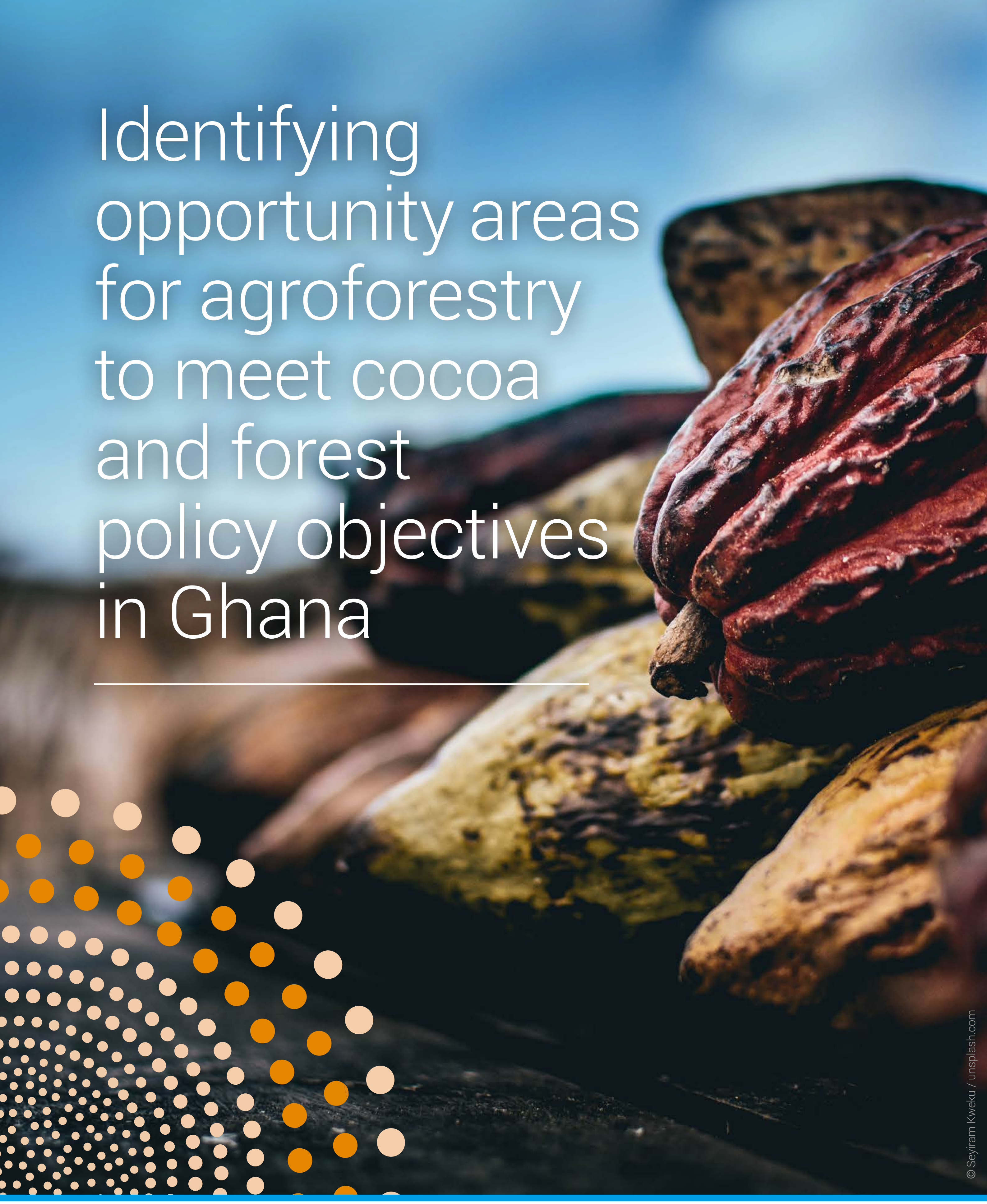
Identifying opportunity areas for agroforestry to meet cocoa and forest policy objectives in Ghana



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Identifying opportunity areas for cocoa agroforestry in Ghana to meet policy objectives

ISBN: 978-92-807-3986-2

Job Number: DEP/2484/CA

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Suggested citation: United Nations Environment Programme (2022). Identifying opportunity areas for cocoa agroforestry in Ghana to meet policy objectives. UNEP World Conservation Monitoring Centre. Cambridge UK.

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Acknowledgements: we thank Samantha Hill (UNEP-WCMC) for methodological inputs, Neil Burgess, Lera Miles, and Matt Kaplan (UNEP-WCMC) for internal reviews, Vaughn Lewis and Kollie Tokpah from (UNEP-WCMC) for help with data and Richard Asare (IITA) for external review.

This work was funded by the Norwegian Agency for Development Cooperation (NORAD) through the CocoaSoils project (RAF-17/0009 – CocoaSoils), with additional support from the United Kingdom Research and Innovation's Global Challenges Research Fund under the Trade, Development and the Environment Hub project (ES/S008160/1).

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Key messages

- Cocoa is a major contributor to Ghana's economy and the livelihoods of millions of smallholder farmers. However, cocoa is also a major driver of forest loss in the country's High Forest Zone, including in Forest Reserves.

- The promotion of agroforestry in cocoa is an important element of national level policies such as the Cocoa and Forests Implementation plan, the Ghana Cocoa Forest REDD+ Programme (GCFRP) and the National Climate-Smart Agriculture and Food Security Action Plan

- This report maps several scenarios for agroforestry development in Ghana, which can serve as an input to spatial planning seeking to prioritise interventions to achieve multiple objectives such as sustainable cocoa production, carbon sequestration and biodiversity conservation.

- This study finds that there are opportunities to increase tree coverage across almost 2 million hectares of low-shade cocoa growing lands in Ghana.

- Should low shade/monoculture approaches be adopted across the country this could result in a loss of almost 6.5M tC compared to the current aboveground carbon stocks in cocoa growing areas. On the other hand, implementing national climate smart cocoa recommendations together with forest reserve restoration could yield a potential carbon stock increase of up to 52M tC.

- Areas close to reserved forests and/or close to settlements should be prioritised for the promotion of more highly shaded agroforestry systems, due to the benefits this may provide in connecting habitats and delivering ecosystem services to local communities. Financial or other incentives for farmers are likely required to balance potential trade-offs with production.

- Areas that are expected to remain or become suitable for cocoa production under climate change (middle lower cocoa belt) should be prioritised for cocoa productivity, with shade of at least 30-40% and management practices which enhance resilience and sustainability.

- Implementing agroforestry following spatially explicit climate-smart recommendations in cocoa landscapes can yield multiple benefits for people, nature and climate through the improved delivery of ecosystem services and habitat for biodiversity, though benefits will vary according to local contexts. Measures or safeguards should be put in place to ensure that women and men benefit equally.

- More evidence is needed on how to best implement (highly) shaded cocoa systems locally, in terms of species, spatial arrangement, their costs and benefits, and effects on farmer and farm household wellbeing and resilience in different agroclimatic and socio-economic contexts.

- Finally, spatial analysis can be used to inform the prioritisation and implementation of agroforestry promoting efforts within cocoa cultivation areas, that seek to enhance resilience to climate change, while also providing additional benefits such as carbon sequestration and biodiversity conservation.

Executive Summary

Ghana is one of the world's leading cocoa producers. Between 1994 and 2018, the area under cocoa production has nearly tripled. This has increased income, but it has also imposed costs. As rainforests have been converted into land for cocoa farming, habitat for species has decreased and become increasingly fragmented in one of the world's biodiversity hotspots. Rainforest loss also has huge implications for the ability of land to capture carbon and mitigate climate change globally. Expansion of cocoa farming is expected to aggravate these issues further.

Quality not quantity

To increase income from cocoa, Ghana could expand cocoa plantations but increasing yields on the plantations that it already has would be better for both farmers and the environment. Cocoa yields in Ghana are low and the prices that the crop gets on the global market are poor. This is because most plantations in Ghana are small and run by farmers who often lack the right knowledge, resources and credit to apply management practices, like pruning, pest control and managing soil fertility, that would help them to increase the quality and size of their yields. Climate change is also expected to make lives harder and put the cocoa supply chain at risk by making yields lower than they already are. Agroforestry farming systems are increasingly being proposed as a solution to address these problems and a potential way for the small-holder cocoa farmers of Ghana to improve their livelihoods and for the cocoa sector to maintain a sustainable cocoa supply.

Cocoa can be grown in direct sunlight or under shade provided by taller trees. Farmers in Ghana have been advised over the years that shade would harm their cocoa production, but evidence shows that well-managed shade can also benefit it. Shade trees suppress weed growth and provide habitats for predatory species that control insect pests. Growing cocoa under shade trees also helps to create a stable microclimate beneath the canopy. It can also enhance soil fertility and provide farmers with supplemental income when these other trees produce commercially valuable fruits and timber. Most importantly, well-shaded cocoa plantations will experience lower maximum temperatures than are expected from climate change, can store up to 2.5 times more carbon than those that are unshaded and support higher levels of biodiversity that help protect valuable ecosystem services.

The types and magnitude of benefits from agroforestry systems for different beneficiaries depend highly on their design and the local context. Shade trees can harbour pests. They can also compete with cocoa for resources like water. This is particularly true in drier areas. High humidity levels under canopies created by other plant species can also foster fungal diseases. These challenges are not to be ignored but, when agroforestry systems are well designed, they are outweighed by the overall benefits in smallholder production systems. Indeed, Ghana is now promoting cocoa agroforestry through national level policies such as the Cocoa and Forests Implementation plan, the Ghana Cocoa Forest REDD+ Programme (GCFRP) and the National Climate-Smart Agriculture and Food Security Action Plan.

Prioritising action

It is not realistic to establish shaded plantations throughout the southwestern regions of Ghana all at once. The process will need to be staged as there are 2.3 million hectares of plantations and 1.9 million of them currently have little to no shade. Areas where benefits from increased shading will be highest need to be identified and prioritised.

This new work looked at the locations of all cocoa plantations in the country and applied cocoa and forest national policy objectives as well as spatially explicit climate change adaptation strategies to implement a transition towards more shaded cocoa farming. Using modelling approaches, the work sought to understand the biodiversity, carbon sequestration and erosion control benefits granted by increased shading being implemented in different locations. Combined, this information generated a map that reveals the areas where the implementation of shading would be most beneficial for achieving a combination of benefits for people, nature and climate.

Long term gains

The work shows that establishing appropriately shaded and well-managed plantations in the proposed areas has the potential to protect at least 4,000 tonnes of sediment from erosion each year and store an additional 52 million tonnes of carbon in trees. While shifting to this sort of farming will have some implementation costs and not yield the immediate financial gains that would be expected from more forests being converted into plantations, such a transition can yield significant long-term benefits as smallholder farmers face the challenges presented by a changing climate. When implemented appropriately, it will also enhance ecosystem services that benefit cocoa production, conserve biodiversity and support the livelihoods of farmers. Above and beyond all else, the carbon sequestration benefits granted by shaded plantations have the potential to play a pivotal part in combating climate change. For this to be fully realised, farmers need to be incentivised to adopt agroforestry practices by giving them ownership of the land that they are farming and the trees that grow there. Paying them for the ecosystem services that their land provides would further these incentives by strengthening and diversifying their income too. Beyond the specific situation faced by cocoa farmers in Ghana, this study demonstrates the potential for decision-makers to use spatial planning to understand where, and (partly) how, to implement cocoa agroforestry at scale to meet different objectives.

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List of acronyms

BII	Biodiversity Intactness Index
CFI	Cocoa and Forests Initiative
COCOBOD	Ghana Cocoa Board
CSSV	Cocoa Swollen Shoot Virus
FAO	Food and Agriculture Organization of the United Nations
GCFRP	Ghana Cocoa Forest REDD+ Programme
IDH	Sustainable Trade Initiative
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
REDD+	Reducing Emissions from Deforestation and Degradation
SDGs	Sustainable Development Goals
SDR	Sediment Delivery Ratio
UNEP	United Nations Environment Programme
USLE	Universal Soil Loss Equation
WCF	World Cocoa Foundation

1. Introduction

1.1 Background

The West African Upper Guinean Forest is a global biodiversity hotspot (Myers *et al*. 2000; Poorter *et al*. 2004) that supports crucial global and local ecosystem services, such as carbon sequestration and local benefits such as wild foods, fuelwood, and other resources that local communities depend on for subsistence and income (Darwall *et al*. 2015). In countries such as Ghana and Côte d'Ivoire dense forests only remain in small, protected pockets, whilst degraded forests outside these areas progressively disappear to make way for farming and other uses (Comité Permanent Inter-états de Lutte contre la Sécheresse dans le Sahel [CILSS] 2016).

Ghana is one of the world's leading cocoa producers, second to neighbouring Côte d'Ivoire, producing an average of 0.88 million tonnes of cocoa per year and generating $2 billion in foreign exchange annually (Wessel and Quist-Wessel 2015; Vigneri and Kolavall 2018; Konger *et al*. 2018; African Development Bank [AfDB] 2020). Though current exact figures are lacking there are likely more than 800 thousand cocoa farmers in Ghana (Hütz-Adams *et al*. 2016), mainly concentrated in the western part of the country, indirectly supporting more than 3 million households (Fairtrade Foundation, no date).

