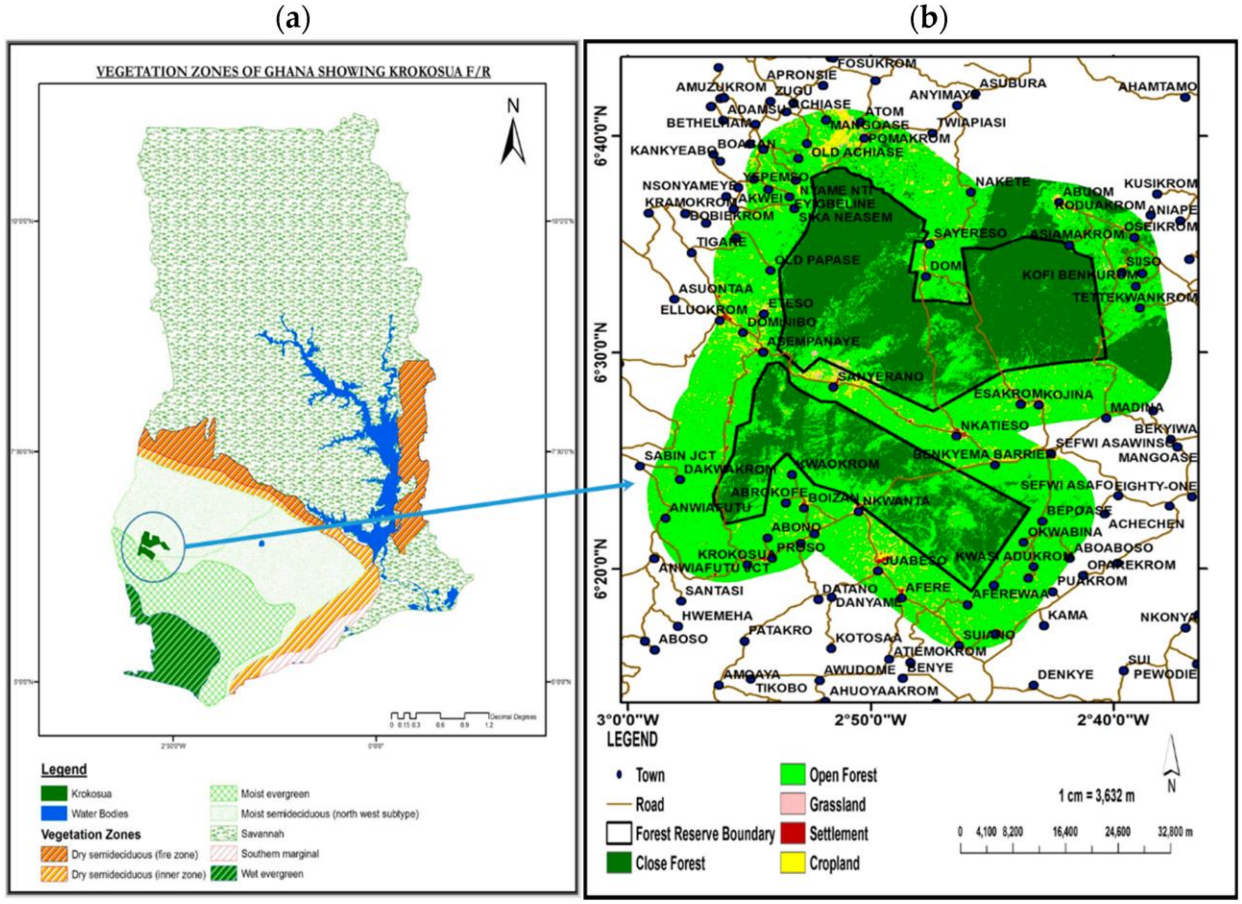

Figure 6. Ecological zones in Ghana highlighting the location of the Krokosua Hills Forest Reserve (KHFR) (a). Ecological zones correspond with the legend, with KHFR located in the moist semi-deciduous zone. Map of KHFR showing approximate locations of study communities is also shown on the right side of the figure (b).

reserves in the Western Region. KHFR covers an area of about 481.61 km^2 (48,160 ha), situated at the east bank of River Bia and bisected by the Sefwi-Wiawso—Côte d'Ivoire border road (6°15′–6°40′ N and 2°40′–3°00′ W) (FC 2010). Cocoa farming (agriculture) is the main source of livelihood for people living around the reserve (Ghana Statistical Service 2010). Between 2006 and 2009, the population of thirteen large fringe communities was 66,766. For management purposes, KHFR has been designated into two major zones: (1) the production zone (where harvesting of timber and non-timber forest products is officially permitted for prospective Timber Utilization Contracts (TUC, a written contract signed by the Sector Minister and ratified by the Parliament of Ghana granting a timber harvesting right to its holder upon a successful competitive public bidding process) and permit holders respectively—23,639 ha) and (2) the protection zone (includes areas of high biodiversity conservation priority, areas recovering from past disturbances and no timber harvesting areas—24,521 ha) (FC 2010).

Prior to the official designation of the KHFR as a Forest Reserve in 1948, fringe communities utilized the land for agriculture and cocoa farming. After the reservation status was conferred, cocoa farms were given legal status to remain in the forest and were termed admitted farms. Per the most recent management plan, there are 38 admitted farms in the reserve. These admitted farms have footpaths as routes connecting farms and huts scattered within the forest. Over time, population growth and land scarcity have forced cocoa farmers to extend their farms further into the forest and outside the area demarcated for cocoa production (admitted farms) (FC 2010). Cocoa farming is the leading driver of deforestation in the region (Noponen et al. 2016).

Farmer selection, data and analysis

The study targeted cocoa farming communities within a range of 2 and 5 km away from the KHFR. The distance varied to sample cocoa farmers who interacted with or specifically had cocoa farms within the KHFR. A mixed method approach (qualitative and quantitative methodologies) was used. Apart from the inherent trait of complementarity of qualitative and quantitative procedures, using mixed methods provides a platform for cross-checking and validation of collected data (Bernard 2006). A list of farmers in the target communities was not readily available so the researchers identified farmers through community heads and leaders. Farmers were then stratified based on gender and randomly selected for interviews. A purposive sampling approach employing snowballing (i.e., respondent referrals) was also used to increase sample size and heterogeneity of respondents. A total of 205 face-to-face interviews were administered in 30 communities surrounding the KHFR between December 2016 and February 2017. Identifying information for responses given were not taken as per the instructions of the Institutional Review Board of the University of Washington. In each community, unequal samples were obtained, with at least 2 interviews in selected communities. Interviews were conducted at home and on farms and lasted between 60 to 90 min. Notes were taken as the interview progressed with corresponding answer choices checked as well. Questions were prepared in English but the local language, Twi, was used during the interview except in situations where respondents could understand English. Survey enumerators were given prior training in translation and the survey instrument.

Survey questions were structured into four different themes: (1) knowledge about climate change, (2) perceptions about climate change mitigation strategies, (3) roles of local and external stakeholders, and (4) potential setbacks to climate change mitigation strategies, and examined for demographic trends (e.g., gender, age, level of education and migrant status). Questions were designed to collect mostly quantitative data (structured) but also included qualitative data collection through semi-structured (open ended) questions that allowed farmers to expatiate on opinions and in so doing verify answers given on structured questions.

Answers to survey questions were first summarized in Microsoft Excel and R statistical software was used for statistical analysis. Descriptive analysis such as modes, frequencies and percentages were used to summarize data. As responses from farmers did not follow a normal distribution, a Mann-Whitney and Kruskal-Wallis (KW) test were employed where variables had only two levels (gender, migrant and household status) and three or more levels (community, age and educational level) respectively. Individual questions on knowledge and perceptions of climatic changes, causes and related impacts (Table A13) were used as dependent variables. For statistically significant results on variables with three or more levels, a post-hoc Dunn Test using the Bonferroni-type adjustment of p-values (to reduce type I error) was used to determine which group(s) accounted for the significance.

Based on the four themes of the survey, Likert scale questions were utilized. Questions on five-point scales were converted to three groups; group one combined responses for agree and strongly agree, disagree and strongly disagree on group two and neutral responses on group three. Questions on 4-point Likert scales were converted into binary variables; e.g., not at all worried and not very worried were recorded as zero whiles somewhat worried and very worried were recorded as one for the binary variable (Niles and Mueller 2016). Open-ended questions were categorized under the survey question themes and further sorted for recurring words and phrases (open coding, (Strauss and Corbin 1998)).

Monthly means of maximum and minimum temperature and monthly precipitation climate data were collected from the Ghana Meteorological Agency for the period 1970–2017 from the closest weather station (Sefwi Bekwai), which is about 55 miles from the study area. Data were used to describe the physical environment and compare perceptions of climate change to climatic records. A Mann-Kendall (MK) test was used to determine monotonic trends in climatic variables over the period (Mann 1945, Kendall 1975). A cutoff of $\alpha = 0.05$ was used to determine significance in trends (Helsel and Hirsch 2002). The weather data allows for comparisons with the experiences and observations of individual farmers and the overall community experience. To verify answers on perceptions regarding the length of dry and wet seasons (drought), the Standardized Precipitation-Evapotranspiration Index (SPEI) was used. SPEI is based on a combination of Palmer Drought Severity (PDSI) and Standardized Precipitation Indices (SPI) (Vicente-Serrano et al. 2010). SPEI incorporates temperature by finding the difference between precipitation (P) and potential evapotranspiration (PET) (using Thornthwaite's equation (Thornthwaite 2010)) to produce an adjusted log-logistic distribution. Upon choosing an appropriate time scale, standard deviations of average values are calculated (Vicente-Serrano 2012). SPEI lends from SPI to classify drought severity in a range between no drought (≥ 0) and extreme drought (≤ -2) (Charusombat 2011). Estimation of SPEI was done using the SPEI package in R (Beguería and Vicente-Serrano 2017).

