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Patterns of (future) environmental risks from cocoa expansion and intensification in West Africa call for context specific responses

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ABSTRACT

Cocoa is an important historical driver and direct cause of forest loss and degradation in the West African Upper Guinean biodiversity hotspot. To inform efforts to prevent further cocoa-driven deforestation in the West African cocoa zone, we mapped areas that are important for biodiversity and ecosystem services (carbon, water, forest products) and potentially most at risk from further cocoa expansion based on climatic suitability, a continuation of past deforestation trends and the potential role of cocoa therein. We found that cocoa expansion and intensification risks further impacting ecologically important areas in West Africa, but that patterns vary in space, may be compounded by climate change and demand context specific responses. In Ghana and Côte d'Ivoire, remaining forests should be better protected, degraded forests should be restored, and agroforestry systems should be supported where possible to maintain or enhance biodiversity and ecosystem services provision in cocoa landscapes. In countries with large areas of remaining forests (e.g., Liberia and Cameroon) that are highly suitable for cocoa and where cocoa is expanding, the approach used in this study can help identify areas with the highest biodiversity and ecosystem services values and inform planning of future cocoa development to maximise cocoa system productivity potential, biodiversity and ecosystem services from the national to local scale. Adaptation strategies are required to avoid the loss but also improve the conservation of biodiversity and provision of ecosystem services across the region.

1. Introduction

The West African Upper Guinean forest is a global biodiversity hotspot (Myers et al., 2000; Poorter et al., 2004), supporting globally important ecosystem services, such as carbon sequestration, as well as local benefits such as wild foods, fuelwood, and traditional medicines that poor communities depend on for subsistence and income (Darwall et al., 2015). Between 1975 and 2013, 15% of dense and degraded forests in the West African Upper Guinean forest zone was lost to farming and other uses (CILSS, 2016). Maps of forest cover in West Africa show how in countries such as Ghana and Côte d'Ivoire dense forests only remain in small, protected pockets (Fig. S1). Cocoa, and associated human migrations, is an important historical driver and direct cause of this loss (Ruf et al., 2015; Barima et al., 2016; Asubonteng et al., 2018), and the area under cocoa production is still expanding (FAO, 2020; Brobbey et al., 2020; Vivideconomics, 2020) including inside protected forests (WRI, 2019).

Currently about 70% of the global cocoa supply originates from West African smallholder farmers and cocoa is a major cash earner in cocoa-producing areas (Gayi and Tsowou, 2016). Yet, average cocoa yields are low (400–500 kg/ha), largely due to inadequate maintenance, low input use and aging plantations. Cocoa is traditionally first established on fertile forest land but after about 30 years, yields decline and pest and disease pressure increase. As smallholder farmers often lack the means to rejuvenate their plantations, this leads to a new cycle of forest clearing (Benefoh et al., 2018; Gockowski and Sonwa, 2011; Wessel and Quist-Wessel, 2015; Ruf, 1995). A new cocoa plantation is traditionally initiated under a (thinned) forest canopy, however a historical drive for intensification, driven by increasing demand for cocoa and supported by new highly productive sun-tolerant hybrids has led to a gradual decrease in shading, especially in Côte d'Ivoire and Ghana (Ruf, 2011). However, intensive full-sun systems require more inputs such as fertilisers which

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are often out of reach for overwhelmingly poor smallholder cocoa farmers, explaining low yields in many such systems (Waarts et al., 2019). Moreover, shade trees in cocoa provide farmers with (income from) timber, fruits, fuelwood and other benefits, increasing their resilience to shocks such as fluctuating cocoa prices and climate change (Clough et al., 2009; Vaast and Somarriba, 2014).

To support recent commitments and efforts to end cocoa-driven deforestation (Carodenuto, 2019), sustainable intensification has been advocated by the cocoa industry as a "land -sparing" approach. Including public-private initiatives such as the Cocoa Forest Initiative (CFI) in Ghana and Côte d'Ivoire (Republic of Ghana, 2018; Republic of Cote d'Ivoire, 2018), the Roadmap to Deforestation Free Cocoa in Cameroon (Government of Cameroon, 2021) but also by cocoa importing countries in Europe (EC, 2020). These efforts often seek to align with national REDD+ strategies, as well as national policies on forest and biodiversity conservation (GFC, 2016; Republic of Côte d'Ivoire, 2017). On the other hand, these initiatives also increasingly promote agroforestry, traditionally considered a "land sharing" perspective, to help diversify cocoa farmers' incomes and increase their resilience. Sustainability certification schemes already exist that include criteria on shade (e.g Rainforest Alliance, Bird-friendly). Whether and where "sparing" or "sharing" makes most sense in the future of sustainable cocoa is likely to vary depending on context, such as the location of current and potential future cocoa production in relation to remaining forests, the biodiversity and ecosystem services values of these forests, but also the ecosystem services within existing cocoa landscapes (Schroth et al., 2011).