Despite the economic importance of the commodity crop, cocoa production and expansion have been directly and indirectly linked to high levels of deforestation in West Africa, with estimates suggesting 2.3 million hectares of forest were lost to cocoa cultivation between 1998 and 2007 (Gockowski and Sonwa 2011; Mighty Earth 2017). Protected reserve forests in Ghana have been no exception (Asare *et al*. 2014), as exemplified by the seven-fold increase in deforestation within three reserves in the High Forest Zone of Ghana in the period 2010-2019, compared to 2001-2010. Key drivers of this encroachment include agricultural expansion (particularly cocoa), population increases, illegal logging, extraction of wood for fuelwood and mining activities (Tropenbos Ghana 2019). Nationally, 72% of all protected areas contain cocoa plantations, affecting 14.5% of their total area (Abu *et al*. 2021).

The negative social and environmental impacts associated with tropical forest loss are increasingly apparent, particularly the links between deforestation, climate change and biodiversity loss (Carodenuto 2019). Forest loss can result in reduced water quality, increased soil erosion, negative impacts on local climate regulation, reduced access to timber and non-timber forest products, and loss of habitat for biodiversity conservation. Pressure is mounting on commodity traders and retailers to commit to zero-deforestation policies and to improve the sustainability of their supply chains.

Within the Ghanaian cocoa sector, efforts to implement deforestation-free supply chains have increased, particularly from traders (such as Barry Callebaut and Cargill) and retailers for mass markets (such as Mars and Hershey's) through the Cocoa and Forest Initiative (CFI) led by the World Cocoa Foundation (WCF) and the Sustainable Trade Initiative (IDH). These industry actors also increasingly recognise the importance of working with the government to achieve their commitments. In fact, zero-deforestation commitments by the private sector could in turn support national policies on reducing deforestation and restoring forest cover, including the achievement of national REDD+ strategies, landscape restoration and the Sustainable Development Goals (SDGs) (Carodenuto 2019). Though there may also be trade-offs between and among private and public sector policies, for example where cocoa productivity increases are supported to reduce pressure on forests, without protecting forest from agricultural expansion; or where private sector focus is put solely on forest and tree cover for carbon storage and sequestration with limited focus on the habitat and local ecosystem services values of forests encompassed by public policy.

Cocoa production in Ghana

Cocoa production in Ghana is estimated to have tripled from 300,000 tonnes in 1995 to 900,000 tonnes per year in 2014 (Wessel and Quist-Wessel 2015) with peaks of over 1 million tonnes in the 2010/2011 and 2020/2021 seasons (African Press Agency [APA] News 2021). This rise in production is attributed to support through the government-owned cocoa marketing board, COCOBOD, established in 1947. This has included increases in farm gate prices, the introduction of pest and disease control programmes, hybrid seeds, fertilisers, insecticides, fungicides, and improved marketing and infrastructure in cocoa growing areas (Asante-Poku and Angelucci 2013). However, this increased production has mainly been due to a near tripling of harvested area to nearly 1.8 million ha between 1994 and 2018, resulting in large scale deforestation (Wessel and Quist-Wessel 2015; Food and Agriculture Organization of the United Nations [FAO] 2020).

Cocoa in West Africa is primarily grown on smallholder farms, of approximately 2 ha or less (Hainmueller *et al*. 2011). Many cocoa farmers are extremely poor, with almost half earning an average income lower than the World Bank extreme poverty line and the majority not earning a Living Income, with women-headed households significantly less likely to achieve a Living Income (Bymolt *et al*. 2018; van Vliet *et al*. 2021). Furthermore, farmers often lack the right knowledge, resources and credit to invest in practices which maintain and improve cocoa production on their farms (Namirembe *et al*. 2015).

Approximately 20% of cocoa farms are headed by women. On male-headed farms, women contribute around 45% of the labour input to cocoa production, including post-harvest activities. Yet, women cocoa farmers tend to have less access to land, the income from cocoa, extension services and other forms of support such as credit and loans (Bymolt *et al*. 2018).

The average cocoa yield in Ghana is estimated at a low 400 kg/ha, though it has the potential to reach much higher values (1,500-2,000 kg/ha) (Aneani and Ofori-Frimpong 2013). In comparison, the average cocoa yield in Malaysia is estimated to be 1,800 kg/ha, followed by 1,000 kg/ha in Indonesia and 800 kg/ha in Côte d'Ivoire (Laven and Boomsma 2012; Wessel and Quist-Wessel 2015). Despite the introduction of high-yielding Amazon hybrids, inadequate management and input use, and ageing cocoa trees have resulted in the average Ghanaian yield remaining low (Wessel and Quist-Wessel 2015). Furthermore, high-intensity systems often require high levels of pesticide use, linked to water and soil pollution as well as adverse effects on human health (Wainaina *et al*. 2021).

Pressure from disease is also affecting cocoa productivity. The two major diseases reported in Ghana are Black pod disease (or Phytophthora Pod Rot) and the cocoa swollen shoot virus (CSSV), with black pod being the dominant cause of disease related losses. According to COCOBOD (2014, cited in Akrofi *et al*. 2015), Ghana lost over 25% of its annual output of cocoa beans to black pod disease in 2012. A 2017 survey of Ghana's cocoa farms revealed that of the 1.95 million hectares of cocoa across the country, 17% was affected by CSSV disease and 23% was over-aged (World Cocoa Foundation 2021). Furthermore, pests including capsids, cocoa shield bugs, and mirids negatively impact potential yields, with mirids causing crop losses of 25% in Ghana (ICCO 2015; Wessel and Quist-Wessel 2015; Konger *et al*. 2018).

Low productivity leads to low profit margins and a reduced ability to invest in farming practices which may boost production, including fertilisers and pesticides. The expansion of cocoa-growing areas in search of fertile soils has resulted in encroachment of nearby forests and widespread forest loss, negatively impacting local forest ecosystem services (Kroger *et al*. 2017; Kongor *et al*. 2018). Impacts of forest degradation and loss are widely known to especially affect women in natural resource-dependent communities (see also Colfer *et al*. 2016).

Types of cocoa growing systems

Cocoa can be grown in different types of systems reflected in the arrangement of cocoa trees in combination or not with other tree species, providing varying levels of shading (Fig.1).

Cocoa monocultures / low shade cocoa: Cocoa production systems with little or no shade coverage. True monocultures are rare in West Africa, as most cocoa fields include at least a few other tree species. Monoculture systems require cocoa hybrids which perform well under low or no tree canopy coverage when soil nutrients and the application of pesticides (fungicides and insecticides) are not limiting. The promotion of such systems has led to a reduction in tree cover and diversity in cocoa growing landscapes (Ruf 2011; Vaast and Somarriba 2014). In this study, monoculture/low shade (hereafter referred to as low shade) cocoa is defined as having shade canopy coverage below 30%

Cocoa agroforestry: Production systems that incorporate and maintain non-cocoa tree species on the same plot as cocoa production. These provide shade for cocoa trees, habitat for useful organisms and can provide extra resources for farmers (timber, fruit, fuelwood), though there can also be trade-offs when non-cocoa trees compete with cocoa trees or when shade trees harbour pests and diseases. There is no single model for their design and implementation, the choice of shade tree species and planting density depends on local factors (such as climate), historical extension services influence and the needs and objectives of farmers. Guidance on the optimal level of shade cover varies, and some guidelines include:

- Le Conseil du Café-Cacao (Côte d'Ivoire): 30-50%
- COCOBOD: 30-70%
- Rainforest Alliance/SAN: at least 40%

Figure 1 Different types of agroforestry systems: from highly diverse multistrata system to mixed with forest remnants and planted fruit and cocoa trees to more simple edge-planting systems (graphic M. Sassen)

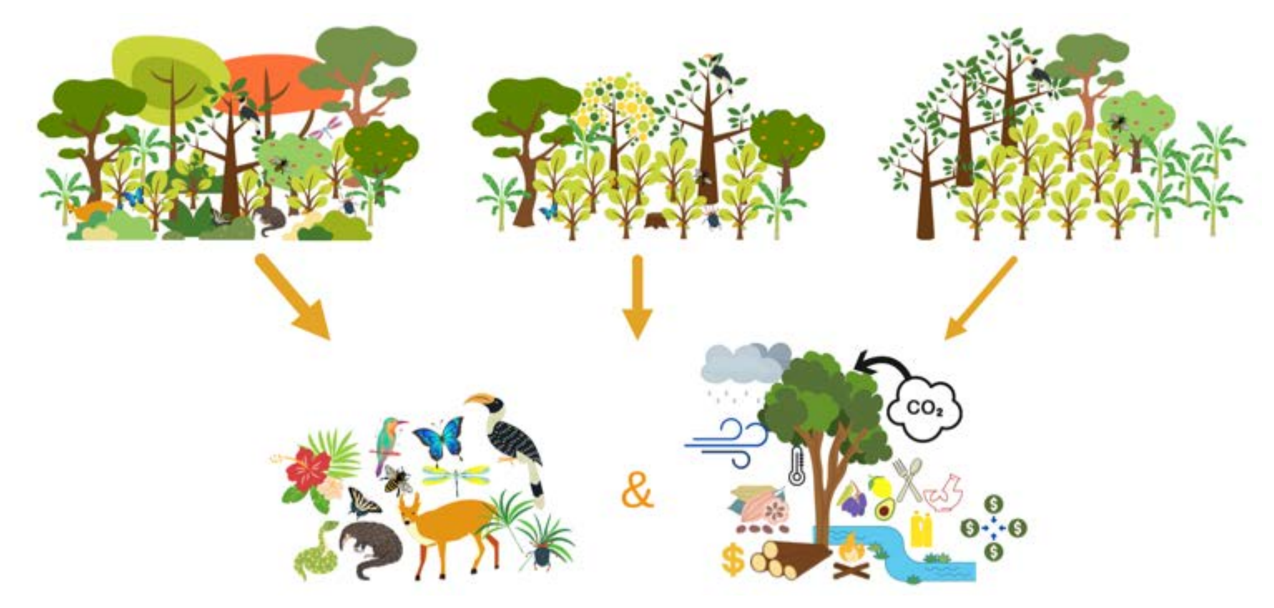

Figure 2 Different types of agroforestry systems support different levels of biodiversity and a different balance of ecosystem services (graphic M. Sassen)

From full sun to agroforestry: changing narratives

Historically, cocoa farmers in Ghana and Cote d'Ivoire have been advised that shade would negatively affect cocoa production (Ruf 2011), bringing disease (Clough *et al*. 2009, though see Niether *et al*. 2020) and competing for resources with cocoa trees (Sanchez 1995; Blaser *et al*. 2018). However, smallholder farmers have been unable to invest in the inputs and management required to maintain productivity in monoculture high input systems (Waarts *et al*. 2019). It has become clear that cocoa agroforestry may be a more appropriate system for low input smallholder farming systems, with the potential to support more sustainable yields over time if well managed (Johns 1999; Nijmeijer *et al*. 2019)

Depending on their design, cocoa agroforestry systems can potentially deliver a range of benefits that benefit local and wider communities (Fig.2). Cocoa agroforestry is seen as an opportunity to support sustainable cocoa yields while at the same time increase the resilience of farmers through income diversification (from secondary crops) (Waldron *et al*. 2012; Blaser *et al*. 2018; Niether *et al*. 2020) and provide a higher return on labour than less diverse high input systems (Armengot *et al*. 2016). Cocoa agroforestry systems can also potentially help habitat connectivity (Asare *et al*. 2014) and quality for some wildlife species, support microclimate regulation and carbon sequestration (Morel *et al*. 2019). Furthermore, agroforestry presents an opportunity to restore tree cover within cocoa landscapes by increasing the number of trees found on cocoa farms. A meta-analysis by Neither *et al*. (2020) demonstrated that cocoa agroforests have significantly higher carbon stocks when compared to cocoa monocultures. Cocoa agroforests may have higher levels of sediment retention compared to low-shade or full sun systems (Tscharnke *et al*. 2011), preventing soil from entering streams and reducing water quality for those downstream. The increased timber and fruit tree species on agroforestry plantations may provide additional timber and non-timber products for both the farmers and local communities.

However, the types and magnitude of benefits depends highly on the design of the agroforestry system and the local context. The relationship between soil fertility, cocoa productivity and shading, for example, is not well understood. Results vary widely among and within studies, depending on how shade trees are managed and other factors (Niether *et al*. 2020). Similarly, little is known about the relationship between cocoa management (e.g. level of shade) and biological pest control. In some cases, transitioning to shaded systems may decrease the effect of certain pests on yield losses, in others it may increase it. Some studies found positive effects of (native) shading on pest and disease incidence (e.g. Bisseleua *et al*. 2013; Andres *et al*. 2018; Armengot *et al*. 2020; Asitoakor *et al*. 2022). Though, from their meta-analysis, Niether *et al*. (2020) concluded that no specific system performs better with regard to regulation of all pests and diseases taken together. Some shade tree species may be avoided by farmers as they are known to harbour pest species which attack the cocoa trees, however there may be a trade-off with the additional income they provide (Acheampong *et al*. 2014). The benefits from secondary products such as timber or non-timber products depend on the availability of and access to markets.

Cocoa and Climate Change

The expansion of cocoa into forests has negative implications for global efforts to mitigate climate change. Tropical rainforests in Ghana have among the highest carbon storage of any ecosystem type, and their conversion to cocoa production results in large emissions of CO2 into the atmosphere (Gockowski and Sonwa 2010). Addressing deforestation in cocoa supply chains is key to meeting national emissions reduction commitments as well as global goals to mitigate climate change.

Though carbon stocks in cocoa farms are lower than in natural forests, carbon stocks in cocoa agroforestry systems are on average 2.5 times higher than in monocultures, depending on shade tree species (Niether *et al*. 2020).