RESULTS

Historical Climate Trends

Temperature

Based on the MK test on data from 1970 to 2017, temperature has significantly increased, a probable manifestation of climate change. Analysis of mean monthly minimum ($\tau = 0.285$, $p < 0.001$) and maximum ($\tau = 0.168$, $p < 0.001$) temperature both indicated statistically significant increased trends (Figure 7a, b). The mean temperature observed for the period 1970–2017 ranges from 22.6 °C to 32 °C for minimum and maximum respectively. Seasonal MK tests (SMK) also revealed an increasing seasonal temperature trend for minimum ($\tau = 0.395$, $p < 0.001$) and

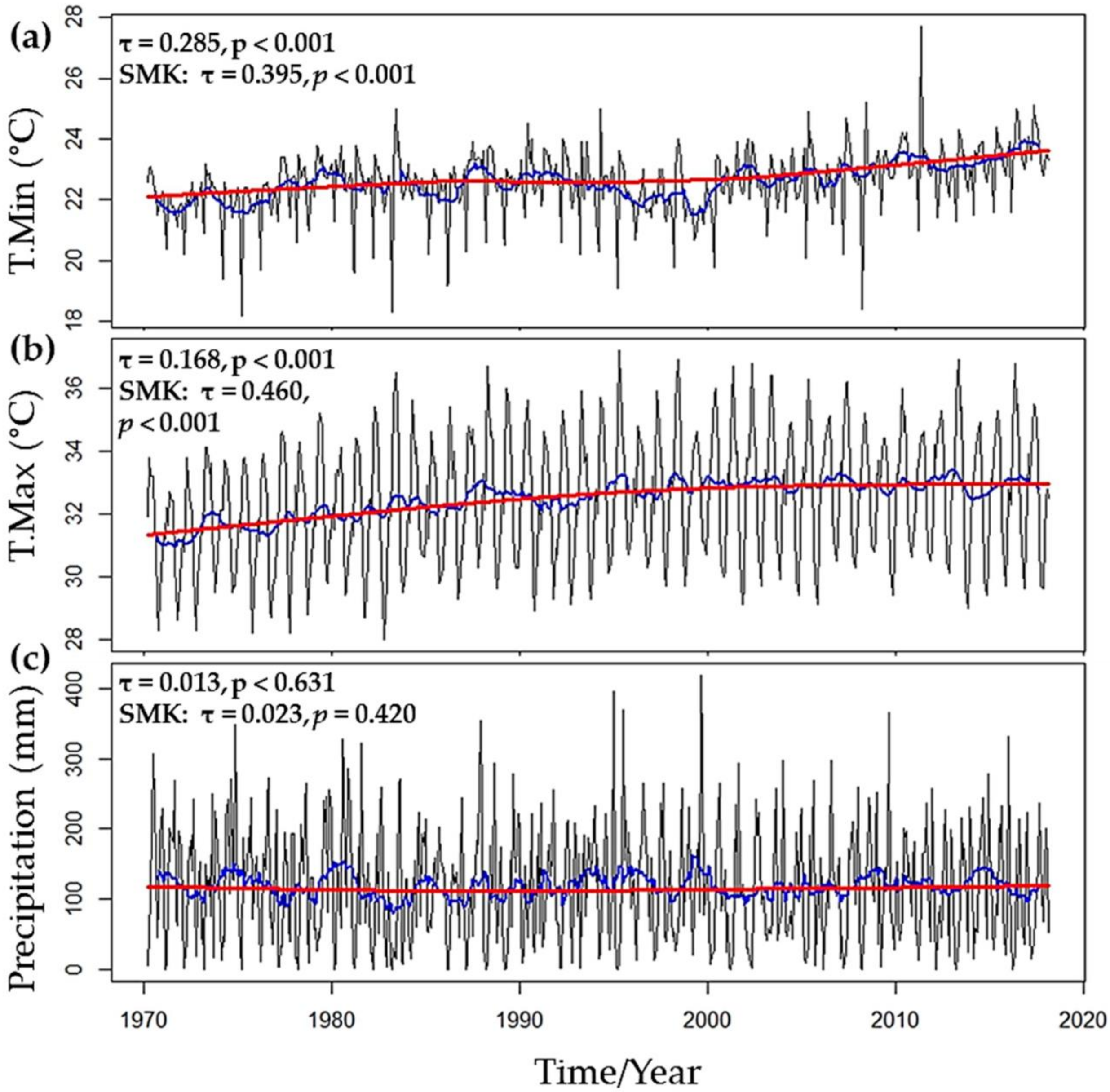

Figure 7. Monthly trend analysis of minimum and maximum temperature (a,b) in °C and precipitation in mm (c) at the Sefwi Bekwai weather station. Data was obtained from the Ghana Meteorological Agency (Kumasi, Ashanti Region, Ghana). Test for overall trend in data is shown by the red line with statistical test results indicated by Kendal's Tau (τ) and a resultant p-value. Tests for seasonality in data is indicated in blue and results shown with the Seasonal Mann-Kendall test (SMK). The "Kendall" package in R statistical software was used for the analysis.

maximum ($\tau = 0.460$, $p < 0.001$). For recordings of mean minimum temperature, the lowest record for the period (1970–2017) was 18.2 °C which was in January 1975, while the highest record was 27.7 °C in February 2011. Maximum temperature on the other hand, had its lowest record as 28 °C in August 1982 and highest record for the period as 37.2 °C in February 1995. Generally, low temperatures were mostly between August to January while February to June were the hottest months.

Precipitation

Weather records indicated that since 1970, mean precipitation has consistently been above 1000 mm. Trend analysis however indicates an erratic rainfall pattern which is confirmed by the MK test. Specifically, the MK test detected no specific trend ($\tau = 0.013$, $p = 0.631$). Although Kendall's tau remained positive ($\tau = 0.013$), that is overall rainfall increased, the increase was not significantly different from zero. A seasonal MK test (SMK) further confirmed no seasonality trend in precipitation over the period ($\tau = 0.023$, $p = 0.420$) (Figure 7c). Apart from 1977, 1981, 1982, 1983, 1986 and 2016, all other years recorded rainfall greater than 1250 mm, the minimum value required for optimum cocoa production. The lowest and highest precipitation were recorded in 1983 (1071 mm) and 1980 (1826.5 mm) respectively. The most significant drought event in Ghana occurred in 1983, reinforcing the significantly low precipitation level for that year.

SPEI (Drought Severity)

Figure 8 shows SPEI values (using monthly data) for the study area, showing a decrease in extended wet periods. Periods of dryness on the other hand have increased, particularly from 2000–2017. There is indication that the area witnessed its worst drought (SPEI < -2) between 2014 and 2016.

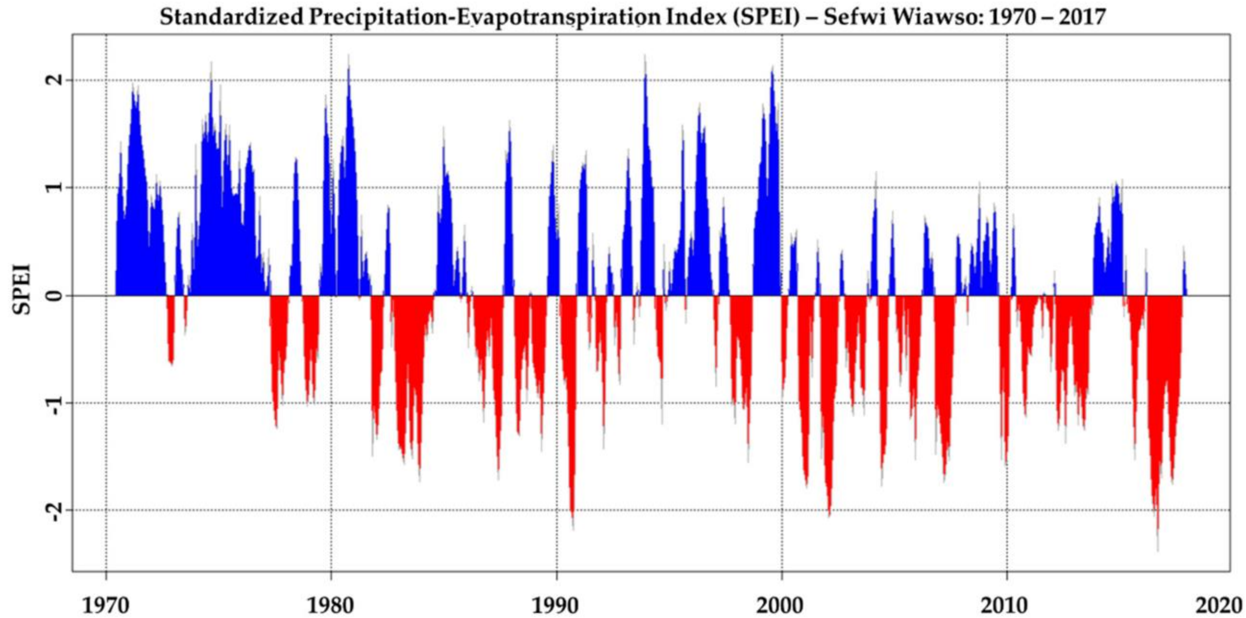

Figure 8. Time series of Standardized Precipitation-Evapotranspiration Index—SPEI values for Sefwi Wiawso (55 miles from study site): 1970–2017. Areas in blue indicate periods of no drought and red depicts periods of drought and corresponding SPEI values.

Characteristics of Respondents

Survey respondents were all adults (>18 years) mostly between 30–59 years; 67% were male and 33% female, a proportion epitomizing cocoa farming as a predominantly male-dominated activity. Approximately 65% of respondents were over 45 years-old. Educational levels ranged from basic (46%), to secondary (16%), to tertiary (7%) and no formal education (31%). Male farmers were generally more educated, 74% (compared to 61% of females) having received either basic, secondary or tertiary education. While females had similar basic education (51%) to males (49%), more males (19%) than females (6%) had received secondary education. Among male respondents, 87% were household heads. Only 23% of females were heads of their households. Natives of communities were generally more educated (71%) than non-natives (66%). Most respondents were married (86%), Christian (80%) and natives of their respective communities (71%) (Table 13).

Table 13. Demographic characteristics of cocoa farmers in communities surrounding the KHFR (n = 205).

Attribute	Category	Percentage of total respondents
Gender	Male	67
	Female	33
Age	Less than 18	0
	18 – 29	3
	30 – 44	32
	45 – 59	49
	> 60	16
Highest Level of Education	Basic	46
	Secondary	16
	Tertiary	7
	No Formal Education	31
Marital Status	Married	86
	Single	6
	Divorced	4
	Widowed	4
Migrant Status	Native	71
	Non-native	29
Religion	Christian	80
	Muslim	10
	Traditionalist	5
	Other	5

Farmer knowledge and perceptions of Climate Change and impact on cocoa production

Most farmers had perceived changes in climatic patterns over the last 20 years. Notably, farmers perceive rising temperature (88% of farmers) and reduction in the amount of rainfall (89% of farmers) in recent times. Within the same period, the length of the wet season was perceived to have become shorter (81%), with a resultant increase in dry spells (89% of farmers) (Table 14). A small proportion (<1%) of farmers indicated they had witnessed spikes in cases of wildfires within the same period. Farmers overwhelmingly (95%) agreed that observed and experienced climatic changes over the past decade have had a negative impact on cocoa yields. The remaining respondents were evenly split on yields: some said they remained the same (2%) or improved (2%), respectively over the last decade.