Policies or programmes that seek to help prevent further deforestation due to cocoa, need to prioritise their efforts and identify those areas that are most at risk. Zero-deforestation initiatives generally prohibit deforestation in High Carbon Stock (HCS) or High Conservation Value (HCV) areas. Yet, these areas are not yet mapped at the national scale in the West African cocoa producing countries. National-level spatial analysis showing where expansion of cocoa is most probable and where risks to forests, biodiversity and ecosystem services are highest can inform the prioritisation of action. Similarly, a better understanding of the distribution of biodiversity and ecosystem services within existing cocoa growing areas can help target different strategies such as sustainable intensification, agroforestry or other interventions.

The cocoa belt of West Africa is defined as the cocoa producing areas between Sierra Leone and Cameroon as in Schroth et al. (2016). Here we map and identify areas that are important for biodiversity and ecosystem services and potentially at risk from further cocoa expansion and intensification in this region. We considered risk based on climatic suitability for cocoa growing as well as the risk posed by a continuation of past deforestation trends (due to cocoa and other land uses). We used spatial analysis and modelling tools to link measures of biodiversity and ecosystem services to potential change in land use.

2. Data and methods

2.1. Cocoa production areas

We used spatial data on climatic suitability for cocoa developed by Schroth et al. (2016) as a proxy for likelihood of current cocoa cultivation and risk of expansion (Fig. 1). Schroth et al. (2016) modelled the relative climatic suitability for cocoa in the West African cocoa belt by combining data on the current extent of cocoa farming with climate variables from the WorldClim database (Schroth et al., 2016). We also considered the potential implications of future climate change on the potential suitability for cocoa growing in the region as increasing temperatures and variability in rainfall are expected to affect future cocoa production in West Africa (Schroth et al., 2017).

2.2. Ecosystem services

We assessed ecosystem services using the web-based spatially explicit ecosystem services assessment tool Co$tingNature V3 (Mulligan et al., 2010; Mulligan, 2015b). We ran the model at a resolution of 1-km, using fractional land cover data based on Copernicus 2015 (Buchhorn et al., 2019). The analysis included a total of five ecosystem services: fuelwood, non-wood forest products, clean water provision, carbon and natural hazard mitigation. We combined and normalised all ecosystem services maps to present total ecosystem services for potential services (produced but not "consumed") and realised services ("consumed" services). To identify areas that are important for ecosystem services and at risk from cocoa driven land use change, we combined the ecosystem services layer for the region with modelled cocoa suitability based on Schroth et al. (2016) in a bivariate map. A bivariate map helps to visualise the geographic relationship between two variables, in this case where high importance for ecosystem services and high climatic suitability for cocoa overlap.

2.3. Biodiversity

In order to provide an indication of how 'important' a given area is for biodiversity, we used a metric based on range size-rarity (i.e., endemism) (Hill et al., 2019). Scores for all species were aggregated to make a map of rarity-weighted richness. The underlying data was based

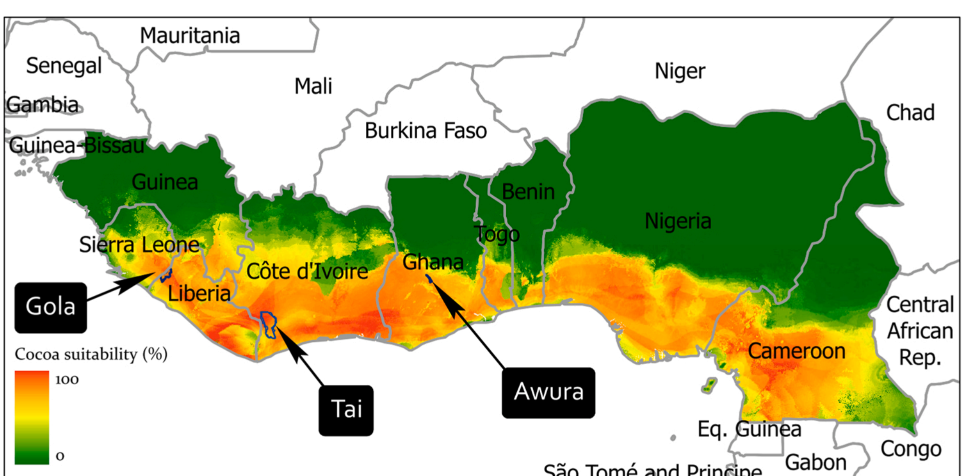

Fig. 1. study area showing cocoa suitability based on Schroth et al. (2016) and location of some key protected areas in Liberia, Côte d'Ivoire and Ghana (UNEP-WCMC and IUCN, 2019).