Moreover, cocoa production potential will be affected by climate change and requires adaptation to maintain production (Schroth *et al*. 2016; Bunn *et al*. 2019). According to the IPCC Fifth Assessment Report., temperatures in tropical West Africa are expected to increase faster than the global average, one or two decades before the rest of the world (Mcsweeney *et al*. 2010; Niang *et al*. 2014). Cocoa is a heat sensitive crop, and increasing temperatures can inhibit pod growth, reducing their yield. Furthermore, a changing climate will impact upon pests and diseases, and could influence host/pathogen relationships, affecting how farmers manage crops to reduce losses caused by pests and diseases (Anim-Kwapong and Frimpong 2008; Gordon 2011). Therefore, strategies to adapt to climate change and increase climate resilience are key to ensure the long-term sustainability of the sector and the livelihoods of cocoa growers and their families.

Climate-Smart Cocoa

Climate-smart cocoa, including the promotion of sustainable intensification through agroforestry, is increasingly recognised as a means to address three key challenges in the sector: improving productivity and farmer incomes, enhancing adaptation and resilience to climate change, and reducing emissions from deforestation and forest degradation (Wainaina *et al*. 2021). Though local complexities and trade-offs at different scales are likely to pose challenges to its implementation and success at scale (Nasser *et al*. 2020).

Bunn *et al*. (2019) developed recommendation domains to guide decisions to scale out site-specific climate change adaptation practices in the West African cocoa sector under current and future climates. Adaptation recommendations include the uptake of best agricultural practices and agroforestry (and their correct implementation to avoid maladaptation), transitioning to other tree crops where the climate becomes unsuitable, and identifying opportunity areas where climate becomes more suitable for cocoa. Agroforestry, through the integration of shade trees, is seen as a promising system to support climate change adaptation in cocoa and is a major focus of climate-smart cocoa promotion efforts (Vaast *et al*. 2016).

Policy context for cocoa agroforestry in Ghana and West Africa

Ghana is promoting cocoa agroforestry through a combination of sectoral strategies, laws, regulations, approved cocoa agroforestry definitions, models and standards (Thomson *et al*. 2020). A recent report found 92 Sustainable Livelihood Initiatives relating to the cocoa sector across Ghana and Cote d'Ivoire. These are led by a range of actors including, buyers, not-for-profits (NGOs and private foundations), international donors and local actors (such as local government agencies and farmer led initiatives (Capillo and Somerville-Large 2020).

The Cocoa and Forests Initiative (CFI) is coordinating efforts to end deforestation in the cocoa sector, with the engagement of many of the world's leading cocoa and chocolate companies. The main pillars of the CFI are forest protection, forest restoration, sustainable production, farmer livelihoods, social inclusion, and community engagement (Republic of Ghana 2018). The CFI Implementation Plan of Ghana builds on existing national policies and programmes such as the Ghana Cocoa Forest REDD+ Programme (GCFRP), the National Climate-Smart Agriculture and Food Security Action Plan (Republic of Ghana 2020). All these policies recognise the need to address gender equality and include plans to do so.

The promotion of climate-smart cocoa is a major objective of Ghana's REDD+ Strategy and the Cocoa Forest REDD+ Programme (Republic of Ghana 2016). The programme aims to increase cocoa yields in the face of climate change, increase shade trees on cocoa farms and restore degraded forests. The National Cocoa Rehabilitation Programme, led by COCOBOD, aimed to provide 20 million cocoa seedlings to cocoa farmers for free in 2012, as well as a rehabilitation and replanting scheme which included the replanting of 20 percent of the existing cocoa farms in 2014 (Laven and Boomsma 2012; COCOBOD 2014).

The cocoa industry and relevant national policies increasingly recognise that women play a key role in enhancing cocoa crop yields and cocoa bean quality, and that investing in supporting gender equality is part of their long-term sustainability strategy (Osorio *et al*. 2019).

1.2 Objectives

The analysis aims to identify opportunity areas for the implementation of cocoa agroforestry within existing cocoa landscapes, in alignment with different policy objectives, including the recommendation domains for climate-smart cocoa in Ghana (Bunn *et al*. 2019). Using ancillary datasets and considering different potential future scenarios, this study seeks to help prioritise areas for agroforestry implementation based on potential for the greatest biodiversity conservation and ecosystem service benefits (Table 1). This report presents the methodology and its application to identify and prioritise those areas.

This is a spatial prioritisation exercise to identify the potential to achieve mainly environmental objectives and limited socio-economic benefits. The latter are limited to the assessment of ecosystem services that may be available at the local level due to the introduction of agroforestry, based on existing knowledge about the potential benefits from ecosystem services in local livelihoods. Gender-related considerations could not be assessed due to a lack of relevant spatial data Such considerations, should be part of any subsequent step towards implementation of agroforestry in the priority areas identified through this study.

Table 1 Overview of the analysis

Issue	Description
Systems analysed	Monoculture/full-sun cocoa, shaded cocoa, high-shaded cocoa and very high-shade cocoa
Policy issues	Cocoa expansion, deforestation, national REDD+ programme, climate-smart agriculture, restoration
Location	National (focused on cocoa growing areas)
Ecosystem services analysed	Carbon storage, sediment retention, biodiversity intactness
Business-as-usual trend	Declining tree shade cover in cocoa systems (transition towards monoculture cocoa from shaded systems), promotion of conventional intensification
Sustainable Development Scenarios	1. A shift to shaded systems nationally and highly shaded systems in forest reserves 2. A shift to shaded systems nationally and highly shaded systems in forest reserves and a 1km buffer around them 3. Implementation of climate-smart cocoa recommendation domains in the cocoa zone, and very highly shaded systems in forest reserves

2. Methods

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2.1 Datasets

Analysis was conducted in the region of Ghana currently under cocoa production, identified using the 2019 National Land Use Land Cover map of Ghana (Resource Management Support Centre of Forestry Commission [RMSC - FC] 2020 fig 3).

This dataset splits cocoa growing areas into low shade (including some monoculture) and shaded cocoa classes. It was combined with other datasets (Table 2) to identify areas to promote cocoa agroforestry, using criteria and constraints defined for different scenarios.

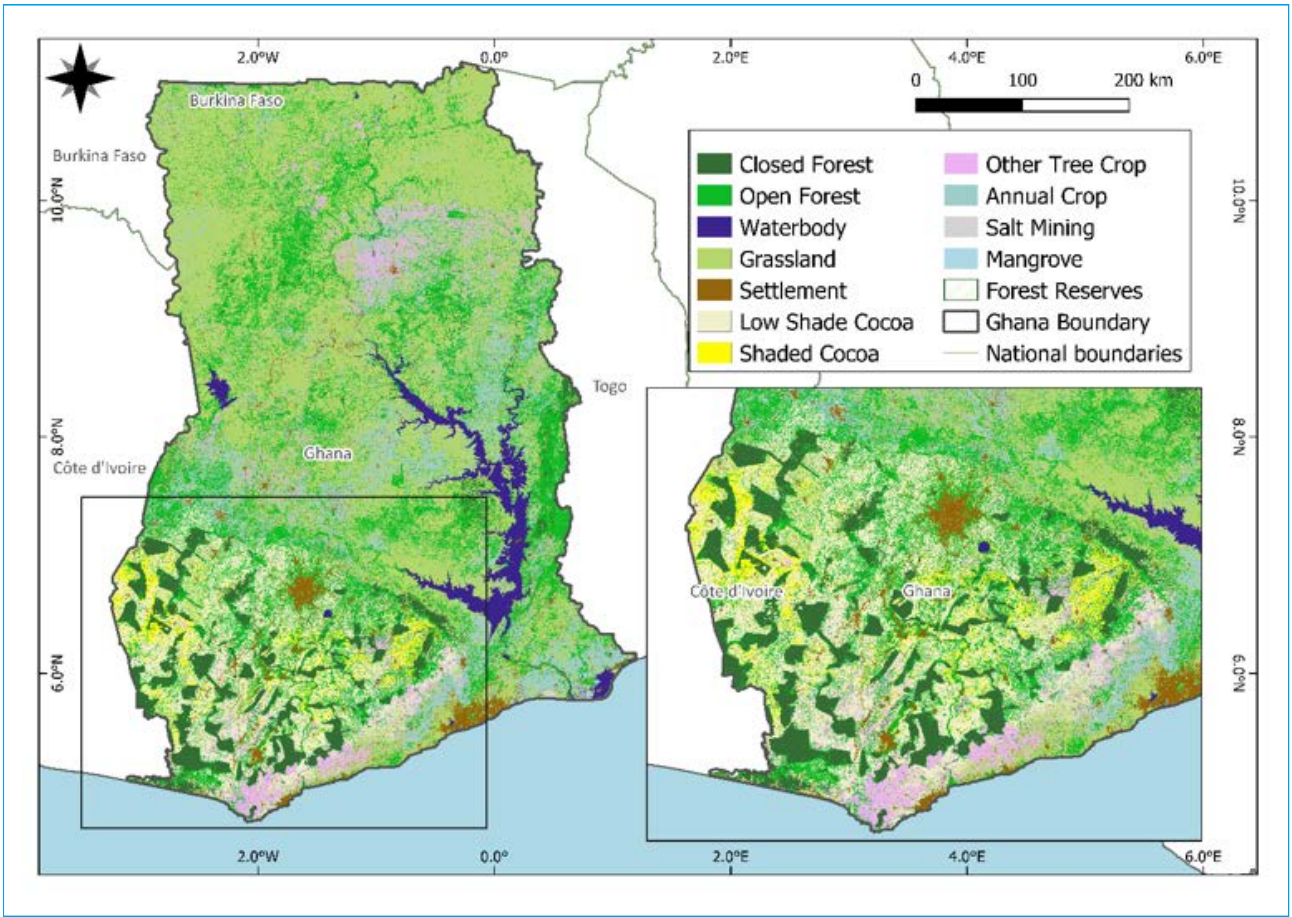

Figure 3 Ghana landcover in 2019 (Source: RMSC - FC 2020). Inset: Study area, Ghana cocoa landscapes. The low shade class was originally called monoculture, in this study, it has been interpreted as including low shade plantations. The boundaries and names shown, and the designations used on this map do no imply official endorsement or acceptance by the United Nations.

Table 2 Datasets used in the analysis, their source, temporal and spatial resolution

Data	Source	Description	Temporal resolution	Spatial resolution / format
Land cover	RMSC - FC (2020)	Land cover of Ghana in 2019	2019	~20m
Forest reserves	Ghana Forestry Commission	Forest reserve areas in Ghana	Variable	Polygon
Cocoa climate recommendation domains	Bunn *et al.* (2019)	Cocoa climate recommendation zones categorised as opportunity, transformation, systemic resilience, systemic adaptation and incremental adaptation	2040 - 2069	~1km
Ghana Road Network	OpenStreetMap, World Food Programme	An extraction of roads from OpenStreetMap data made by WFP following UNSDI-T standards	Present (early 2022)	Polyline

2.2 Scenarios

This study seeks to assess the implications of implementing different policy objectives that look towards agroforestry as a sustainable, climate-smart cocoa production system that restores biodiversity and ecosystem services across Ghana.

A low shade scenario and three alternative scenarios for the potential transition of cocoa growing areas to different agroforestry management types were defined as follows:

- **Transition to low-shade:** Conversion of all cocoa agroforestry to low shade cocoa (shade cover <30%).
- **Transition to shaded cocoa:** All monoculture cocoa systems transition to shaded systems (30-40% shade; 15-25 trees per hectare). Within forest reserves a higher level of shade is applied (40-50% shade (20-45 trees per hectare).
- **Transition to shaded cocoa+:** All monoculture cocoa systems transition to shaded systems (30-40% shade; 15-25 trees per hectare). Within forest reserves and a 1km buffer around them, a higher level of shade is applied (40-50% shade; 20-45 trees per hectare).
- **Climate-smart cocoa:** Cocoa production areas outside forest reserves transition following spatially explicit climate-smart cocoa recommendations as defined by Bunn *et al*. (2019) and based on descriptions provided by the World Cocoa Foundation 'Climate-Smart Agriculture in Cocoa' training manual (Dohmen *et al*. 2018). Under this scenario, the recommendation domains (Bunn *et al*. 2019; Figure 4.) are classified into adaptation zones (coping and opportunity, adjustment and transformation) with different land use and management recommendations. Cocoa growing areas within forest reserves transition to very high shaded cocoa (50-70%; 25-50 trees per hectare) as a means to support tree cover restoration within these areas.

The **coping and opportunity zone** includes the 'opportunity' and 'incremental adaptation' recommendation domains. Within these areas, climate change is not expected to affect cocoa as negatively and the areas will remain, or become, suitable for cocoa production. A minimum cocoa shade of 30-40% as well as management practices which enhance resilience and sustainability is recommended.