Table 14. Respondent perceptions of climatic changes (n = 205).

Climatic Variables	Increased (%)	Decreased (%)
Temperature	88	5
Rainfall	2	89
Length of Wet Season	9	81
Length of Dry Season	89	6

Descriptive examination of survey responses indicated that farmers believe that climatic changes are mostly as a result of human activities; precipitation (181: 88%) and temperature (175: 86%). This finding is consistent with farmers' belief that climatic changes are not just isolated climatic anomalies. Farmers mostly disagreed that both precipitation (71%) and temperature (75%) were climatic anomalies. Superstitious (curses/spells) association with climatic changes were mostly dispelled by respondents with respect to changes in precipitation (85%) and temperature (81%). On the possible human attributable causes of climatic changes, illegal logging (95%) was the most highlighted. Slash and burn agricultural practice in the area (84%) as well as pollution from vehicles (83%) were similarly pointed out as detrimental to the environment. According to 80% of respondents, widespread woodfuel harvesting could also contribute to climate change. Despite previous research on the potentially harmful environmental impacts of implementing full-sun cocoa systems (cocoa monocultures), the majority of farmers (65%) believed such systems do not contribute to climatic changes, as opposed to 30% who perceive a change to full-sun cocoa systems, a plausible climate change driver (Figure 9).

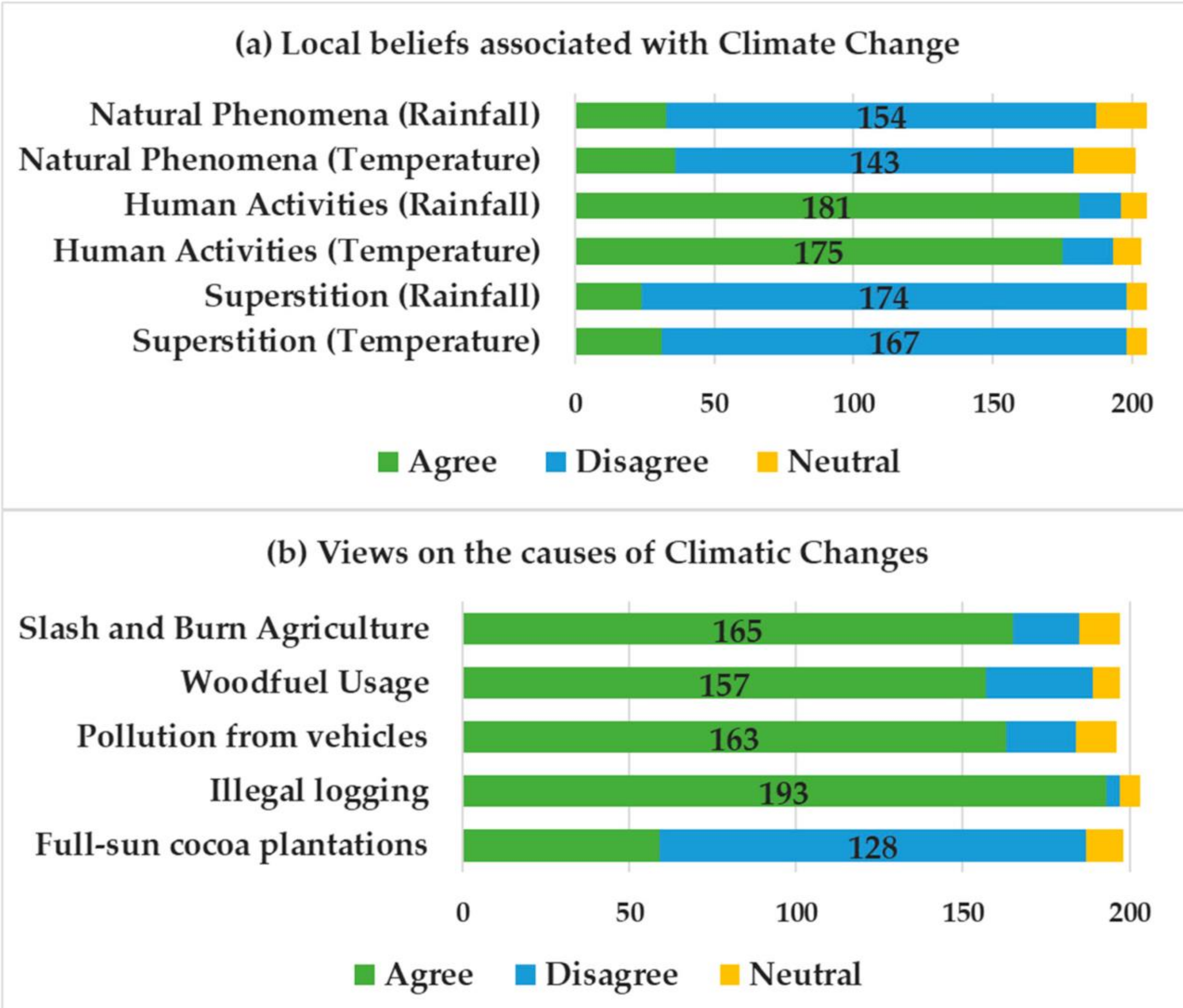

Figure 9. Number of survey responses to two questions on beliefs associated with climate change (a) and causes of climatic changes (b). A total of 205 responses were collected with few respondents choosing not to respond. Groups were created from a 5-point Likert scale in 3 categories: Agree, Disagree and Neutral. Each stacked bar depicts responses into 3 groups with the corresponding question listed in the left strip. Labelled bars indicate only the majority response.

Farmers' experience of climatic changes in recent times has heightened their fears about the future outlook of their main income earner, cocoa farming. Almost all farmers, 202 out of 205, expressed worry about changing climate. Concerns were mostly about reduction in cocoa yields (195), food crop loss due to droughts (181), increased rate of crop disease and pest infestation (135), increased wildfire incidents (127), and increased cocoa tree mortality associated with flooding (76). As a climate ameliorating mechanism, respondents held similar opinions on the role of trees in helping to regulate temperature (94%) and contribute to increased precipitation (93%). According to respondents, specific climate change initiatives will mostly require a participatory approach (94%) as well as governmental interventions (78%). When farmers were asked to elaborate on what participatory approach they were specifically referring to, comments like "it is not any government, but we must get involved in the fight against climate change", "government and citizenry must make concerned effort in the fight against climate change", "government alone cannot fight the climate change menace so we must get involved", "government and stakeholder should all rise against climate change", and "all should participate in effort to combat climate change" were made. This suggests that farmers believe their active participation in developing/implementing climate change mitigation efforts is paramount to its eventual success. Farmers believe climate change is a reality and also agree, almost unanimously, that interventions are vital to avert potentially devastating impacts on future generations (92%).

Information Related to Climate Change Mitigation Strategies and Perceptions of Farmers

Hybrid cocoa is the predominantly cultivated variety in the communities surveyed. More than 80 percent of farmers claim to plant this variety. Farm observations revealed that, such farms had a combination of trees, cocoa and food crops, with significant open patches in tree canopy to allow an optimum level of sunlight. Some farmers (10%) had some of their farms with closed overhead tree canopies being described as traditional shaded cocoa stands. Other farmers (7%) also noted that they had some farm-lands dedicated to cocoa monocultures. Cocoa lands were mostly acquired from relatives who were still alive or through inheritance (46% of farmers). Some farmers procured their own lands (42%), while others leased (15%) or had lands in multiple ownership categories. Farm sizes depicted the overarching Ghanaian smallholding cocoa farm/cultivation technique, revealing specifically that farmers mostly had 2 tracts of lands between sizes 0.4–2 ha, with cocoa trees ranging between one year to 19 years.

According to farmers, the choice of cocoa variety was influenced mostly by the time required to grow to maturity (90%), resistance to pests and diseases (67%), expert advice from extension agents (62%), and seedling availability (49%). Maintaining trees on cocoa lands seems plausible to many farmers (92%) in the study area by virtue of the inherent benefits to the environment. Interestingly, the idea of direct monetary benefits for tree maintenance on cocoa lands met a lesser response than preserving trees for their inherent value. Although the majority of farmers agreed that they will maintain trees on their farms for direct monetary benefits, a reduction of 17% was observed (a total of 75%) for farmers who answered yes. Farmers were almost even regarding their views on current tree tenure, which allocated ownership/benefits from trees differently based on location of tree within the forest reserve and outside it. It was specifically observed that 51% of 205 farmers were satisfied with the current tree tenure, in sharp contrast to the remaining 44%, who held a dissatisfied opinion of tree tenure.

Investigation into the Role of External Stakeholders in Cocoa Farming and Pathways to Increased Acceptability of Climate Change Mitigation Strategies and Potential Setbacks

Results revealed that communities in the study area had witnessed a substantial presence of extension agents from governmental organizations and initiatives on cocoa as well as that of non-governmental organizations. Overall, farmers were satisfied (84%) with the influence such stakeholders have had on cocoa farming. Farmers in general indicated their inclusion in any direct income earning climate change mitigation strategy will hinge on the details of such a strategy. A total of 81% shared this opinion. Most farmers (89%) suggested that the presence of extension agents will be vital in developing a bond of trust for any such project. Ultimately, the provision of farming incentives (68%) and assurances on the sustainability (63%) of climate-related strategies are equally important to enhance farmers' interest.

The study results show that the cultural practices of cocoa farmers tend to release carbon due to vegetation removal. Although this was not evident on the farms that were visited, 76% of farmers interviewed revealed they mostly cut down cocoa trees when they see significant reduction in yield. Cutting down illegally cultivated cocoa trees in the area has mostly been done by staff of the Forestry Commission (the government body in Ghana tasked with management and regulation of forest and wildlife resources) to combat further encroachment of farm-lands into the forest reserve, making this finding surprising. Some farmers (27%) also indicated that they removed some timber trees to open the canopy and subsequently allow more incident sunlight to cocoa trees, when cocoa trees begin to decline in yield. The remaining farmers either leave the cocoa farm/trees or abandon the land completely when cocoa yields decline beyond economically acceptable levels.