on IUCN range data (IUCN, 2017) for all available species of mammals, amphibians, birds and reptiles and refined to include only terrestrial area of habitat (AOH) (Brooks et al., 2019). We rasterised and refined the data at 1 km resolution using data on species' altitudinal limits and habitat affiliations from IUCN, linked to a global habitat types map for 2015 (Jung et al., 2020), and GMTED2010 (Danielson and Gesch, 2011) elevation data. The habitat types map is based on Copernicus land cover for 2015 (Buchhorn et al., 2019), at 100 m resolution, with additional classes relevant for mapping biodiversity. This fine resolution habitat information was maintained for each AOH by calculating fractional values for each 1 km cell.

In addition to a baseline rarity-weighted richness score for 2015, we adapted a change metric from van Soesbergen et al. (2017) to show the proportional change in AOH for each species in the deforestation scenario (see below), aggregated across species to provide a change value for each pixel. We compared these rarity-weighted richness layers with modelled cocoa suitability for the region (Schroth et al., 2016) and the ecosystem services layers using a series of bivariate maps.

2.4. Modelling potential pressure from cocoa expansion

We modelled potential cocoa-driven deforestation using a rule-based land use change model (QUICKLUC 2.0, Mulligan, 2015a). Deforestation rates calculated from Terra-I (Reymondin et al., 2012) deforestation data between 2010 and 2017 were projected forward to 2050 within areas currently suitable for cocoa (suitability greater than 25% based on Schroth et al., 2016). This period was chosen, partly for practical reasons as Terra-I rate data for this period is readily available in the QUICKLUC 2.0 model but also as it is representative of longer-term recent deforestation trends. Comparison with additional deforestation data obtained from Global Forest Watch portal (https://www.globalforestwatch.org/; Hansen et al., 2013) shows comparable rates for this period (Fig S0), as well as a previous period (2004–2010) but even higher deforestation rates for more recent years (2017–2020). Therefore, we consider the deforestation rates for this period plausible for future projections. Modelled forest loss was replaced with full sun cocoa, represented as having a per-pixel tree cover of 5% or less. It should be noted that the Copernicus fractional tree cover includes tree crowns 5 m tall and above and *Theobroma cacao* is often between 4.5 to just above 5 m tall. We assume here that new plantations will have average heights below 5 m.

Cocoa, and especially cocoa in shaded agroforestry systems, behaves much like a forest from the perspective of the ecosystem services included in this assessment (water-related services, carbon and forest resources). The effect of conversion from a mature forest to an agroforestry system would be more difficult to distinguish at the scale of this study than conversion from forest or cocoa agroforestry to full sun cocoa. As the latter has been the trend in West Africa until now, we assume a full sun system replacing forest.

The cocoa expansion scenario data was then used to assess potential changes in ecosystem services in the Co$tingNature model, and to model potential changes in biodiversity using the biodiversity change metric. We acknowledge that not all past deforestation used in the expansion model can be attributed to cocoa, but since there are no data that allows for making the distinction, we use all deforestation in suitable areas to highlight potential risk.