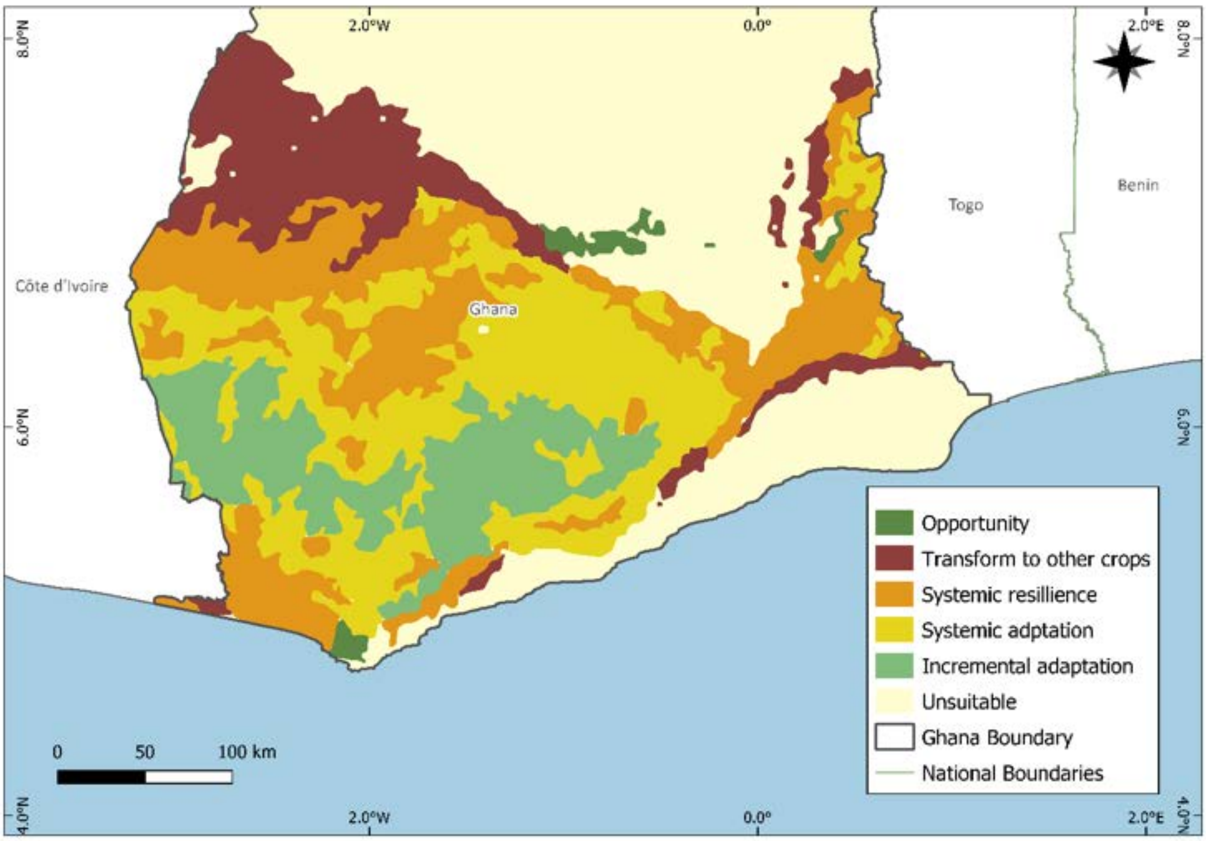

Figure 4 Ghana recommendation domains from Bunn et al. *(2019). The boundaries and names shown, and the designations used on this map do no imply official endorsement or acceptance by the United Nations.*

The **adjustment zone** includes the 'systemic adaptation' and 'systemic resilience' recommendation domains and recommends a minimum shade canopy cover of 30-50%. Within these zones, there is a high certainty of climate change which will require adaptation to ensure cocoa production remains at or near current levels. Best management practices which promote sustainable agriculture are recommended in these areas. In particular, 'no-regret' solutions such as shade enhancement or diversification with shade tree species which are known to provide multiple benefits and protect against potential climate change related threats.

Finally, in the transformation zone, Bunn *et al*. (2019) recommend a transition to other tree crops, as the climate will likely become unsuitable for cocoa growing. Therefore, any cocoa currently within these areas were transitioned to the 'other tree crops' class.

The minimum requirements of practice implementation at the farm level to achieve a basic level of resilience against the various climate hazards and threats that define each impact zone have been considered in our analysis (in this case, the minimum canopy coverage recommended). The recommendation domains also identify areas which may become suitable for cocoa under future climates, though cocoa expansion is not modelled in this study.

2.3 Biodiversity intactness analysis

Natural forests in West Africa, including those in Ghana, are a global biodiversity hotspot. These forests contain high levels of species richness and endemism (CEPF 2015), and are home to critically endangered species including pangolins, several primate species (e.g. White-naped Mangabey monkey), endemic butterflies and amphibians. These forests are under threat, with only pockets of them remaining in Ghana. Secondary forests and cocoa agroforests retain some of this biodiversity value and can support connectivity between natural forests (Asare *et al*. 2014), though values depend on cocoa land use history – especially whether there has been more intense land-use in the past (Nijmeijer *et al*. 2019; Niether *et al*. 2020; Martin *et al*. 2020; Maney *et al*. 2022). A recent study quantified these effects by modelling the effects of land-use change linked to cocoa cultivation on whole-community biodiversity intactness (combining species richness and compositional similarity to intact forest) based on original biodiversity field data from 36 studies (1295 sites) across the world (Maney *et al*. 2022). The study allowed us to make inferences about the potential consequences of transitioning between primary forests and cocoa agroforests under natural shade or monoculture systems and between monoculture or less shaded systems to planted-shade cocoa agroforestry.

In our analysis, Biodiversity Intactness Index (BII) values for different land uses were extracted from models generated using the PREDICTS database (Hudson *et al*. 2017), also used by the Maney *et al*. (2022) study. Coefficients for primary and secondary forests, cocoa-based agroforestry systems derived from either naturally-shaded or open land, and open-land systems were sourced from that study, whilst the model was extended to establish coefficients for settlements, grasslands, and mines based on a wider set of studies in similar biogeographic regions. The BII metric measures relative intactness of biodiversity within this globally important biodiversity hotspot, comparing land cover classes to remaining primary forest.

Not all land cover classes from the land cover dataset had exactly matching land use types in the PREDICTS database. A cross-walk between the two was therefore performed to allocate coefficient values to the needed land cover classes. Some RMSC-FC land-cover classes had to be allocated to the same PREDICTS land-use type (e.g. "other tree crops" land cover was allocated to the "open land systems" land use type, which also includes cocoa monocultures and annual crops). The variation in BII among land covers assigned to a land use type was assumed to fall within the range of uncertainty present in the model coefficients' 95th confidence intervals. Different BII coefficients, falling within the confidence interval of the land use type, were assigned to individual land cover classes within a single PREDICTS land use type. The coefficient assigned was based on our judgement as to the degree of expected relative biodiversity impact. (Table 3).

At a landscape scale, implementation of shaded cocoa agroforestry may also improve connectivity between remaining forest habitats in national parks and forest reserves, increasing accessible habitats for wildlife (Asare *et al*. 2014). However, connectivity mapping was outside the scope of the study and therefore not included.

2.4 Ecosystem services analysis

Cocoa agroforestry systems have the potential to improve the production of a number of ecosystem services compared to monoculture or low-shade systems (Wainaina *et al*. 2021). Several services were reviewed in the context of this study, these included provisioning services (e.g., freshwater provisioning, timber and non-timber forest products, cash crops and food crops), regulating (e.g., carbon sequestration, biological pest and disease control) and supporting services (e.g., nutrient cycling, water cycling). The effects of the different scenarios on carbon sequestration and sediment retention were mapped. However, due to modelling constraints and lack of available data in the literature corresponding to the land cover classification and cocoa agroforestry systems used, only the impacts of the scenarios on carbon storage and sediment retention were mapped.

Carbon storage

Carbon stocks and cocoa management

Cocoa growing plots with shade trees have higher total carbon stocks than monoculture cocoa plots, and the majority of carbon is stored within the shade trees (Niether *et al*. 2020). We assumed that cocoa trees themselves store 7.45 tC/ha (average based on ground measurements from Acheampong *et al*. (2014) which were not found to vary significantly between plots; value also used by Dawoe *et al*. (2016)), though in reality this value varies with age of the cocoa plantation (Konsager *et al*. 2013; Benefoh 2018).

Table 3 Biodiversity Intactness Index (BII) coefficients matched to land cover.

Land Cover	Suggested PREDICTS database Land Use type match	Suggested level within plausible range for the land use	BII coefficient applied
Closed forest	Primary forest	Mid	1
Open forest	Mature secondary vegetation	High	0.85
Waterbody	NA	NA	Excluded
Grassland	Primary non-forest	Mid	0.84
Settlement	Urban/Settled	Low	0.15
Low shade cocoa	Open land systems	High	0.31
Shaded cocoa	Open land-derived CAfS	Mid	0.41
Other tree crop	Open land systems	High	0.31
Annual crop	Open land systems	Mid	0.25
Salt mining	Urban/Settled	Low	0.15
Mangrove	Primary forest	Mid	1
High shade cocoa	Open land-derived CAfS	High	0.48
Very high shade cocoa	Forest-derived CAfS	Mid	0.64

The highly significant relationship between shade tree crown cover and carbon stocks found by Acheampong *et al*. (2014) was used to derive aboveground carbon stocks in shade trees in this study (Table 4):

Shade tree C stock (tC /ha) = 0.8566 * crown cover % - 0.5507

Soil organic carbon (SOC) represents a significant carbon pool across ecosystems (Mohammed *et al*. 2016). However, stocks vary with climate, ecological zone, soil type, land use history etc. and the effect of increasing shade coverage on SOC in cocoa landscapes is not well understood. Therefore, soil organic carbon pools were not included in this analysis. Belowground, deadwood and litter biomass classes were also not included in the analysis, likely meaning that the difference in carbon stocks between low-shade and shaded systems is underestimated.

Carbon stocks are influenced by the density of shade tree species, age of the trees, and ecological zone. Therefore, there will be a high degree of uncertainty with these values and actual values may fall across a large range.

Carbon storage by land cover class

Carbon storage values for land cover classes other than cocoa were sourced from the literature (Table 5), focusing on Ghana and other West African countries. Default IPCC values were used where appropriate. Appropriate values were selected based on their alignment with land cover class descriptions. Values were sourced for the aboveground biomass pool of each land cover class. Carbon stocks are highest in closed forests, open forests and mangroves. The estimated carbon stock value for 'other tree crops' is higher than those estimated for 'very high shade cocoa' systems. The carbon stock value for 'other tree crops' is estimated

Table 4 Estimated above-ground carbon stocks within cocoa management classes for the study based on the equation derived by Acheampong et al. *(2014)*

Cocoa management class	Shade coverage range (%)	Median shade tree coverage (%)	Cocoa tree carbon stocks (tC/ha)	Shade tree carbon stocks (tC/ha)	Total tree biomass (tC/ha)
Low shade	<30	15	7.45	12.3	19.75
Shaded	30-40	35	7.45	29.43	36.88
High shade	40-50	45	7.45	38	45.45
Very high shade	50-70	60	7.45	50.85	58.3

Table 5 . Carbon stocks in aboveground across each land cover class based on literature values. Following IPCC (2006) recommendations, carbon stocks in settlement, waterbody and salt mining classes were assumed to be 0.

Land cover Class	Aboveground biomass carbon (tC/ha)	Source
Closed forest	192.9	Leh *et al*. 2013 (average of closed forest class values)
Open forest	155.18	Leh *et al*. 2013 (average of open and closed to open forest class values)
Waterbody	0	N/A
Grassland	11.48	Ghana Forestry Commission, 2021
Settlement	0	N/A
Monoculture cocoa	19.75	See table 2
Shaded cocoa	36.88	See table 2
High-shade cocoa	45.45	See table 2
Very high-shade cocoa	58.3	See table 2
Other tree crop	74.4	Kongsager *et al*. 2013 (average of oil palm, rubber and orange plantations)
Annual Crop	5	IPCC (2006), used in Ghana Forestry Commission (2021)
Salt mining	0	N/A
Mangrove	75.1	Bryan *et al*. (2020)

from Konsager *et al*. (2013), using the average values reported for rubber, oil palm, and orange plantations. Their study estimated high carbon stocks in rubber plantations (213.6 tC/ha), which was in line with values reported from studies in China (Konsager *et al*. 2013).

These carbon stock density values were assigned to the land cover datasets for each scenario and cells were multiplied by their area in hectares to assess the total potential carbon stock stored in aboveground biomass at a national level.

Sediment retention

Soil erosion is negligible in mature cocoa systems except when located on very steep slopes (Tscharnke *et al*. 2011, citing Hartemink 2005). Therefore, a transition to cocoa agroforestry may in younger and steeper cocoa plantations reduce erosion-induced loss of nutrients from the soil and soil transport downstream, as a result of the increased number of shade trees.

Sediment erosion and transport downstream can have both positive and negative economic and well-being effects depending on the context. While erosion and transport of sediments have detrimental effects for farmers at the source, they can benefit farming downstream by providing an important source of nutrient rich soils. However, increases in sediment loading may result in increased treatment costs for drinking water supply, impacts on the health and distribution of aquatic populations and inland fisheries, diminishing reservoir performance or increasing sediment control costs (Sharp *et al*. 2020).

To map the change in sediment retention service under each scenario, we developed a model based on the InVEST SDR model (Sharp *et al*. 2020) which is based on the Universal Soil Loss Equation combined with a connectivity index to calculate the hydrological linkages between sources of sediment (from the landscape) and sinks (e.g. streams.) For each pixel, the model first computes the amount of annual soil loss from that pixel, then computes the sediment delivery ratio (SDR), which is the proportion of soil loss actually reaching the stream. To calculate the sediment retention service, the model simulates a scenario of bare soil and compares that with the current vegetation. Outputs are presented as total sediment retained aggregated over sub-basins (Hydrosheds level 7; Lehner and Grill 2013). Sediment retention quantifies the sediment which has been eroded but is retained downslope by vegetation on the landscape. For the 2019 land cover dataset and each scenario, sediment retention per pixel was produced, potential change under each scenario was estimated relative to the sediment retention under the current land cover. The change values were then aggregated over each sub-basin (Hydrosheds level 7).

The model includes land management factors associated with each land cover, the parameters used in the model are crop cover management (C) and support practice (P) factors which were based on values used by Leh *et al*. (2013) (Annex B). The land cover classes did not match those used in this study exactly, therefore factors were assigned based on similarity and are not calibrated to the landscape, and may therefore have a large degree of uncertainty. Values for different levels of agroforestry management were not available in the literature. The model does not take into account the ages of the plantations as it not possible to map these, this will introduce some uncertainty to the results.