During preparation of lands for cultivating cocoa and other agricultural crops, slash and burn is the preferred strategy (88% and 32% respectively). Illegal logging is quite prevalent in the study area and cocoa farms with economically attractive timber species are the prime targets. Farmers indicated that illegal logging is reported to the Forestry Commission (57%). Despite this observation, farmers indicated that response and actions to such offenses are not always effectively dealt with. Farmers are sensitive about this topic, since illegal loggers do not conform to any logging standards and almost always leave significant damage to cocoa trees in the process. As a safeguard strategy, farmers resort to inducing mortality (through girdling, burning and pouring hot water on roots) of economic tree species before they reach maturity or merchantable structure/form (23%).

Statistical Variations among Responses Based on Demographic Attributes

We found differences in responses among farmers based on socio-demographic attributes including: community, age, gender, educational status, migrant status, and family/household status. Variations among communities were the most prevalent. All thirty communities generally shared similar climate experiences, with the majority response of increasing temperature/length of dry season and decreasing rainfall/length of wet season contributing 87% of responses, in comparison to 13% of other responses ($p < 0.05$). Gender also showed statistical differences among responses to observed temperature ($p = 0.01$), and rainfall ($p = 0.03$) variations; male respondents were more likely to have perceived increasing temperature (93%) and rainfall (93%) than females (78% and 81% respectively). On the other hand, age, migrant, and household status appears not to be a significant contributor to responses on climate experience ($p > 0.10$ for all responses).

Despite near unanimous agreement (95% of community responses) on the potentially negative impacts of climatic changes, concern regarding climate change impacts on cocoa yields varied significantly ($p < 0.001$). Most communities (77%) believe that collection/harvesting of woodfuel contributes to climate change. Other respondents (23%) had an opposing view which was statistically different from the majority response ($p < 0.001$). Responses to questions on slash and burn as an agricultural practice that contributes to climate change (80% of responses) also varied significantly among communities ($p = 0.03$). The age of a respondent may also contribute to farmers' views on the contribution of illegal logging to climate change ($p = 0.06$); with respondents 18–29 years old more likely to believe this (100%) than those in other age groups (94%). Cocoa monocultures have been highlighted as a potential environmental degrading agent, however native farmers (59%) found this to be less of a problem than non-native farmers (72%; $p = 0.02$).

The association of traditional beliefs and myths (such as curses and natural causes) to climate change appears to be community specific ($p < 0.01$). However, farmers' thoughts on human activities effects on rainfall patterns were statistically uniform ($p = 0.22$). Gender ascription of superstition (e.g., curses) to changes in rainfall patterns as a result of climate change was found to be statistically significant ($p = 0.01$). Females were found to be more superstitious than men. To a lesser extent, gender also influenced perceptions on rainfall just being a natural weather anomaly ($p = 0.09$). Overall, there was a general consensus (98% of responses) on the immediate concern about climate change impacts on their livelihoods and social well-being. However, farmers' view of future implications of climate change varied significantly among the study communities ($p < 0.001$); 92% of community responses pointed to a high likelihood of negative impacts.

Farmers' responses showed no differences in the perceived ability of trees to regulate temperature ($p = 0.88$) but there was a difference in response to trees' role in regulating rainfall ($p = 0.04$). There was a general acceptability of cocoa production which includes tree maintenance for ecosystem services exclusively, and one that remunerates farmers for maintaining trees on their farms, however, answers varied significantly among communities ($p < 0.001$). Tree tenure has historically been a contentious issue particularly at the community level. Communities have different opinions on current tree tenure arrangements ($p < 0.001$); and a slight majority (51%) believed that current tenure patterns are satisfactory in contrast to those (44%) who hold a dissatisfied opinion about tree tenure. The educational and migrant status of farmers plays a significant role ($p = 0.02$ and $p = 0.04$ respectively) in respondents' opinions on existing tree tenure regulations. Post-hoc tests indicate statistical differences among respondents with basic education (58% satisfied) and those without any formal education (38% satisfied; $p = 0.01$). Native farmers (56%) were generally more satisfied with current tree tenure than migrant farmers (40%). Age ($p = 0.07$) and gender ($p = 0.09$) also contributed to respondent thoughts on tree tenure. Younger age groups were more satisfied with existing tree tenure arrangements than older generations. Lastly, although farmers believe the influence of external help (through extension services) has mostly resulted in positive on-farm cocoa production (84%), a section of responses disagreed (13%; $p = 0.03$). Education also influenced farmer impressions on the input of extension and related services ($p = 0.04$) (Table 15). Respondents with basic education (42%) were more satisfied whereas those with tertiary education (6%) were the least satisfied with the influence of external help.

Table 15. Kruskal Wallis and Mann Whitney test results indicating statistical differences ($p < 0.05$) between farmer groups/responses based on variables: community, age, gender, education, migrant status and household status.

Description of Variable	Group	Community	Age	Gender	Education	Migrant Status	Household Status
Section 1							
Observed climatic changes							
Temperature	Increased	0.004**	0.588	0.009**	0.464	0.703	0.178
Rainfall	Decreased	< 0.001***	0.852	0.034*	0.425	0.184	0.124
Length of Wet Season	Same	0.007**	0.897	0.801	0.343	0.089·	0.187
Length of Dry Season	Don't know	< 0.001***	0.972	0.936	0.935	0.840	0.260
Climatic impacts on cocoa yield	Positive Negative No impact Not sure	< 0.001***	0.920	0.088·	0.677	0.228	0.125
Views on causes of climatic changes							
Cocoa monocultures		< 0.001***	0.838	0.248	0.354	0.024*	0.518
Illegal logging	Agree	0.015*	0.056·	0.811	0.988	0.764	0.277
Vehicular pollution	Disagree	0.081·	0.885	0.952	0.391	0.141	0.198
Woodfuel usage	Don't know	< 0.001***	0.356	0.653	0.658	0.140	0.544
Slash and burn agriculture		0.032*	0.150	0.837	0.835	0.984	0.798
Climate change beliefs							
Curses (Temperature)		0.009**	0.568	0.223	0.357	0.545	0.880
Curses (Rainfall)	Agree	0.002***	0.288	0.009**	0.806	0.913	0.348
Human activities (Temperature)	Disagree	0.002***	0.899	0.833	0.780	0.479	0.481
Human activities (Rainfall)	Don't know	0.223	0.486	0.416	0.419	0.637	0.884
Natural occurrence (Temperature)		< 0.001***	0.657	0.261	0.520	0.566	0.237
Natural occurrence (Rainfall)		< 0.001***	0.488	0.088·	0.510	0.529	0.218
Tree regulation of climate change							
Temperature regulation	Agree	0.877	0.091·	0.501	0.596	0.210	1.000
Rainfall regulation	Disagree Don't know	0.042*	0.098·	0.289	0.325	0.416	0.216
Concern about climate change	Yes No	0.691	0.364	0.193	0.785	0.859	0.136
Future implications of climate change	Yes No	0.001***	0.256	0.130	0.109	0.489	0.987
Section 2							
Tree maintenance for ecosystem services	Yes No Maybe	0.002***	0.580	0.916	0.253	0.106	0.734

Tree maintenance for payment	Yes No Maybe	< 0.001***	0.190	0.697	0.403	0.030**	0.563
Rating of tree tenure	Good Bad Neither	< 0.001***	0.071·	0.099·	0.013**	0.044*	0.103
Section 3							
Rating of external help	Good Bad Neither	0.029*	0.468	0.925	0.044*	0.282	0.262

Significant difference: ***>**>*>·

DISCUSSION

Variations in Climate Change Knowledge/Perceptions Based on Social Indicators and Potential Impacts

Accuracy in Climate Change Knowledge/Perceptions

Changes in climatic pattern were widely acknowledged by resident cocoa farmers in communities surrounding the Krokosua Hills Forest Reserve. Perceptions about increasing temperature patterns are consistent with trend analysis (Figure 7). Trend analysis of rainfall, however, did not conform with respondents' views. The trend analysis indicated no significant change in the amount of rainfall over the same period (1970–2017), contrary to popular respondent belief that rainfall amounts have become reduced. These observations have been previously stated by Läderach et al. (2013) with regards to temperature. The problems associated with rainfall observations have also been highlighted in the literature (McSweeney et al. 2010).

The respondents' perceptions appear to have been influenced by drought, which was captured by SPEI values. Prolonged dry spells, in particular are a major concern to respondents due to their strong influence on cocoa yields and productivity. Respondents suggest that plummeting cocoa yields in the area are a manifestation of climatic changes. These concerns have been raised previously by Schroth et al. (2016), Wiah and Twumasi-Ankrah (2017), Hutchins et al. (2015) and Rainforest Alliance (2019). The correct observation of increasing temperature trends and length of dry season in this study also brings into perspective that farmers accurately perceive weather patterns in relation to crop production and tend to amend their farming practices accordingly (Niles and Mueller 2016).

Since the link between climate change perceptions and people's likelihood of subscribing to environmental protection strategies (in general) has already been established (Niles and Mueller 2016 and Meze-Hausken 2004), we evaluated the level of accuracy with which local indigenous small holder farmer climate change knowledge compares with empirical weather data. Farmers' reliance on their indigenous knowledge and associated perceptions, leading into a defined climate experience, leads them into taking core decisions regarding their farming/cultural practices (Atkins and Eastin 2012). Ultimately, the accuracy of climate change perceptions, or specifically the potential for negative impacts of climate variability, are essential for maintaining cocoa agriculture (Ehiakpor et al. 2016). Our findings suggest farmers do not always perceive climatic changes accurately, leaving room for further efforts to relay climate information to them.

Interplay between Social Indicators, Climate Experience and Potential Outcomes

A major observation of this study was that although communities were situated in the same geographic location, opinions on climate change and related occurrences vary considerably. Thus, community heterogeneity is of paramount concern in the enactment of any climate-based initiative since farmers' opinions and experiences differ within the least temporal and spatial differentiation, irrespective of geographical location (Derkyi et al. 2018). Contrary to other studies (Huxley 1999, Debela et al. 2015, Mustapha et al. 2012), age did not have a strong influence on perception or knowledge on climate change. Age may however influence opinions on the causes of climate change, biological climate control methods, and tree tenure. Gender, on the other hand, significantly influenced overall farmer climate experience, demonstrating that gender influences knowledge and perceptions on climate change (Asfaw and Admassie 2004, FAO 2011). Similar to findings that determined male farmers generally have more access to climate information than female counterparts, male respondents were found to be more educated at higher levels than females. Although this study did not find a strong linkage between education and perception/knowledge on climate change among male and female farmers, education played a significant role in determining opinions and differences regarding current tree tenure mechanisms and ratings of external/extension help with cocoa farming. It was noted that these differences were mostly between educated and non-educated farmers.