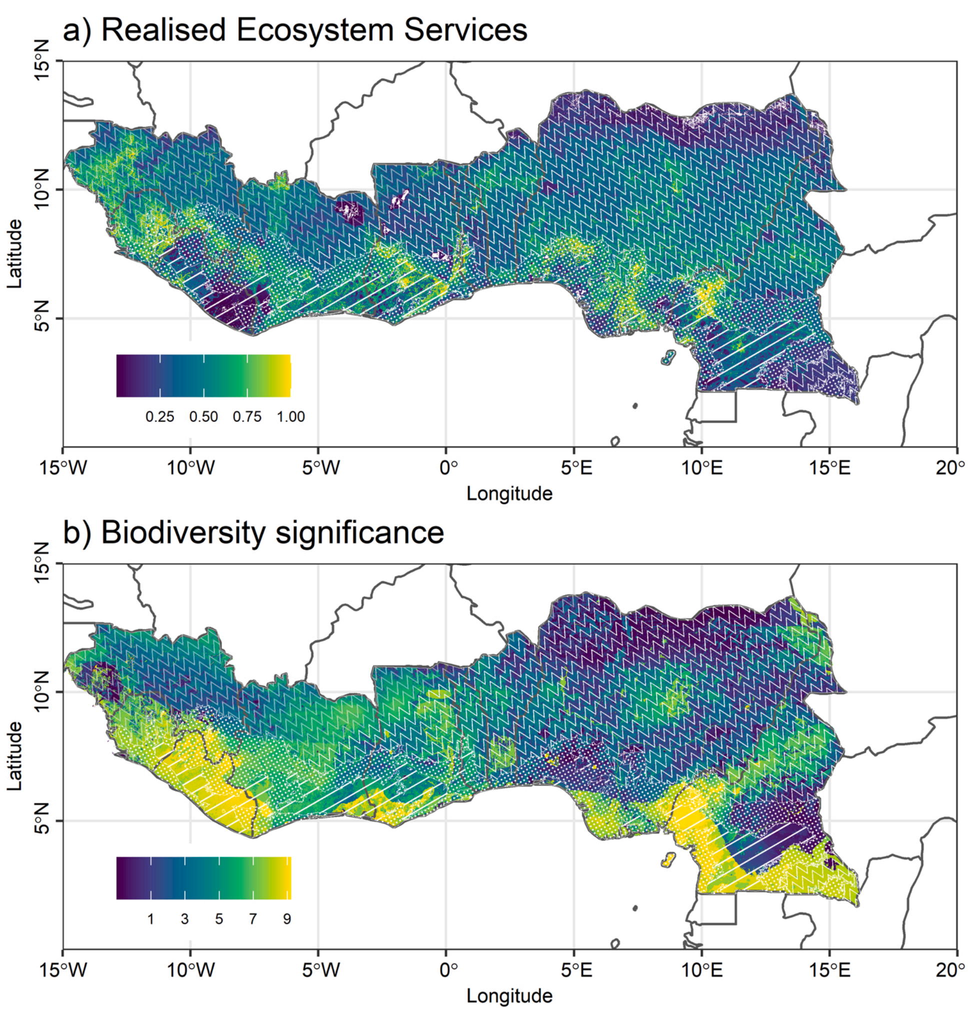

Fig. 2. a) Baseline relative (0−1) total realised ecosystem services in the cocoa zone; b) Baseline biodiversity significance (log 10 rarity weighted richness for mammals, amphibians and birds) in the cocoa zone. Three broad zones of increasing vulnerability to climate change based on Schroth et al. (2017) are represented by striped areas (remain suitable), dotted areas (remain suitable with certain adaptation needs) and waves (are or become unsuitable). In reality these zones do not have clear-cut boundaries.

3. Results

3.1. Ecosystem services and biodiversity significance

The total realised ecosystem services for the cocoa zone (Fig. 2a) shows high values in agricultural areas of Sierra Leone, Ghana (around the city of Kumasi) and Cameroon close to the Nigerian border. The key realised services in these areas are carbon sequestration, natural hazard mitigation and fuelwood provision, indicating relatively high tree cover densities in these landscapes, because trees are important to support the delivery of multiple ecosystem services as well as the presence of beneficiaries. High potential services on the other hand (Fig. S2a) are found in low population but densely forested areas (Fig. S1) such as in Liberia (including Gola rainforest on the border with Sierra Leone), Taï forest in Côte d'Ivoire, and along the border between Ghana and Togo.

The areas of highest significance for biodiversity in the cocoa belt (Fig. 2b) are concentrated in the forested areas of Cameroon and Liberia with more scattered patches in Côte d'Ivoire, Ghana and Nigeria (Fig S1). Areas of high biodiversity significance are typically clustered in remaining protected areas of forest (Côte d'Ivoire and Ghana) or in mountainous forest areas (such as those in the North-western region of Cameroon). The latter likely reflects natural endemism from isolation by geographic barriers, whereas elsewhere this may be due, in part, to land use change leaving pockets of biodiversity surrounded by human dominated landscapes (as seen in the remaining forest patches in Ghana).

3.2. Areas at risk

Areas that are important for the delivery of ecosystem services and biodiversity may be at risk due to current high (dark blue colours in Figs. 3a and 3b, and Fig. S3) and future continued (Fig. 2 and S2) suitability for cocoa. In areas important for realised ecosystem services (Fig. 3a), the main risk is a loss of tree cover within often largely agricultural landscapes. Expansion into the densely forested areas e.g., in Liberia and Cameroon and the remnants in Côte d'Ivoire and Ghana would affect important national level (potential) ecosystem services, such as carbon sequestration (Fig. S3).