2.5 Prioritisation for multiple benefits

In order to determine where to prioritise a transition to agroforestry taking into account multiple benefits, the Climate-Smart Cocoa scenario was selected as it promotes resilience to climate change and is part of Ghana's policy objectives. Several input layers were overlaid to produce a simple hotspot map of potential benefits.

Input layers were normalised between 0-1 and included carbon stock and BII gains (results from this study), proximity to forests, settlements and roads. Close proximity to forests, settlements, and roads were considered a benefit in this case, however the appropriateness of this would need to be considered in local contexts. Close proximity of agroforest to forests may improve availability and connectivity of habitats for wildlife. Increased shade tree coverage near settlements may provide additional benefits to local communities in the form of ecosystem services (e.g. timber and non-timber forest products), and cocoa plantations near roads may have improved access to markets, benefiting farmers in selling their products.

3. Results

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3.1 Cocoa growing areas

Cocoa growing areas cover more than 2.3 million hectares (9.7%) of Ghana. Of this, more than 1.9 million hectares are estimated to be low shade plantations (83.7%) and around 378 thousand hectares are under shaded management systems (16.3%), according to the land cover dataset used (Table 6). Approximately 86 thousand hectares of low shade cocoa plantations and 18 thousand hectares of shaded management systems were found in forest reserves (4.5% of total forest reserve area). Closed and open forests were the largest classes in forest reserves, covering approximately 901 thousand and 570 thousand hectares respectively (63% of total forest reserve area).

Table 6 Land cover class descriptions and areas over the total national area (Source: Ashiagbor et al. *2020; RMSC - FC 2020).*

Land Cover class Ghana 2019 (RMSC - FC 2020)	Description	Area (ha)	Area (%)
Closed forest	Closed canopy forest constitutes primary and secondary woody vegetation stands of 1m minimum mapping unit with more than 60% crown canopy and with 5 m height. The CCF class is mainly found within the forest reserves and protected area	1,268,334	5.3
Open forest	Open canopy forest class represents degraded forests as resulting mainly from logging activities, usually with crown cover between 30% and 60%. The area also covers riverine vegetation usually outside the reserve and protected area	5,272,703	7.45
Waterbody	Area covered with water (e.g. lakes and rivers)	767,653	3.2
Grassland	Grassland and savanna areas	9,972,617	41.8
Settlement	These include human-settlement areas, bare lands, mined areas, etc	732,389	3.1
Low shade cocoa	Full sun cocoa represents monoculture cocoa farms with few or no natural or planted trees within.	1,936,089	8.1
Shaded cocoa	Shaded cocoa represents cocoa farms with natural or planted trees incorporated and creates a relatively closed canopy system with double strata. The upper canopy with non-cocoa trees forming the upper strata and the cocoa canopy forming the second strata	378,297	1.5
Other tree crop	These are established citrus, oil palm (*Elaeis guineensis)* and rubber (*Hevea brasiliensis*) plantations etc. within the landscape	987,117	4.1
Annual crop	These include food crops, grasslands/fallow areas and shrub vegetation	2,499,155	10.4
Salt mining	Extraction of salt	11,871	0.05
Mangrove	Mangrove forests	22,466	0.1
Total		**23,848,691**	**100**

3.2 Agroforestry transition scenarios

The different scenarios lead to different spatial patterns of cocoa agroforestry systems (Fig. 5). Low shade cocoa is only found under the current land use (year 2019) and in the 'transition to low shade' scenario. 'High shade' cocoa is introduced in the 'transition to shaded cocoa' and 'transition to shaded cocoa+' scenarios.

In the latter, introducing a 1-km buffer around forest reserves increases the area transitioning to 'High shade' cocoa from around 86,000 ha to more than 300,000 hectares (Table 7).

'Very high shade' cocoa is introduced in the 'climate-smart cocoa' scenario, following the guidance laid out in Dohmen *et al*. (2018). The climate-smart cocoa scenario results in the largest areas of 'high-shade' agroforestry and 'very high-shade agroforestry'.

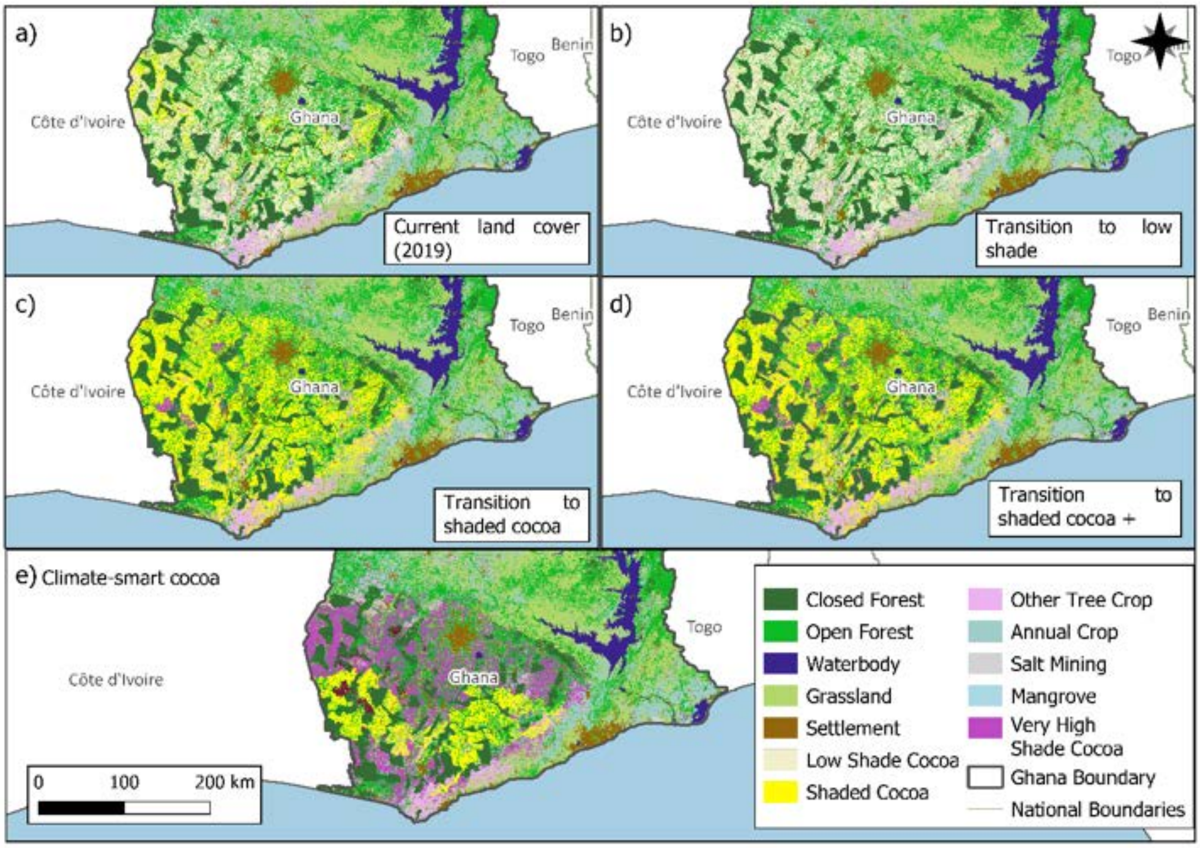

Figure 5 Maps of land cover in Ghana a) in 2019 (Source: RMSC - FC 2020), b) under the Transition to low shade scenario, c) under the Transition to shaded cocoa scenario, where monoculture cocoa transitions to shaded cocoa, and high-shade cocoa is implemented in forest reserves where cocoa is currently planted, d) Transition to shaded cocoa+ scenario, implementing high-shade cocoa in 1km buffers around forest reserves as well, and e) the Climate-smart cocoa scenario. The low shade class was originally called monoculture, in this study, it has been interpreted as including low shade plantations. The boundaries and names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations

*Table 7 Land cover area estimates under each scenario assessed. * High-shade and Very high-shade cocoa agroforests were not included in the 2019 national land cover map; any areas present will have been classed as 'shaded cocoa'*

Land cover	Current (2019)	Transition to low shade	Transition to shaded cocoa	Transition to shaded cocoa+	Climate-smart cocoa
Closed forest	1,268,334	1,268,334	1,268,334	1,268,334	1,268,334
Open forest	5,272,703	5,272,703	5,272,703	5,272,703	5,272,703
Waterbody	767,653	767,653	767,653	767,653	767,653
Grassland	9,972,617	9,972,617	9,972,617	9,972,617	9,972,617
Settlement	732,389	732,389	732,389	732,389	732,389
Monoculture cocoa (<30% shade)	1,936,089	2,314,386	0	0	0
Shaded cocoa (30-40% shade)	378,297	0	2,228,194	2,012,727	696,022
High-shade cocoa (40-50% shade)	0*	0	86,193	301,660	1,375,658
Very high-shade cocoa (50-70% shade)	0*	0	0	0	104,470
Other tree crop	987,117	987,117	987,117	987,117	1,125,353
Annual Crop	2,499,155	2,499,155	2,499,155	2,499,155	2,499,155
Salt mining	11,871	11,871	11,871	11,871	11,871
Mangrove	22,466	22,466	22,466	22,466	22,466
Total	**23,848,691**	**23,848,691**	**23,848,691**	**23,848,691**	**23,848,691**

3.3 Biodiversity intactness change

Relative to the transition to low shade scenario, which entails a loss in biodiversity intactness due to the trend of decreasing tree cover in cocoa plantations, the intervention scenarios all have large areas of "avoided" loss in BII. The climate-smart cocoa scenario also has large areas of mild benefit for biodiversity intactness (light green in Fig.5), some areas with greater BII benefit (dark green in Fig.5), but small areas in the northwest where a decrease would be expected (red in Fig.5).

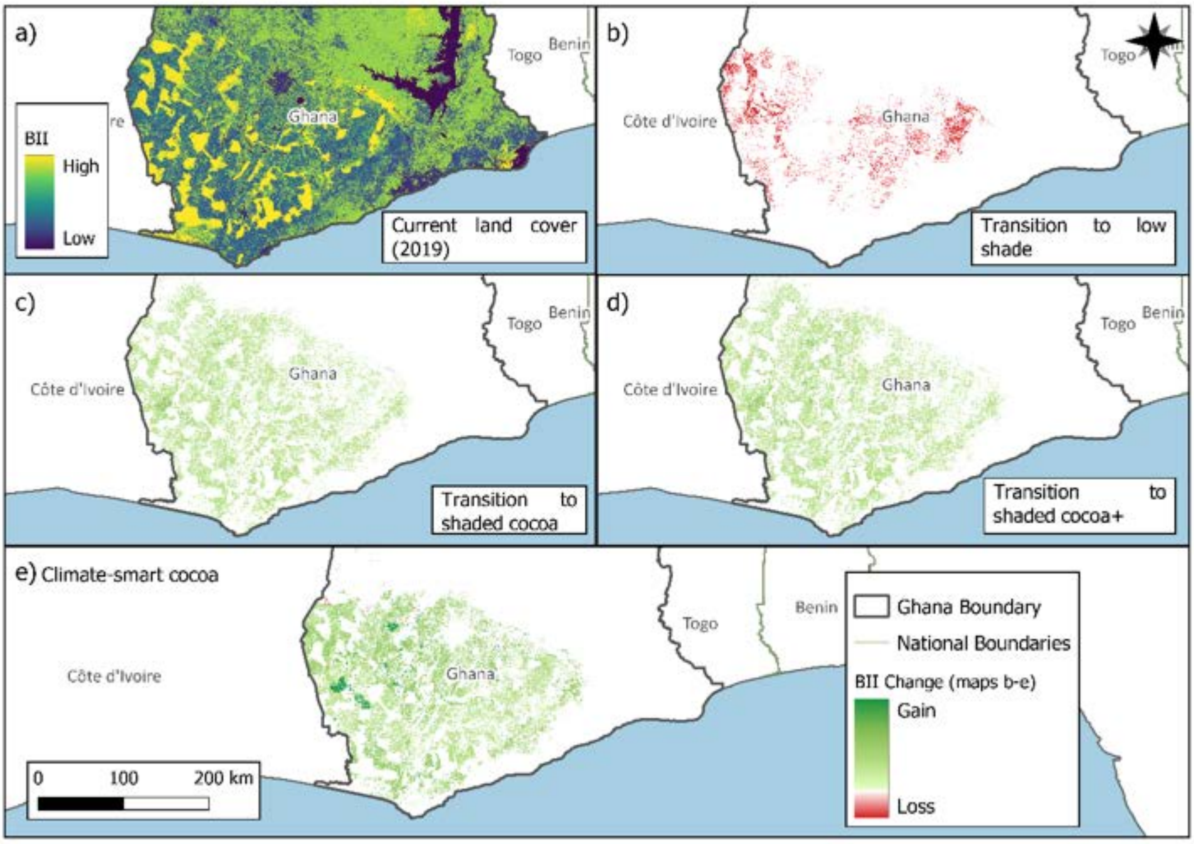

Figure 6 Biodiversity Intactness Index (BII) under current land use (a) and change in BII resulting from each land use scenario (b-e). The boundaries and names shown, and the designations used on this map do no imply official endorsement or acceptance by the United Nations

3.4 Ecosystem service impacts

Carbon storage

Under the transition to low shade scenario, where shade cover in cocoa lands continues to decrease and low shade/monoculture approaches are adopted nationally, almost 6.5M tC could be lost at the national level compared to the current aboveground carbon stocks (approximately 17.13 tC/ha). Each of the agroforestry scenarios resulted in increased levels of aboveground carbon stocks in cocoa lands as shaded cocoa agroforestry is adopted with varying levels of shade. The climate-smart cocoa scenario provides the highest potential carbon stock increase in cocoa lands: up to 52M tC (Table 8), most of this potential (48.7M tC) is in agricultural lands outside of forest reserves.