The sensitivity of tree and land tenure was also observed in this study. Migrant farmers (non-natives) offered harsher criticism of existing tree tenure arrangement than natives. This is however not a surprising finding. A lack of property rights among migrant farmers may influence interest in long-term investments (Antwi-Agyei et al. 2015), like tree planting and management in this case. In addition, migrant farmers are more likely than native farmers to engage in cocoa monoculture. Since migrant farmers lack property rights, it heightens their propensity to engage in activities or cocoa farming practices (in this case), that may be detrimental to the environment.

Cocoa Farming for Livelihood and Climate Change Mitigation: Views of Smallholders

This study investigated how farmers felt about incorporating climate change mitigation mechanisms, like REDD+ into their farming activities. As seen in Agyei et al. (2014) and Baruah (2017), the main attribute of climate change mitigation mechanisms is to improve livelihoods and concurrently, enhancement of environmental protection goals. Farmers in general, acknowledged the importance of environmental protection and correctly noted aspects of their farming activities that are detrimental to the environment. Farmers also appreciate the climate ameliorative ability of trees and tree maintenance on their farms. The addition of monetary incentives, however, was marked with skepticism among farmers. Fewer farmers appeared to understand how a system of tree maintenance on their cocoa farms was going to provide them direct income as against one that prescribes maintenance for environmental protection. The only direct mechanism known to farmers is one in which the tree is eventually harvested, and some proceeds are extended to a farm/tree owner (per prescribed benefit sharing arrangements; see MLNR 2016). Such a system clearly navigates away from the goals of REDD+ but seems to be the only plausible explanation, apart from maintaining trees for ecosystem benefits exclusively. Elsewhere in one of the very first REDD+ project sites in the Brazilian Amazon region, farmers' perceptions and eventual participation in the project was significantly improved with a decentralized approach. This approach fostered active farmer participation in the planning phase of REDD+, a move that promoted equity at both the community and individual farmer level regarding information on REDD+. This significantly influenced acceptability and success of the project in the area (West 2016). In essence, this study corroborates the findings of Atangana et al. (2014) which asserted that socio-cultural attributes significantly influence social acceptability of agroforestry systems. For purposes of this study, community heterogeneity and migrant status appear to be the significant factors for the adoption of climate change mitigation mechanisms in cocoa farming. Community heterogeneity in particular has been discovered to have a strong connection with social capital, which is the driving force for improved performance of mainstream developmental initiatives (like REDD+). Specifically, pronounced community heterogeneity may influence social capital (Coffé 2009).

Pathways to Integration of Climate Change Mitigation Mechanisms: The Role of Stakeholders (Extension, Forestry Commission, Farmers' Cooperatives/Community Based Organizations, Civil Society Organizations, Cocoa Buying Companies)

The essential role of agricultural extension has been reported in implementing a Climate-Smart Cocoa (CSC) approach (Asare 2014). The approach recommends broadening the scope of cocoa-related extension efforts to increase and improve the capacity of cocoa farmers (Asare and Kwakye 2014) to adopt environmentally friendly mechanisms which also fulfill socio-economic goals. Within the CSC framework, this study noted that farmers generally held a satisfactory opinion regarding the influence of other stakeholders when it comes to cocoa farming.

Stakeholder influence has mostly been directed towards helping farmers make sound decisions from cocoa cultivation to final cocoa bean sale. The already established cordiality between cocoa farmers and other stakeholders presents an opportunity to disseminate information on climate change mitigation and could also act as a social safeguard for farmers willing to invest time and other resources towards mitigation strategies. An added benefit of such safeguards will see a reduction in costs of implementation and monitoring of climate change mitigation strategies (Chhatre et al. 2012). The active participation of civil society organizations in general has been highlighted as a proponent of REDD+ related activities (Chhatre et al. 2012).

Potential Roadblocks to the Successful Incorporation of Climate Change Mitigation Strategies into Cocoa Production

Climate change related strategies generally prescribe mechanisms aimed at carbon neutrality. REDD+ in particular hinges on specific implementation criteria: (1) simplification of tree tenure and benefit-sharing mechanisms, (2) clear demonstration of the impact of REDD+ in comparison to scenarios without it (additionality), (3) assurance of adherence to REDD+ goals for as long as the project lasts (permanence and risk assessment) and (4) guarantees that REDD+ project sites do not promote carbon release in other areas (leakage) (Asare and Kwakye 2014, Agyei et al. 2014, MLNR 2010). Cocoa farming in general, has had a checkered history when it comes to its association with forests, in fact spearheading massive deforestation since it became a mainstay of the Ghanaian economy (Gockowski 2007, Kolavalli and Vigneri 2011). This study showed that although cocoa farming communities around the KHFR recognize the importance of environmental protection and its relation to climate, their activities, per se, pose potential challenges for the implementation of a full-scale REDD+ project. Illegal logging on cocoa farms has necessitated an historical imperative for farmers to take preventative actions by inducing mortality in trees of economic importance before they reach maturity. Farmers often have several portions of fragmented cocoa farms. It is unclear how to make sure farmers maintain carbon neutrality on other portions of lands, especially in cases where they put only portions of their lands under REDD+. Cultural practices of farmers tend to favor carbon release in cases where cocoa productivity declines significantly due to age or shade. Farmers noted that tree removal was essential in such cases to reduce the level of shading to optimum levels. Undesirable cocoa trees are also removed during shade tree removal. The importance of tree tenure needs to be emphasized. A REDD+ project will need to develop ways to address all these challenges to facilitate full scale implementation and realization of its goals.

We identified a lack of willing participation in programs which provide payments for ecosystem services (PES). The skepticism of farmers on PES could lead to an eventual removal of intrinsic and altruistic characteristics relating to environmental conservation/protection. The motivation behind general environmental stewardship could potentially be reduced to how much can be earned, and becomes even more complicated when you place people receiving payments for ecosystem services in close proximity to those who are not (Kolavalli and Vigneri 2011).

CONCLUSIONS

The novelty of climate change mitigation strategies has been heralded by the international scientific community as a gateway to the implementation of desirable forest governance mechanisms with significant potential to influence the livelihoods of developing economies. This notwithstanding, such mechanisms are prone to several obstacles which could work against implementation. Since the inception of REDD and REDD+ ideologies into scientific platforms in Ghana, several attempts have been made to move beyond pilot projects towards full scale implementation. While these attempts are laudable, this study provides data to support a bottom-up approach to effectively manage the challenges surrounding climate ameliorating strategies in general.

There is reason to recommend a REDD+ strategy that takes into consideration specific community needs. This study revealed that even within the same geographical location, perceptions and knowledge on climate change vary significantly. The cocoa growing mosaic presents an entirely new challenge to the implementation of REDD+. Cocoa has historically driven the economies of communities in these areas and though farmers welcome other livelihood and environment enhancing opportunities, there is skepticism about the potential success and sustainability of such 'new ideas'. As farmers suggested in this study, climate change mitigation efforts need to effectively ensure the participation of farmers in initial project designs. A "think big, but start small" approach has the potential to help formulate community- or location-specific strategies, and acceptance, towards implementation of REDD+. With that in mind, the global community needs to deliberate on measures to implement an adaptable REDD+ program moving away from the strictly national-scaled orientation of strategies. There are several ecological zones in Ghana, each with unique physiography, biological assemblages, and agroforestry capacity. It remains to be determined if a single definition of a forest is equally applicable to all such ecosystems. This study suggests REDD+ and other climate change mitigation strategies may need to adopt a significant degree of flexibility and focus more on the human dimensions aspect, especially in areas where cocoa production is interwoven into general forestry practice. See Table 16 for a summary of major findings of the study.

Table 16. Summary of major findings.

Findings	Implications/Recommendations for Climate Change Mitigation
Farmers' accurately perceive changes in climate (particularly temperature and drought)	Perceptions guide farmers in choosing farming practices.
Farmers' perceptions on precipitation and length may not always be consistent with empirical weather data	It is prudent to accurately inform farmers about climate since this may have implications for environmental protection in general.
Population/community demographics plays a major role in climate perceptibility and subsequent actions to take regarding cocoa farming	Mitigation strategies need to zero in on specific community/population attributes to foster effective implementation.
The concept of payment for ecosystem services; which has been adopted by most climate change mitigation strategies, has not been fully explained	There is a need to adopt strategies that engage farmers in designing climate change mitigation strategies or better still, improve their capacity to understand the concept.
Cocoa farmers share a cordial relationship with extension services and other stakeholders associated with cocoa farming	This presents a practical opportunity to relay information on climate change mitigation strategies to cocoa farmers.
The current situation of illegal logging on cocoa farms may exacerbate carbon release	Pertinent measures are needed to curb illegal logging on cocoa farms.
Cultural practices favor removal of overhead shade to facilitate productivity/yield of cocoa	Strategies need to emphasize practices that favor tree retention on cocoa farms.

AUTHOR CONTRIBUTIONS

Conceptualization, L.K.A. and G.J.E.; Methodology, L.K.A. and G.J.E.; Software, L.K.A.; Validation, L.K.A. and G.J.E.; Formal Analysis, L.K.A.; Investigation, L.K.A., K.L. and G.J.E.; Resources, G.J.E., L.K.A. and G.J.A.-K.; Data Curation, L.K.A. and G.J.E.; Writing—Original Draft Preparation, L.K.A., G.J.E. and K.L.; Writing—Review & Editing, L.K.A., G.J.E., K.L. and G.J.A-K.; Visualization, L.K.A. and G.J.E.; Supervision, G.J.E. and K.L.; Project Administration, L.K.A.; Funding Acquisition, G.J.E. and L.K.A.

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Chapter 4. CONCLUSIONS: STUDY SYNTHESIS

The plethora of studies on cocoa and related industries (i.e. all activities and industries involved from producing cocoa beans to those involved in processing) points to an undeniable conclusion that cocoa farming is and will remain intertwined with forestry in Ghana. The insurgence of full-sun or zero-shade systems on the cocoa landscape may suggest a possible pathway towards a streamlined mono-agricultural system which perhaps directs thoughts towards a cocoa production system that may move away from forest lands. The cocoa tradition of Ghana however will sustain interest in cocoa farming within the cocoa production mosaic and the High Forest Zone. In essence, the ongoing trend of deforestation and land use change associated with cocoa farming remains unchanged with either traditional shade grown cocoa or zero-shade cocoa. The latter however has more dire environmental connotations; a potential to foster widespread tree removal causing deforestation and land degradation. It is therefore essential to study both timber and cocoa industries concurrently to identify pathways toward a healthy coexistence between the two industries.

The idea of coexistence appears to be the logic behind the concept of admitted farms, which officially allowed cocoa farming and other agricultural use of land within gazetted forest reserves in Ghana. Although this has become the bane leading the surge in cocoa production, to the demise of primary and secondary forests, it is, to say it bluntly, cruel, to lay blame on defunct environmental protection institutions and personnel. The ramifications of removing or destroying cocoa farms within that period would have had irreparable social and economic upheavals. This study is built on the premise of the need to study cocoa and forestry along the lines of sustainability; that is, what are some of the options we can make/take to ensure a sustained supply of cocoa/chocolate, forest resources and foster forest/environmental protection without jeopardizing the opportunity for future generations to do the same. The balance of sustainability is also dependent on our ability to effectively maneuver our cocoa and forest landscape to escape the undesirable impacts of globally changing and dynamic climatic patterns. This in itself may present a viable option or pathway towards forest restoration particularly on already degraded lands. There are realistic conceptual models that can direct both cocoa and shade trees in a cyclical way similar to the existing rotational harvesting of trees within compartments/forest management units with the view to making degraded lands available for both cocoa farming and forest restoration.

The main body of this study, Chapters 2 and 3 are structured to combine all the three pillars of sustainability; social, economic and environmental in a coherent way to depict current trends in cocoa farming and forestry in Ghana via an inquiry into cocoa agroforestry. The arrangement in the dissertation does not imply importance but simply a way to enhance readability of a concurrent study. Chapter 2 invokes forest ecology principles and land use change and how it relates to deforestation in a forest/cocoa mosaic; laying more emphasis on environmental and economic aspects of cocoa agroforestry. Chapter 3 delves heavily into the social aspects of cocoa agroforestry. It starts with a description of environmental and economic inquiry to answer questions on how farmers perceive climatic change patterns. It then determines how close their perceptions are compared with empirical climate data and the potential impact of climate change on cocoa farming. Lastly, Chapter 3 evaluates impressions of farmers on the practicability of involving climate mitigation strategies as an alternative income generating opportunity into cocoa farming. Without attempting to replicate conclusions that have already been made in the preceding chapters, the discussion below provides a simplified synthesis of the preceding chapters with the view to showing the linkage between them by structuring the main findings in an orderly list not necessarily followed in the text.

1. **LAND USE CHANGE:** Cocoa farming promotes land use change: there is evidence that most land use change within the Krokosua Hills Forest Reserve and its immediate off-reserve area in Ghana is attributable to cocoa farming.
2. **PLANT COMMUNITY DIFFERENCES:** Adult and juvenile tree species composition differ according to the management status or protection level associated with the current land use. Specifically, adult tree composition shows a tendency toward trees with lesser economic value (Class 2 and 3 species) in more protected areas compared to areas where timber production/harvesting is allowed, and cocoa farming intensity is higher. Natural areas where cocoa is not cultivated tend to have a more diverse species composition (Classes 1, 2 and 3). Timber production areas generally have higher numbers of naturally generated pioneer species than protected and natural areas; a consequence of pronounced forest disturbance.
3. **COCOA FARMING INTENSITY/YIELD**: Off-reserve cocoa farms exhibit higher cocoa management intensity and yield than admitted cocoa farms. Management intensity within admitted farms also differs based on the level of protection ascribed to segregated areas of a reserve area. Cocoa farms in the timber production area are generally more productive than those in the protected areas.
4. **COCOA SYSTEM**: Trends show that zero-shade cocoa is the dominant cocoa system in the area. In 2017, zero-shade cocoa systems in the Krokosua Hills Forest Reserve and the immediate off reserve area had about 20,000ha more land under monoculture compared with cocoa agroforestry.

Research questions/ideas derived after findings in chapter 1:

A. How can farmers be encouraged to revert or keep to traditional shade cocoa systems?

B. Are climate change projects with monetary incentives a feasible option as an alternative income avenue, since other studies have shown the change to zero-shade systems as economically motivated?

C. As a first step, how do cocoa farmers perceive climate change and how much knowledge do they have about its implication for cocoa farming?

5. **FARMERS KNOWLEDGE AND PERCEPTION ON CLIMATE CHANGE**: Farmers acknowledge that climate is changing. Specifically, farmers believe temperature is rising and precipitation levels are falling. Perceptions on precipitation did not conform with empirical weather data. Although farmers' views on causes of climate change and associated local myths on climate change differed among fringe communities, the level of general knowledge on climate change presents an opportunity for climate change projects.

6. **PARTICIPATION IN CLIMATE CHANGE PROGRAMS**: Due to past experiences with so called livelihood enhancing economic opportunities and unclear tree tenure mechanisms in Ghana, in general, cocoa farmers expressed significant skepticism on how potential benefits of climate change projects added to cocoa farming will be disbursed. This notwithstanding, cocoa farmers expressed willingness to participate in climate change projects so far as they are involved in the initial project design.

7. **RECOMMENDATION (Forest restoration pathways through cocoa agroforestry)**

   The study so far has identified cocoa farming as a precursor of deforestation and forest degradation. This argument has been mostly directed at the practice of zero-shade cocoa which entails the removal of overhead tree canopy to facilitate faster growth of cocoa and for that matter, quicker returns on investment. While the practice of traditional shade grown cocoa, on the other hand enhances the retention of trees on cocoa farms, a more substantiated methodology needs to be developed to direct this practice towards restoration of degraded forest lands with a functional theme of satisfying the livelihood attributes/objectives of the cocoa farmer as well as environmental protection goals. Such a system needs to create a realistic mix of silvicultural, ecological, social and agricultural considerations inclined towards forest management and cocoa farming.

Within the aforementioned framework, a drive towards forest restoration in Ghana has been set through the Engaging Local Community Involvement in REDD+ (ELCIR+) and Enhancing Natural Forest and Agroforest Landscapes (ENFAL) projects. These projects and several previous plantation efforts have been geared towards rehabilitation of degraded forests inculcating climate-smart cocoa farming approaches. Such approaches aim towards promoting public awareness of the environmental impacts of zero-shade cocoa, capacity building to improve knowledge of tree tenure and benefit sharing mechanisms (Chapter 3), revealing opportunities for livelihood enhancement through carbon sequestration (Chapter 3), among others. While these efforts are laudable, this study suggests the idea of *TeoTimber* (Chapter 2 and Figure 10), as a recommendation and model targeting the restoration of degraded and cocoa-led deforested forest reserves in Ghana.

TeoTimber is a proposed sustainable cocoa agroforestry system for Ghana. The creation of sustainable forestry systems globally is often in conjunction with well-developed, profitable silviculture systems, although globally sustainable forestry is relatively rare as evidenced by deforestation and land development (Ettl 2010). It is difficult to deny that cocoa production in Ghana is unsustainable as closed forest land leads to degraded land over several decades. *TeoTimber* proposes a complete silviculture system which allows sustainable agroforestry. I first describe the Ghanaian forestry conditions presented to farmers and its role in driving the current degradation pathway. Then I propose alternative transitions "restorative forestry" (Ettl 2010) to return closed canopy forest conditions. Finally, the need for relative proportions of land in each state are described in order to deliver sustainable agroforest management at multiple levels.

The idea of *TeoTimber* originates from the following premises:

I. A fundamental variable essential for cocoa farming is land. The success of cocoa farming in Ghana is largely attributable to the expansion in area under cultivation. Until policies and practice navigate away from this, land availability will continue to be an important factor dictating cocoa-led deforestation.

II. Through the concept of admitted farms, cocoa farms have become a major land use option in forest reserves in the high forest zones and cocoa suitability areas of Ghana.

III. Cocoa rehabilitation as a cultural practice when trees are old and productivity declines (i.e., less than 10 pods per year), is laborious and economically unattractive for most farmers compared with chartering unto new lands entirely to plant cocoa.

IV. Logging, as a silvicultural practice (legal and illegal) presents an opportunity for lands to be utilized for cocoa farming. Logged lands situated in production reserves or areas with ongoing/active tree felling are especially vulnerable (chapter 2).

V. Cocoa farmers are interested in tree planting initiatives and so far as sharing of benefits accruable for tree planting is made clear, verifiable and practical, interest will be sustained.

Major transition scenarios describing the forest degradation and development pathway which is often set in place by the current state of cocoa agroforestry in Ghana.

A. **Closed Forest – Open Forest:** Logging mostly accounts for this transition and may either be legal or illegal. As described in chapter 1, closed forest represent vegetation cover of a minimum 1m mapping unit with no less than 60% overhead tree canopy cover well-structured into 3 vertical layers (upper, middle and ground) having a minimum height of 5m. Such intact or less disturbed forest areas are mostly located within forest reserves and in some cases, off-reserve areas. Open forests are characteristically more disturbed forest lands having canopy cover between ranges of 15% - 60%. Thus silvicultural treatments in some cases may promote significant canopy removal and subsequently, a change to open forest lands. Forest openings can spearhead deforestation in cases where there are no specific plans to enhance regeneration. On the other hand, silvicultural treatments can be used to aid the transition back to closed forests. When conditions are favorable (i.e. natural regeneration), an abandoned open forest will slowly regain canopy closure. This may be applicable to protected areas of the reserve where tree species diversity can be improved with assisted natural regeneration, where naturally occurring tree regeneration is protected and managed to ensure survival. For the timber production zones, a bigger effort is needed to purposefully select and plant trees with high commercial value. Either options will need to establish clear rehabilitation objectives to foster and gauge interest before implementation.

B. **Open Forest – Cocoa AFS:** Cocoa agroforests thrive on the usage of forest canopy openings. Such openings, particularly in cases where logging/silvicultural prescriptions are not adhered to (illegal logging) could create deforested patches/gaps in forest cover. These offer opportunities for lands to be utilized for the purposes of agroforestry and Modified Taungya. An abandoned shade grown cocoa system, upon effective tree regeneration, can return to an open forest.

Ghana currently uses a 40-year rotational cycle for tree felling/ timber production (i.e., timber production) in compartmentalized production and reserved areas. *TeoTimber* envisions a system of cocoa production that directs cocoa planting/cultivation and tree planting be done in tandem. This system can strategically rotate farmers and timber harvesters such that final harvests of cocoa are made before maturity and harvesting of trees. In the process of tree harvest, loggers will be mandated to remove cocoa trees as well. Annual incentives/payments can be made to farmers for maintaining tree cover. Ultimately, a bonus structure can be implemented to reward farmers with high value timber on their cocoa farms at tree rotation. The Forestry Commission will maintain all supervisory activities from cultivation of both trees and cocoa until final harvest. The system can target already degraded and degrading portions of a forest reserve as pilots.