Under the climate-smart cocoa scenario, the greatest carbon gains are actually seen in the transition zone due to other tree crops (e.g. oil palm and rubber) having larger tree biomass, and therefore carbon stock values. Under this scenario, forest reserves also show high levels of aboveground biomass carbon stock gain due to the transition to very high-shade agroforestry in these areas (Fig.7).

Table 8 Total aboveground biomass carbon stocks at the national level under each scenario, and compared to the current estimate of carbon stocks in 2019

Scenario	Total aboveground biomass carbon stocks (tC)	Change from current (2019) (tC)
Current land cover (2019)	1,316,649,041	
Transition to low shade	1,310,174,025	- 6,475,016
Transition to shaded cocoa	1,350,555,902	+ 33,906,861
Transition to shaded cocoa+	1,352,401,175	+ 35,752,134
Climate-smart cocoa	1,369,033,198	+ 52,384,157

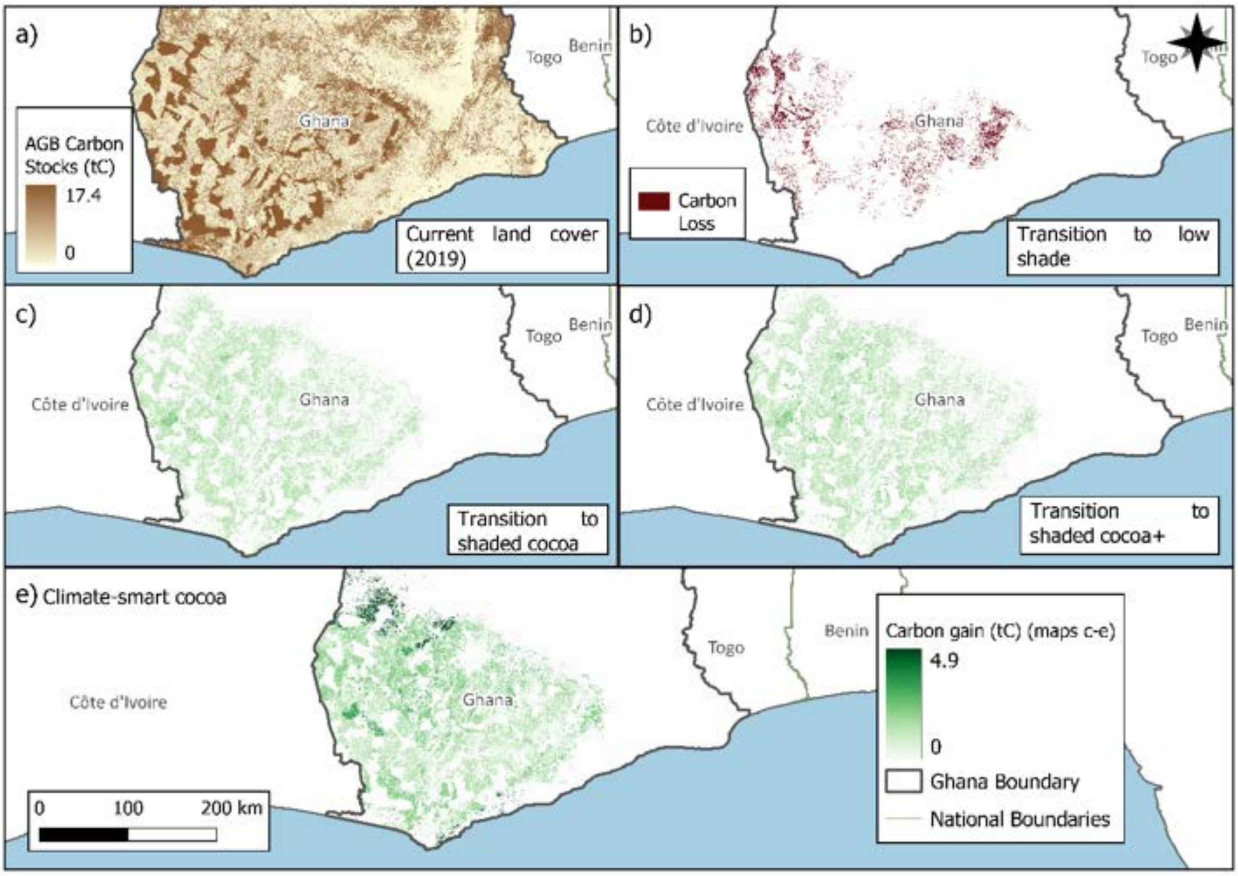

Figure 7 a) Aboveground carbon stocks under current land uses, b-e) change in carbon stock resulting from land use scenarios. In figure b) the only land use change occurring is a transition from shaded to monoculture cocoa, therefore the change value is the same for all cells. The boundaries and names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations

Sediment retention

Sediment retention totalled more than 350 thousand tonnes per year nationally under the land cover in 2019. Under the transition to low shade scenario, total sediment retention decreased by 0.1%. Under the transition to shaded cocoa scenario, sediment retention increased by 0.7%, and by 0.74% under the transition to shaded cocoa+ scenario sediment retention increased slightly further to almost 355,000 tonnes per year. Increased sediment retention was highest in the climate-smart cocoa scenario, particularly due to the implementation of very high shade cocoa within forest reserves. In this case, sediment retention rose by 4,906 tonnes/year at the national level (Table 9).

Change in sediment retention under each scenario is very low compared to the current sediment retention nationally. However, cocoa landscapes cover less than 10% of the national area and not all cocoa growing areas underwent change. Here, the key result is that transitioning to shaded cocoa, and particularly cocoa with very high levels of shade, has a small positive impact on sediment retention services (Fig.8). Further analysis on the downstream impacts of the sediment would be needed to understand how significant this is.

Table 9 Total sediment retention at the national level under each scenario, and compared to the current estimate of 2019

Scenario	Total sediment retention (tonnes/year)	Change from current (2019) (tonnes/year)
Current land cover (2019)	352,313	
Transition to low shade	351,933	- 380
Transition to shaded cocoa	354,704	+ 2,391
Transition to shaded cocoa+	354,920	+ 2,607
Climate-smart cocoa	357,219	+ 4,906

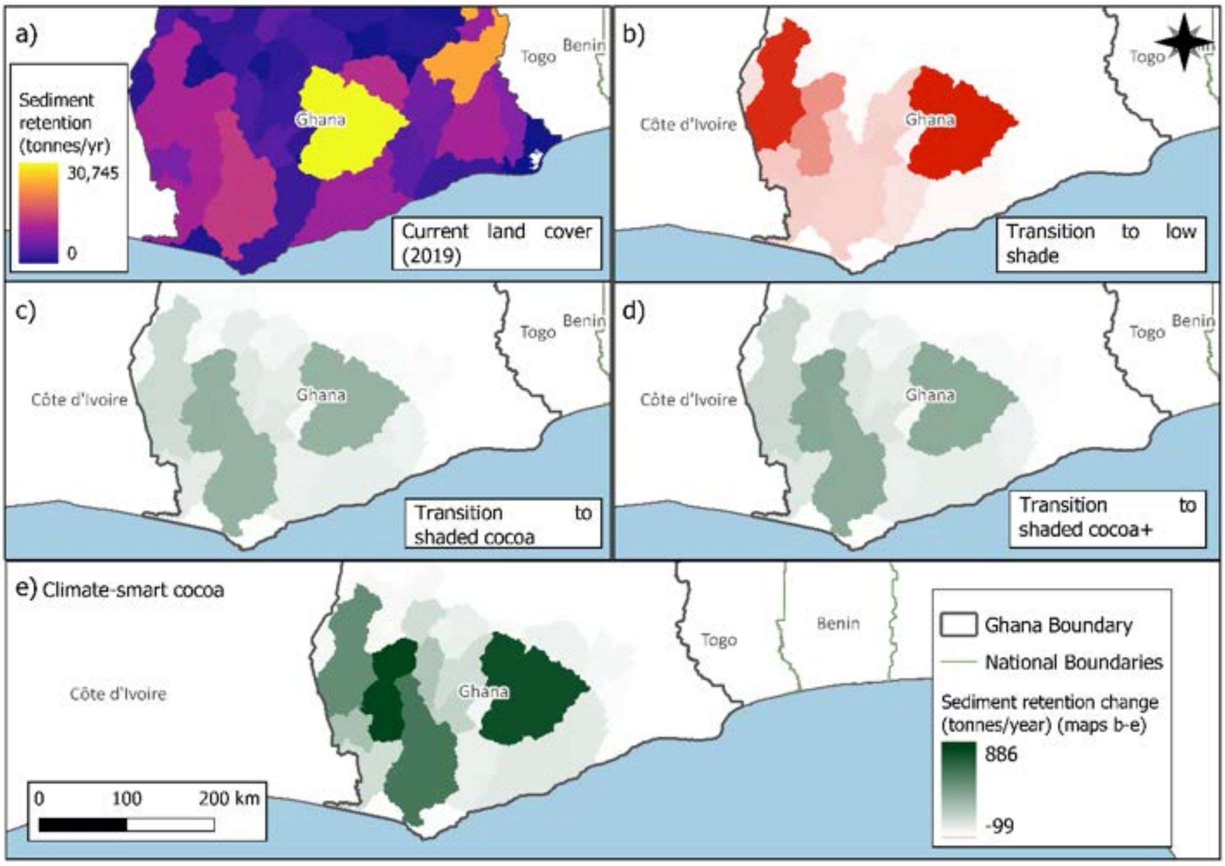

Figure 8 a) Total sediment retention (tonnes/year) aggregated over sub-basins (Hydrosheds level 7) with current land cover. b-e) change in sediment retention summed over sub-basins. The boundaries and names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations

3.5 Prioritising agroforestry implementation at a national scale

To determine where a transition to agroforestry taking into account multiple benefits might be prioritised, the results of the carbon stock and BII change from the climate smart cocoa scenario were combined with proximity to forest, roads and settlements ((Fig. 9) into one final prioritisation layer (Fig. 10).

In the final prioritisation layer incorporating proximity to forests, settlements and roads, (Fig. 10), areas of high importance are those found in existing forest reserves due to the implementation of 'very high shade' agroforestry, which has the high gains in carbon stock and biodiversity intactness. Areas around reserved forests and/or close to settlements are also ranked highly, due to the benefits they may provide in connecting habitats and delivering ecosystem services to local communities. Lower areas are seen in middle-lower belt of the cocoa area, this is due to these areas falling within the coping and opportunity zone, where the minimum shade canopy coverage is lower compared to other zones.

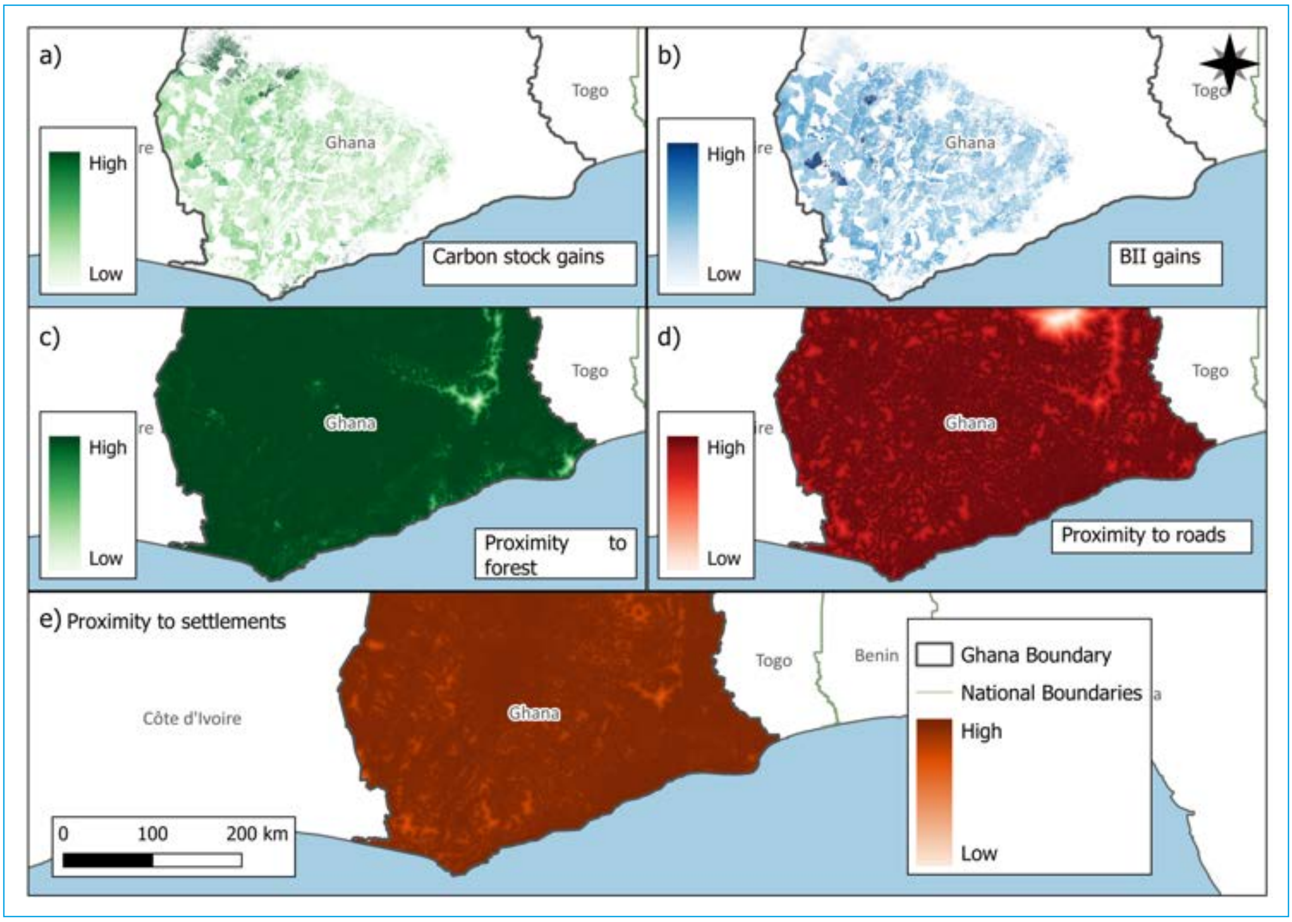

Figure 9 Data inputs to the climate-smart cocoa prioritisation layer including a) carbon stock and b) BII gains, c) proximity to forest, d) roads and e) settlements. Sediment retention was not included due to changes at the pixel level being very small (changes at the basin level should be considered) and patterns of changes being very similar to those of carbon stock gains. The boundaries and names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations

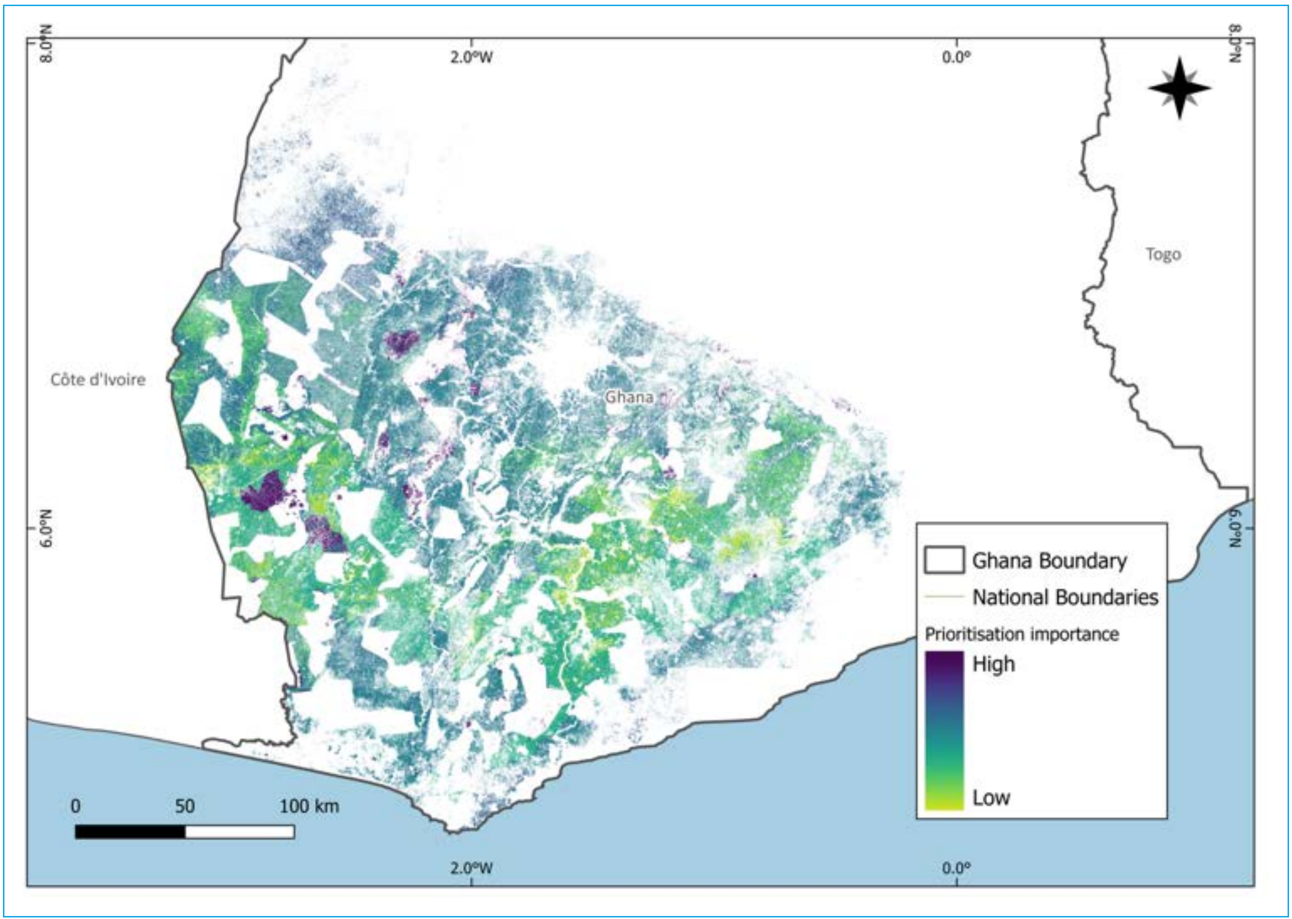

Figure 10 Final prioritisation layer based on carbon stock and BII gains, as well as proximity to forests, settlements, and roads. The boundaries and names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations

4. Discussion

This study provides a spatially explicit assessment of potential priority areas for increasing tree cover in cocoa growing areas in Ghana, based on specific policy objectives. It demonstrates the potential for decision-makers to use spatial planning in understanding where, and (partly) how, to implement cocoa agroforestry at scale to meet multiple objectives. Of the more than 2.3 million hectares of cocoa growing lands in Ghana, nearly 2 million hectares are estimated to be monoculture or low shade (<30%) plantations. This provides an important opportunity to increase tree cover in cocoa-growing areas in Ghana and contribute to national policy goals, including climate change mitigation (e.g. the Ghana Cocoa Forest REDD+ Programme (GCFRP)). In particular, this can be done in ways which improve resilience to climate change and aid forest restoration efforts (e.g. within cocoa plantations already established in forest reserves).

Prioritising areas for increasing shade tree cover in cocoa lands requires understanding of the landscape context (e.g. improving connectivity with remaining intact forests, enhancing the delivery of ecosystem services to local communities) as well as trade-offs with production, water availability and pest control. Spatial planning can aid decision-makers at both national and local scales to ensure positive outcomes for local communities as well as wider benefits (e.g. global climate regulation).

On the ground, other factors than the level of current shading will impact where different types of cocoa agroforestry systems can be implemented. The type and age of shade trees should be considered in addition to quantity to determine the canopy cover they provide at any given time of the life cycle of the cocoa plantation. Land ownership and planned future land uses such as settlements and infrastructure development, must be taken into consideration. Cocoa management must meet a variety of needs for farmers and the broader community, and these needs should be considered when implementing agroforestry programmes at the local scale.

4.1 Implementing cocoa agroforestry at scale

Climate-smart cocoa, and in particular the uptake of agroforestry practices has the potential to form part of the solution to multiple challenges, including climate change mitigation, climate change adaptation, sustainable development and biodiversity conservation.

Transitioning to cocoa agroforestry across large areas of cocoa landscapes presents several challenges and both short and long-term trade-offs need to be considered. Whilst establishment of agroforestry systems on forest land through thinning is cost-effective as removed trees can be sold, encroachment into remaining forest land needs to be avoided. Establishing agroforestry systems on monocrop cocoa is more costly than converting natural forest, particularly if high quality planting material is to be sourced from nurseries. Natural regeneration of trees is cheaper but limited to the seeds available in the soil and so does not guarantee high quality planting material that meets market demands, if income diversification is a primary objective. Agroforestry systems with timber trees only provide returns after years, making it a difficult strategy for farmers who require more immediate benefits. In addition, agroforestry systems may increase system level outputs, but do not necessarily translate into higher incomes. Prices for cocoa are often higher than prices for the shade tree products, as the latter are typically sold on the local markets and some directly consumed by the household or not harvested due to lack of labour or limited market opportunity. In Ghana, farmers do not own the naturally occurring trees on their land, which hampers the adoption of agroforestry practices (Roth *et al*. 2017). This needs to be addressed in combination with broader support to farmers including credit, access to inputs and extension services targeting both men and women cocoa farmers (Asaaga *et al*. 2020).

The balance of benefits and trade-offs from agroforestry implementation may vary at different scales and groups of people: men, women, old, young. At the national scale, targeting areas which would have the greatest benefits for people and nature in general may be of highest importance. For example, this may include ecosystem service benefits at the basin or administrative level, or connecting habitats and restoring forest reserves. Factors such as distance to settlements, roads and intact forests may be taken into account. On the one hand agroforestry may benefit from being near these features (e.g. access to markets for secondary crops when near roads and settlements) or provide additional benefits (e.g. improved ecosystem services near settlements, and habitat availability and connectivity when implemented near intact forests). On the other hand, being close to settlements and roads may also increase pressure on agroforestry systems, leading to the rapid removal of valuable trees and a transition to a less shaded system. Therefore, at the local scale, it is crucial to assess these potential impacts and ensure mitigation measures are in place, such as adequate incentives to farmers.

For cocoa agroforestry and other climate-smart cocoa systems to be successful, design and implementation at the local scale needs to take into account the agroecological conditions and the context of the broader landscape as well as the needs of farmers and farming households, men and women. For example, women are often the main collectors of firewood, responsible for household nutrition and income from secondary crops in cocoa plantations. They may therefore have different perspectives on the most desirable design of cocoa production systems to meet these needs than men (e.g. fuelwood, fruit and medicinal species).

The benefits derived from implementing these systems at all levels will depend on the interactions between the shade tree species planted, the cocoa, the wider landscape, community and climatic and edaphic factors. Trade-offs (particularly in the short-term) are likely and there are many institutional and socio-economic barriers to scaling these approaches. These systems are dynamic and require ongoing incentives and support for their long-term success.

4.2 Addressing potential trade-offs

Despite numerous potential benefits from agroforestry practices, there are several potential trade-offs when compared to monoculture cocoa systems. Transitioning to an agroforestry system may require upfront costs, result in even lower cocoa production levels on the short term, and the incorrect selection of shade tree species, or level of shade, may result in shade trees competing with cocoa trees and increased pests and diseases (Abdulai *et al*. 2017). In cocoa systems with low management levels in West Africa, yield has been shown to benefit from shade levels of up to 30% (Asare *et al*. 2018; Blaser *et al*. 2018) or even up to 50% (Andres *et al*. 2018), whereby yields decline under higher shade levels. Abdulai *et al*. (2018; 2020) found yields to be significantly lower in the dry region compared to medium and wet regions, though shade trees (canopy cover, tree density and diversity, basal area) did not seem to be reducing yields. But again, shade cover in Ghana overall is rather low (<40%). However, a reduction in cocoa productivity due to higher shade levels may be compensated by the timber or fruit crops produced by shade trees or other ecosystem services.

Only few studies have compared well managed cocoa agroforestry systems with intensive cocoa monoculture. Koko *et al*. (2013) showed that with good agricultural practices high cocoa yields can be achieved when intercropped with fruit trees (citrus, avocado). In their farmer trial in Côte d'Ivoire, cocoa yields of 1349 kg/ha were achieved when intercropped with citrus and 1260 kg/ha when intercropped with avocado. Gockowski *et al*. (2013) and Asare *et al*. (2014) assumed that intensive cocoa monoculture is 20% higher yielding than well-managed cocoa agroforestry. This assumption is based on a long-term experimental trial comparing no-shade, medium and high shade over 20 years at the CRIG-Tafo station (1959-1982) (Ahenkorah *et al*. 1987).

Even though there is a general agreement that the relationship between shade and cocoa yield is non-linear, there remains limited knowledge about the optimal shade level for different climatic and soil conditions, management levels and the specific agroforestry vegetation structure. There is also a need to revise the common perception of low yields in cocoa agroforestry systems. Compared to current yield levels in most cocoa growing regions, high cocoa yields can be achieved under moderate shading, if cocoa is well managed and the shade structure adapted to local conditions. Consequently, in many cases, particularly in West Africa, yields can be increased without need to reduce shade or in systems with no or low shade even when shade is increased. Furthermore, economical yields can be sustained over a longer time compared to monocropping systems. The optimal level of shade (and shade tree species composition) will depend on the farmer and farm household objectives, the agroecological conditions and management.

Climatic suitability for cocoa is expected to shift in Ghana, with regions experiencing different levels of change requiring different strategies for effective adaptive action. Ensuring farmers have the knowledge to plan for climate change impacts, avoiding maladaptation and inefficient resource use is crucial (Bunn *et al*. 2019). Even in areas where climate is projected to remain suitable, cocoa yields could still be at risk due to sensitivity to changes and variability in rainfall. Climate change could further exacerbate yield losses due to pests and diseases as their life cycles may shift with the climate (Kosoe and Ahmed 2022). Therefore, agroforestry systems must be designed taking future climate changes into consideration.

In order to meet global production demand and national production goals, cocoa will likely have to be intensified in some areas. Within the climate-smart cocoa recommendation domains, areas where intensification of cocoa may be suitable have been indicated. Intensification in some areas, accompanied by strong forest protection measures, may reduce the risk of cocoa lands encroaching on remaining intact forests, which is particularly critical as forested areas suitable for cocoa are often of high importance for biodiversity and ecosystem services (Sassen *et al*. 2022).