C. **Cocoa AFS – Zero Shade Cocoa:** The traditional method of planting cocoa under tree shade is aggressively being replaced by cocoa cultivation systems that require no shade (zero-shade). This involves clearing/removal of trees (deforestation) and symbolizes an intensified cocoa production effort which primarily focuses on maximum returns within the shortest possible time. Admitted farms which are purported to be a mix of shade trees and cocoa (cocoa agroforestry) are the immediate candidates providing available lands for conversion to zero-shade cocoa. Longevity and long-term productivity associated with shade grown cocoa could also serve as a motivation to shift farmer preference compared to zero-shade cocoa systems, which despite recording quicker maturity periods, do not live very long.

D. **Zero-Shade Cocoa – Agriculture:** A transition from zero-shade to agriculture or vice versa could be spearheaded by shifts in farmer preferences towards monoculture systems which may be dictated by market trends like the characteristic boom/bust cycles of cocoa in Ghana.

E. **Agriculture – Open Forest:** Depending on the scale of forest disturbances like fire and illegal logging, open forests can transition to lands that are easily utilized for growing annual crops. Agroforestry and other similar systems like Modified Taungya are possible options for restoring such lands back into open forests.

F. **Agriculture – Cocoa AFS:** A combination of ageing cocoa trees, illegal logging (deforestation) on cocoa farms which mostly results in destruction of cocoa trees during the process of logging could shift farmer preference from cocoa to cultivation of annuals. Agriculture lands could also be planted with shade trees and cocoa as a silvicultural technique towards forested lands via cocoa agroforestry.

Other considerations for transitions

Observations made in this study indicate that it is possible to witness a full cycle of all land use transitions within a period of 50 years. This does not account for the transition from open forest to closed forest, which can take several decades and even centuries to fully restore previous habitat conditions. The reverse of these transitions may also take very different time trajectories. Hypothetically, it may take about 10 years to move from open forests to Cocoa AFS (B). The transition from Cocoa AFS to Zero-Shade (C) may take about 5 years considering scenarios where cocoa and shade trees are removed from the land. Zero-Shade systems are normally interplanted with some annual crops and could hasten a transition to Agriculture (D) if conditions are favorable within a minimum of 2 years. A transition from Agriculture to Open Forests (E) will most likely require at least 30 years to happen from the period of tree planting till trees attain economically harvestable sizes. An intermediate transition between Cocoa AFS to Agriculture (F) may require about 3 years due to the time needed to remove shade provided by both trees and cocoa.

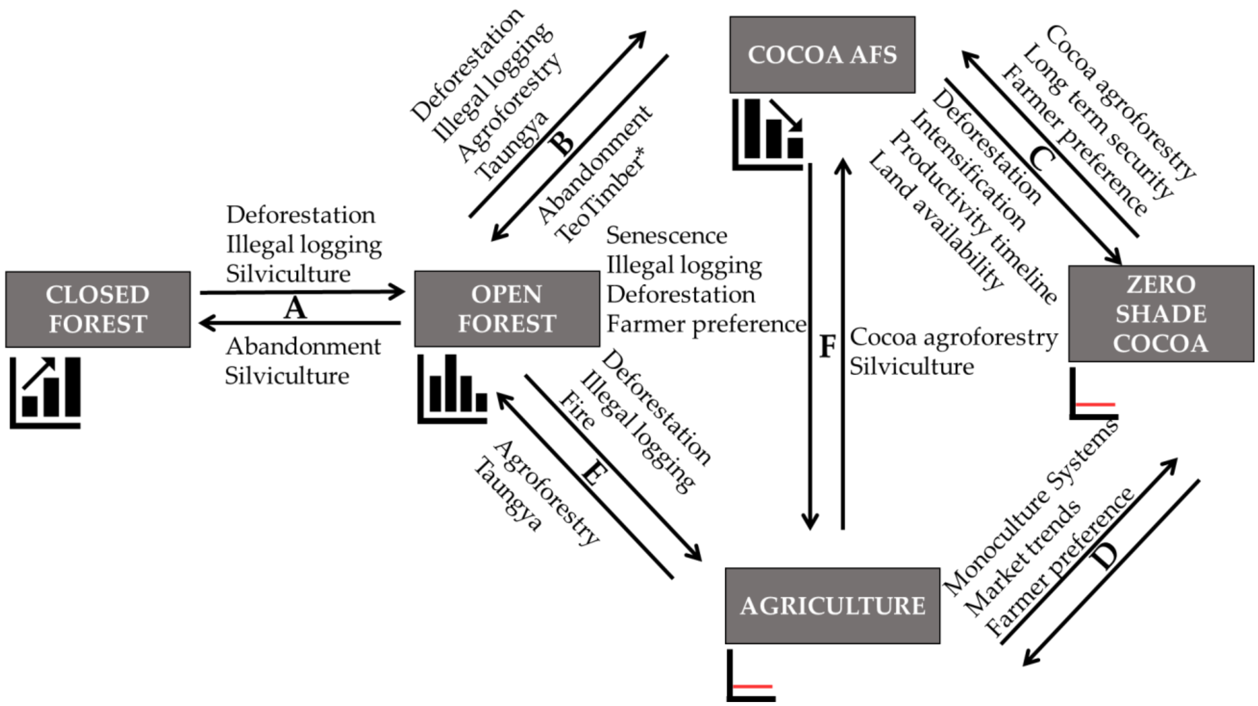

Figure 10. Characteristic transitions of land use types in the study area. Bar graphs on the left depicts hypothesized trends in adult and juvenile tree species diversity. Red lines indicate zero or significantly low tree diversity. *TeoTimber* (*Theobroma cacao* + Timber production) is a model/ concept of incorporating rotational/cyclical timber harvesting in tandem (delayed) with rehabilitating old cocoa farms/trees. The concept envisions a scenario to restore degraded forest lands by planting cocoa ahead of timber tree species and making sure tree removal (selection harvesting) and old cocoa tree removal (timber harvesting) coincide. The idea draws its foundation from the Modified Taungya System (MTS); a system of leasing degraded land to farmers to practice agroforestry and incentivizing farmers through attractive benefit sharing schemes to leave the lands once tree canopy closure is realized (Agyeman et al. 2003). AFS refers to Agroforestry Systems. Zero-shade cocoa is a relatively new system of producing new and improved varieties of cocoa (hybrid cocoa) in monoculture systems (Ruf 2011). A, B, C, D, E and F are used to symbolize the transitions for easy reference. (Figure inspired by Gerstner at al. 2014).

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APPENDIX 1: SURVEY LETTER AND THEMATIC SNAPSHOT OF SURVEY QUESTIONS

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Thank you for agreeing to respond to this survey about how cocoa farmers with small land holdings (small-holders) in Ghana perceive the inclusion of climate change focused projects into their farming activities.

This study forms part of a PhD dissertation at the University of Washington in Seattle. It is intended to investigate the feasibility of climate change projects in cocoa farming towards the goal of helping improve livelihoods of small-holder cocoa farmers in Ghana. We hope the results will incentivize policy makers to include cocoa agroforests into nationwide climate change projects.

Please note that there are no right or wrong answers to this survey. All information is purely for academic purposes and will therefore be accorded the necessary confidentiality.

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COCOA FARMERS VIEWS ON EXISTING PRODUCTION SYSTEMS AND CARBON MANAGEMENT OBJECTIVES

1. Knowledge on climate change

1. Over the past 10 cropping seasons (2007 - 2016), how much did the following environmental parameters change? (If respondent chooses any response option apart from "don't know", proceed with remaining questions).

	Increased	Stayed about the same	Decreased	Don't know
Temperature	◯	◯	◯	◯
Rainfall	◯	◯	◯	◯
Length of the wet season (rains)	◯	◯	◯	◯
Length of the dry season (harmattan)	◯	◯	◯	◯
Other environmental parameters/observation (Please specify)	◯	◯	◯	◯

2. Based on your answer in question 1, the impact on yield from cocoa production has been ...

◯ Positive (Increasing yield)

◯ No impact (Yield has remained same)

◯ Negative (Decreasing yield)

◯ Not sure

COCOA FARMERS VIEWS ON EXISTING PRODUCTION SYSTEMS AND CARBON MANAGEMENT OBJECTIVES

2. Perception of carbon projects

The obvious difficulty in explaining what carbon or more precisely, what a carbon based project is to the rural and lowly educated (in most cases) cocoa farmer demands a well planned way of explaining carbon.

13. What is the title status of the land you are currently farming on? (Kindly check all that apply if respondent has multiple lands with different ownership status).

- ◯ Owner/ Outright purchase
- ◯ Joint Ownership
- ◯ Rent/Lease
- ◯ Inheritance
- ◯ Other (Please specify)

14. What variety of cocoa do you grow on your farm? (Kindly check all that apply)

- ◯ Full-sun
- ◯ Shade varieties
- ◯ Both
- ◯ Hybrid (Full-sun/Shade)
- ◯ Other (Please specify)

COCOA FARMERS VIEWS ON EXISTING PRODUCTION SYSTEMS AND CARBON MANAGEMENT OBJECTIVES

3. Roles of local and external stakeholders.

Stakeholders here refers to Extension Agents, Forestry Commission, Environmental Protection Agency, Farmers' Cooperatives/Community Based Organizations, Civil Society Organizations, Private Cocoa Buying Agencies and other governmental bodies.

20. Overall, how do you rate the help of other stakeholders on cocoa farming in your community?

- ◯ Very satisfied
- ◯ Satisfied
- ◯ Neither
- ◯ Dissatisfied
- ◯ Very dissatisfied

21. Kindly explain the reason(s) for your response to question 20?

22. I will feel more comfortable with a climate change (carbon) project if other stakeholders (Kindly check all that apply).

- ◯ Visit my community often
- ◯ Provide more information on carbon projects including related benefits
- ◯ Provide more details on the sustainability of the benefits from carbon projects
- ◯ Provide more farming incentives
- ◯ Other (Please specify)

23. Are you a member of any farmer cooperative?

- ◯ Yes
- ◯ No

COCOA FARMERS VIEWS ON EXISTING PRODUCTION SYSTEMS AND CARBON MANAGEMENT OBJECTIVES

4. Potential Setbacks to carbon projects

29. How many farms/tracts/plots of land do you cultivate cocoa on?

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ >5 (Please provide specific number)

30. What is the size/area of your farm(s)? (Use check boxes to indicate the number of farms in individual categories, if applicable - Kindly note the unit in which the quantity of land is measured locally)

Less than or equal to 1 acre

Greater than 1 acre but less than 3 acres

Greater than 3 acres but less than 5 acres

Greater than 5 acres (Please specify number is respondent knows)

31. How many age cohorts of cocoa stands do you have on your farm? (Use multiple options if applicable)

1

2 - 5

6 - 10

11 - 15

Greater than 15

32. Kindly specify the age(s) of your cocoa stands. (Add more options if applicable)

Farm 1

Farm 2

Farm 3

Farm 4

COCOA FARMERS VIEWS ON EXISTING PRODUCTION SYSTEMS AND CARBON MANAGEMENT OBJECTIVES

5. Demographic data

36. Name of community

37. Respondent age

- Less than 18
- 18 - 29
- 30 - 44
- 45 - 59
- Over 60

38. Gender of respondent

- Male
- Female

39. Educational status

- Basic
- Secondary
- Tertiary
- No formal education
- Other (Please specify)

40. Marital status

- Married
- Single
- Divorced
- Widowed

APPENDIX 2: RECOMMENDATIONS FOR FARMERS

Striking a balance between cocoa farming and Forestry in the Krokosua Hills Forest Reserve

Have you witnessed any of the following?

- Disappearance of forest lands.
- Scarcity in occurrence of some specific timber trees.
- Increase in number of admitted cocoa farms.
- Changes in weather patterns.
- Interest in planting cocoa without tree shade.

Forest Lands

1. Request recent tree tenure arrangements from the Forest Commission.
2. Determine an estimate of the number and sizes of your cocoa farm(s) and ensure that your admitted cocoa farm within the forest reserve is registered.
3. Maintain/plant/protect trees on your cocoa farm. Consult with cocoa extension agents and Forestry Commission personnel on tree species to plant.
4. Report any illegal timber harvesting activities on your cocoa farm and anywhere within the forest reserve to forest guards or Forestry Commission personnel.

Cocoa under no shade or cocoa under shade - Points to note/ recommendations:

1. Cocoa under no shade (zero-shade cocoa) grows faster.
2. Zero-shade cocoa stop producing cocoa pods sooner.
3. Zero-shade cocoa promotes removal of trees.
4. Zero-shade cocoa requires more farm inputs such as fertilizers and pesticides.
5. Shade cocoa grows much slower compared to full-sun cocoa.
6. Shade cocoa encourages protection of trees.

7. Shade cocoa trees live longer and continue to produce pods even when trees are old.
8. Shade cocoa requires less inputs compared with full-sun cocoa.
9. Shade cocoa provides stable yields in unfavorable weather (e.g. drought) compared with zero-shade.
10. Shade cocoa provides more opportunities for alternative income.

Weather patterns

1. Request for weather forecast information from cocoa extension personnel.
2. Solicit information from cocoa extension personnel on impacts of weather forecasts on cocoa farming (i.e. risks).
3. Request for cocoa planting materials that are tolerant of weather patterns.
4. Request for available farming incentives provided in relation to weather predictions.
5. Request for information on projects focused on weather mitigation and consider participating in them.
6. Report observations on cocoa farms attributable to weather conditions.

Other general recommendations for cocoa farmers

1. With the help of cocoa extension personnel, determine correct age of cocoa trees on your farm and follow management recommendations/prescriptions associated with tree age.
2. Explore more information on cocoa certification and the benefits associated with it.
3. Consult with extension personnel on tree species that are desirable (or undesirable) for cocoa agroforestry.
4. Inquire about opportunities for rehabilitating old cocoa farms/trees within the forest reserve.
5. Participate in stakeholder meetings.

SEFS: Stewarding environments through field-based, hands-on learning and research.

Striking a balance between cocoa farming and Forestry in the Krokosua Hills Forest Reserve

Introduction

Background of Study

In Ghana, cocoa farming is a major livelihood activity for many farmers living in the forested zones. Ghana is the second largest producer of cocoa in the world and this reflects in the contribution it makes to the national economy. In Ghana, most forest lands are also ideal for cocoa farming. Since cocoa needs shade to grow and produce well, planting of cocoa under tree shade has become a traditional practice/system. However, new knowledge on cocoa farming has revealed that cocoa trees can grow without shade and may even produce pods sooner than in the traditional tree shade cocoa system. While this may be the case, cocoa trees exposed to direct sunlight do not experience the longevity and long-term productivity of cocoa planted under tree shade. More importantly, cocoa planted under direct sunlight promotes deforestation particularly in areas where cocoa farming is done in forest reserves.

This study observed cocoa farming in the Krokosua Hills Forest Reserve from 2000 to 2017 using satellite images. Since the Forest reserve has been divided into two management zones; a protected side where timber harvesting is prohibited and another that permits timber harvesting, the study compared cocoa farms and types of trees in these areas as well as the off-reserve areas immediately bordering the forest reserve. Another aspect of the study determined how farmers' views of weather patterns (rainfall and temperature) compares/conforms with official weather data. Since cocoa productivity is associated with weather, this study investigated the views of cocoa farmers on the potential impacts of weather patterns on cocoa and their level of interest in participating in programs/projects that seek to reduce vulnerability to changing weather patterns as well as improving livelihoods.

Objectives

The main goal of this handout is to report research findings to cocoa farmers and interested community members. The research findings, together with knowledge from previous knowledge and information about cocoa farming in the area is then used as a basis to develop potential best practices for cocoa farming.

Summary of Findings

Which cocoa system is the most used in the area?

The study found that cocoa farmers cultivate more cocoa under no tree shade compared with the traditional system of planting cocoa under tree shade. Within the forest reserve, there is more land under no shade cocoa systems than traditional shade grown cocoa. The off-reserve area also showed the same pattern.

Does management zones of the forest reserve influence amount of land used for cocoa farming?

Yes. Zones that permit timber harvesting had more land planted with cocoa than the protected zones. For cocoa production, the same trend was observed.

Are there any differences in the types of trees found on cocoa farms in the different management zones?

Yes. Cocoa farms in zones that permit timber harvesting have more expensive timber trees than the protected zones.

Are perceptions of farmers on weather patterns consistent with weather data?

Yes and no. Farmers knowledge on weather patterns does not always conform with weather data.

Are cocoa farmers concerned about recent weather trends and the potential impact(s) on cocoa farming?

Yes. Farmers have observed that the amount of rainfall is decreasing whiles temperature is increasing. The duration of the dry season is also increasing whereas the rainy seasons are shortening. These patterns are already affecting cocoa productivity in the area.

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This handout and the information reported in it forms part of recommendations made by the author in his dissertation titled, "Biodiversity, Carbon and Chocolate: Toward an Environmentally Friendly Cocoa Production System in Ghana". The author is a doctoral student at the School of Environmental and Forest Sciences, University of Washington, Seattle, United States.

Striking a balance between cocoa farming and Forestry in the Krokosua Hills Forest Reserve

Summary of Findings

Are cocoa farmers interested in projects aimed at reducing vulnerability to changing weather patterns?

Yes. Farmers showed that they are interested in such projects so far as profit sharing mechanisms are well explained to them and they are treated as partners throughout the lifespan of the project.

Recommendations

Cocoa System

1. Educational efforts should be made to enlighten farmers on the environmental impacts of zero-shade cocoa systems.
2. The long-term financial implications and longevity of cocoa under no shade should be emphasized.
3. Previous studies have shown that cocoa under no shade have maximum productivity between 10 – 20 years whereas that for shade grown cocoa is 40 – 60 years.

Forest Management Regimes

1. Fringe communities need to be educated on the regimes implemented for forest protection and the need for strict adherence. The concept of protection primarily for areas of interest should be deemphasized and rather encouraged for entire contiguous forested landscapes (especially forest reserves).
2. Cocoa farmers within the forest reserve need to be incentivized to adopt stewardship roles in forest monitoring and serve as whistleblowers for reporting illegal activities in the forest reserve.
3. Off-reserve areas are important forested areas and efforts need to be made with stool lands to bestow a significant level of environmental consideration to prevent encroachment on forest reserve lands.
4. Laws on forest encroachment for croplands, including cocoa farming and illegal tree harvesting need to be enforced.

Tree Regeneration Efforts

1. Cocoa farmers should be encouraged to promote plant diversity in their regeneration efforts on cocoa farms. Diversity metrics can be developed and utilized for on-farm diversity as a tool for provision of incentives.
2. Regeneration surveys should be included in annual stock survey efforts to inform regeneration and planting efforts.

Information on Weather patterns

1. Community level info sessions on trends in weather can be used to inform cocoa farmers/community members to help remove misconceptions associated with weather patterns/trends.

Environmental Protection Projects

1. Community level info sessions on trends in weather can be used to inform cocoa farmers/community members to help remove misconceptions associated with weather patterns/trends.
2. A bottom-up approach needs to be utilized in developing projects to involve community members and farmers in the initial stages of project development to foster a sense of stakeholdership in the entire project process.
3. Significant efforts must be made to explain clearly, benefit sharing mechanisms to provide a form of security for farmers who want to participate.
4. Projects should be designed to emphasize community level objectives and not nationally scoped to account for differences in communities which may arise due to ecological differences in plant/tree assemblages and more importantly, social and cultural attributes of communities.

This handout and the information reported in it forms part of recommendations made by the author in his dissertation titled, "Biodiversity, Carbon and Chocolate: Toward an Environmentally Friendly Cocoa Production System in Ghana". The author is a doctoral student at the School of Environmental and Forest Sciences, University of Washington, Seattle, United States.

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VITA

Lord Kwakye Ameyaw holds a Bachelor of Science Degree in Agriculture Technology from the University for Development Studies, Ghana. He earned a Master of Science Degree in Rural Sociology from Auburn University, United States (US). Lord is currently in his final quarter as a Doctoral Candidate in Environmental and Forest Sciences at the University of Washington (UW), Seattle. He concurrently serves as the National Technical Assistance Agroforester for the United States Department of Agriculture's Natural Resources Conservation Service (USDA – NRCS), a position held in collaboration with the United States Forest Service's (USFS) National Agroforestry Center (NAC), Nebraska Forest Service and the University of Nebraska-Lincoln (UNL). Prior to that, he worked as a Forester and Forest Ecologist with the Center for Sustainable Forestry at Pack Forest (UW) and Cedar River Watershed (City of Seattle), respectively. In the last 10 years, Lord has also served as an Instructor in Natural Resource Measurements at the School of Environmental and Forest Sciences (UW), Research Consultant for Twin and Twin Trading Limited (United Kingdom and Liberia), Research Assistant (Auburn University) and Assistant District Manager (Forestry Commission, Ghana). Lord's scholarly work involves the interface between Natural Resource Management and the Social Dimensions, for which he has participated in different projects in Southern US, the Pacific Northwest and his home country Ghana, always highlighting the potential of Agroforestry as an alternative for Sustainable Development.