4.3 Data and methodological limitations/areas for improvement

Definitions on cocoa management systems

The original landcover dataset did not identify cocoa areas under high or very high shade, though they may have been present. We assumed these management practices were likely rare and therefore assumed the only agroforestry type present was 'shaded cocoa' (30-40% shade). Different definitions of cocoa management practices make comparing the land cover data inputs to other studies challenging. In this study, 83.7% of cocoa lands were classed as being low shade/monoculture. According to Gockowski and Sonwa (2008), of the total land area under cocoa production, 22.6% is under zero shade, 48.7% is under light shade, and 28.7% is grown under medium to heavy shade. Other studies suggest that approximately 10% is grown under zero shade, and 50% under mild shade. In this study, the monoculture class is likely to represent cocoa under both zero and low/mild-shade management systems.

Data on ecosystem services (e.g. carbon stocks) delivered by different cocoa management practices can vary significantly between studies. This is often due to different definitions of the management practices being used, making direct comparisons difficult. For example, some studies may define monoculture/ full-shaded systems as having no shade trees present, whereas others may include low levels of shade (e.g., < 10%). Several studies describe shaded agroforestry systems but do not include the percentage of shade canopy cover in their description. Furthermore, studies investigating differences in ecosystem service production between cocoa management practices often do not include estimates of percent shade tree canopy cover, instead using shade tree stem density. Tree stem density cannot be easily translated to canopy cover as the size of tree canopies depends on tree sizes and species (Asare & Ræbild 2016), therefore these studies cannot be included.

Carbon stocks

The derived aboveground biomass carbon stocks for monoculture cocoa are slightly higher than those found in the literature. Afele *et al*. (2021) estimates ranged from 4.05-7.25 tC/ha in monoculture/full-sun systems, and Benefoh (2018) estimates 7.65 tC/ha stored in full-sun cocoa plantations (this estimate is restricted to only cocoa trees). Dawoe *et al*. (2016) estimated 15 tC/ha in the above ground biomass of cocoa plantations, and 15.4-17.9 tC/ha in plantations they classed as 'medium shade' (8.1-14.9% shade cover). However, definitions of 'monoculture' or full-sun' systems vary, and our study assumed some presence of shade trees within these plots (up to 30%).

The aboveground biomass carbon stock value derived for shaded cocoa systems (30-40% shade) was largely in agreement with values sourced from the literature. Afele *et al*. (2021) estimated shaded systems to store on average 35.9 tC/ha across their 6 study sites. Similarly, Agibaase *et al*. (2021) investigated the effects of organic vs conventional cocoa agroforests on aboveground biomass carbon stocks, the average value between the two groups was 32.1 tC/ha (organic average = 41.3 tC/ha vs conventional average = 22.9 tC/ha).

Studies including high shade (>40% shade cover) agroforestry systems are lacking in the literature, therefore direct comparisons could not be made. The study used to derive the shade tree carbon stock equation above (Acheampong *et al*. 2014) was derived from study sites with less than 40% shade canopy cover. Therefore, values estimated for the high-shade cocoa and very high-shade cocoa classes in this study may have a high degree of uncertainty associated with them. However, due to the lack of estimates for comparable cocoa plantations in the literature, these values are used.

Only aboveground biomass carbon stocks are estimated by this study. Taking into account all carbon pools (belowground biomass, deadwood, litter and soil organic carbon) would greatly increase the estimated carbon stocks and changes. For example, Mohammed *et al*. (2016) found soils stored the bulk of carbon in cocoa plantations (approximately 89%). However, the relationship between management, shade trees and soil organic carbon is not well understood, therefore this pool was excluded from the analysis.

Finally, carbon stocks are influenced by more than just the management system of the cocoa plantation. In particular, the age of the cocoa plantation can have a significant effect, as well as local climatic and topographical features, and the species of shade trees used. Mohammed *et al*. (2016) found carbon stocks in cocoa plantations were higher in the western region of Ghana than in the East. A study by Morel *et al*. (2019) found a cocoa-timber agroforest in Southern Ghana with higher carbon stocks than in intact forest, due to the high density of timber trees present but rather low cocoa tree densities.

Sediment retention

Due to a lack of previous studies, the model is not calibrated to cocoa landscapes. Instead, the classes were assigned input parameters based on similarities to classes used by Leh *et al*. (2013). However, these may not accurately reflect the relationships between the different classes used in this study and introduce a high degree of uncertainty. In particular, the "c factor" inputs were very similar between the different types of cocoa management practices, contributing to low levels of change in sediment retention between the scenarios. Previous studies have indicated that the c factor is the most sensitive model parameter (Borelli *et al*. 2017, citing Risse *et al*. 1993; Benkobi *et al*. 1994 and Ferreira *et al*. 1995). Ideally, sensitivity analysis should be conducted to understand the impact of different c factor values, alongside ground truthing to ensure output results are of the correct order of magnitude.

Therefore, the exact value outputs of the modelling should be treated with a high degree of uncertainty. However, assuming that the relative difference in parameters between classes is accurate, the results from this study indicate that under the business-as-usual approach, sediment retention services will decrease, with increased sediment retention services under the agroforestry scenarios.

Limitations of the approach

This large-scale analysis cannot address the more nuanced approaches to adapting to climate change in cocoa landscapes as recommended by Bunn *et al*. (2019), such as the outcomes of applying good agricultural practices, types of shade tree and which tree crops are shifted to where the climate becomes unsuitable. The impacts of these interventions need to be assessed at finer spatial scales in consultations with farmers and local communities to ensure needs are addressed.

Also, this analysis at national scale did not include a gender dimension and could therefore not assess impacts on gender equality of the proposed interventions. The importance of taking into account gender in on-the ground interventions can however not be overstated.

4.4 Further studies

There is a need to better understand ecosystem service and biodiversity benefits from a range of shade levels within cocoa agroforestry systems. Studies typically focus on monoculture vs shaded systems (often 30-40% shade). However, in some cases shaded systems with up to 70% shade are being promoted through climate-smart agriculture. Better understanding the benefits and trade-offs these systems offer in terms of productivity, income diversification, ecosystem services and biodiversity benefits will be key to ensuring their long-term uptake. Also, further studies are required to understand who would benefit from implementing different systems, including youth and women.

Ecosystem service benefits associated with agroforestry practices are often challenging to quantify and map spatially, particularly at high spatial resolution. Studies quantifying these benefits beyond carbon and over a greater range of agroforestry practices will improve the quality and usability of this data, as well as their inclusion in decision making. In particular, better understanding of the impact of different levels of shade on services such as erosion control, yields, pollination or others will improve the accuracy of modelling approaches.

Improved economic valuations of ecosystem service values resulting from cocoa agroforestry implementation may improve their integration into decision making processes, particularly at larger spatial scales, and help to design incentives to make them a more attractive option by farmers.

At the national level, linking potential outcomes in the cocoa sector to sustainable development outcomes in other sectors (e.g. other commodity crops, timber production, and mining) would provide a better picture of the long term benefits, as well as planning for achieving goals and commitments around climate change mitigation, climate change adaptation, landscape restoration, sustainable development and biodiversity conservation.

5. Conclusions

5. Conclusions

Continuing on a trajectory assuming progressive loss of tree cover in cocoa areas could have huge consequences across cocoa (and non-cocoa) landscapes. Including the loss of large amounts of carbon currently stored in cocoa landscapes. Furthermore, further transitioning towards low shade cocoa landscapes as well as encroaching on remaining forests would lead to the loss and fragmentation of much habitat for biodiversity, reductions in crucial ecosystem services which benefit local communities, reduce farmer resilience in the face of crop failure, low prices or climate change and increase health risks from increased use of pesticides in intensive systems.

Implementing climate-smart agroforestry following the recommendation domains set out by Bunn *et al*. (2019) could result in significant areas of cocoa lands transitioning to highly-shaded (> 40% shade) systems. If implemented well, the benefits to people, nature and climate resulting from this transition could be significant. More evidence and field trials are needed on how to best implement such highly shaded systems, their costs and benefits, effects on resilience and farmer wellbeing in different agroclimatic and socio-economic contexts.

Improving our understanding of productivity, ecosystem services and biodiversity conservation outcomes under different cocoa management practices and the policy entry points for scaling out sustainable practices will improve their integration into decision-making and uptake by farmers. It will also be crucial to design context appropriate incentives for farmers to adopt agroforestry practices, including financial incentives where needed, such as payments for environmental services.

Prioritising areas for agroforestry, and determining the appropriate level of shade, will rely on several factors and may involve trade-offs between different benefits. Decisions should factor in local ecological and climatic conditions, socio-economic interests, biodiversity outcomes, ecosystem services, and production (both cocoa and other products).

Finally, spatial analysis can be used to inform the prioritisation and implementation of agroforestry promoting efforts within cocoa cultivation areas, that seek to enhance resilience to climate change, while also providing additional benefits such as carbon sequestration and biodiversity conservation.

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Annex A

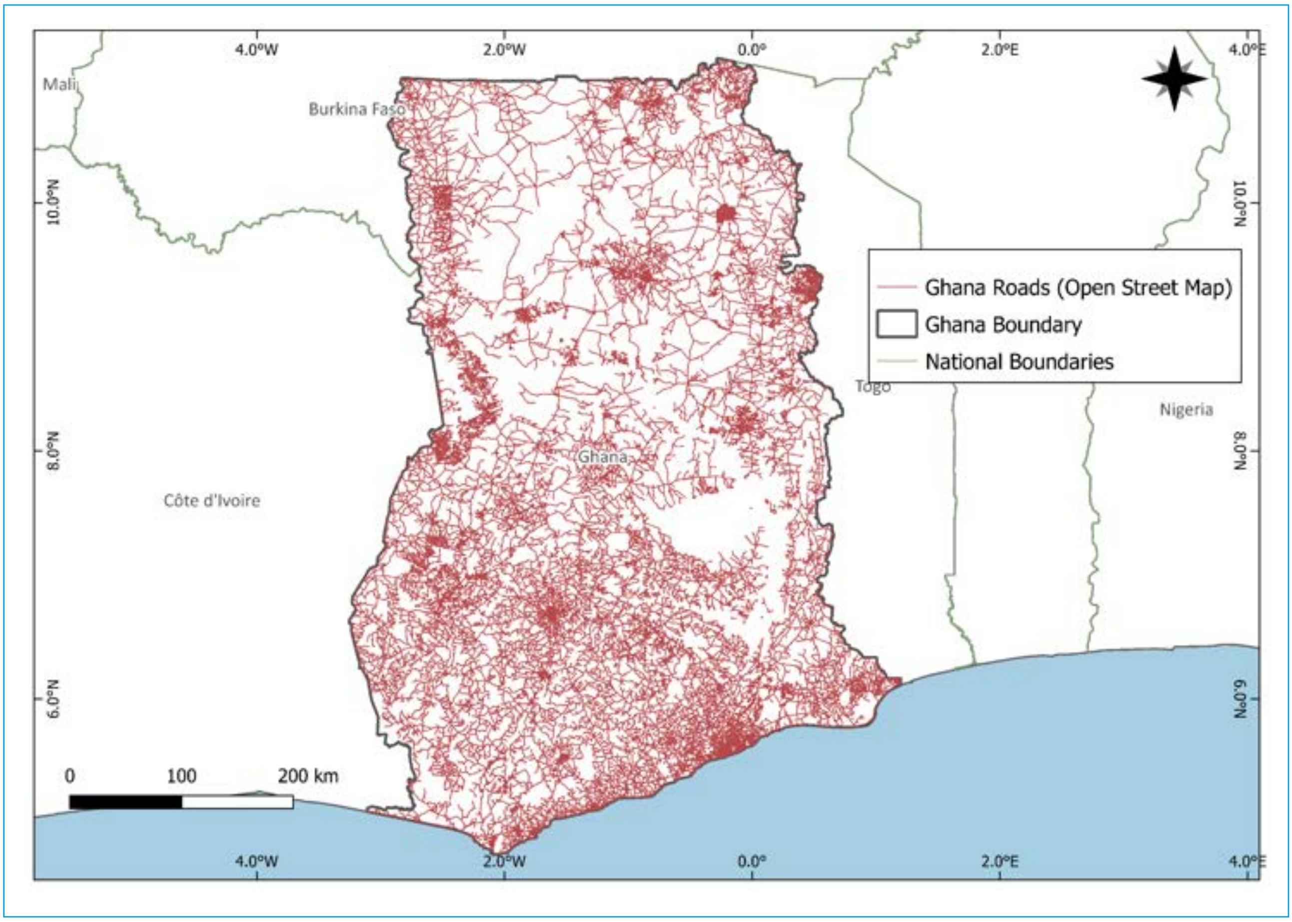

Figure A1. Roads dataset (based on Open Street Map data).

Annex B

Table B1. Parameters for the sediment retention model, based on nearest corresponding class in Leh et al. *(2013).*

Land cover class	Leh *et al.* 2013 Land cover class	usle_c	usle_p
Closed forest	Closed (>40%) broadleaved/needleleaved deciduous/ evergreen forest (>5m)	0.095	1
Open forest	Open (15-40%) broadleaved/needleleaved deciduous/ evergreen forest/woodland (>5m)	0.09	1
Waterbody	Waterbodies	0.01	1
Grassland	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)	0.065	1
Settlement	Artificial surfaces and associated areas (Urban areas >50%)	0.003	1
Monoculture cocoa	Average between cropland and mosaic cropland/vegetation	0.0325	1
Shaded cocoa	Mosaic cropland (50-70%) / vegetation (grassland/ shrubland/forest) (20-50%)	0.04	1
Other tree crop	Mosaic cropland (50-70%) / vegetation (grassland/ shrubland/forest) (20-50%)	0.04	1
Annual crop	Rainfed croplands	0.025	1
Salt mining	Bare areas	0.025	1
Mangrove	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water	0.075	1
High shade cocoa	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)	0.045	1
Very high shade cocoa	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)	0.085	1