Areas with high risk to biodiversity from cocoa-driven deforestation (Fig. 3b, dark blue) are found in forest patches in the south of Ghana and west of Côte d'Ivoire (e.g., the Taï forest). Large tracts of such areas are also present in Liberia and Western Cameroon.

Based on deforestation between 2010 and 2017 (Fig.S4a), the QUICKLUC land use change model projects a mean loss of tree cover to 2050 of 5% within the areas currently suitable for cocoa production (Fig. S4b) but in some countries future tree cover loss is expected to be much higher, e.g., Sierra Leone (18%), Guinea (18%) and Ghana (10%). In the West of Côte d'Ivoire, Ghana and Cameroon, much past and projected future deforestation takes place in highly suitable areas for cocoa. In Sierra Leone most past and projected future deforestation is

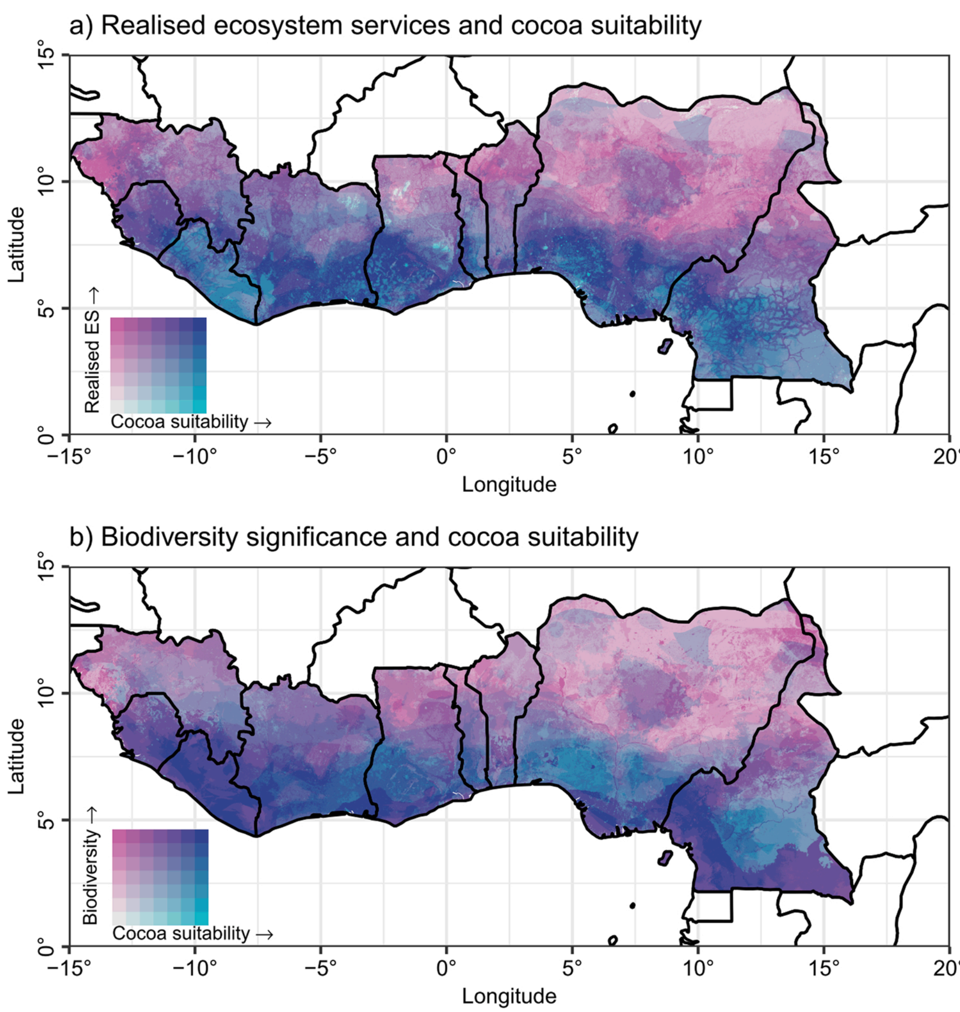

Fig. 3. a) Bivariate map showing modelled cocoa suitability against ecosystem services delivery (see Fig. S3 for potential ecosystem services); b) Bivariate map showing modelled cocoa suitability against biodiversity significance (based on rarity-weighted richness). Dark blue areas are high in ecosystem services delivery or biodiversity as well as high risk from cocoa-driven deforestation.

outside the most climatically suitable area for cocoa, but deforestation is projected to increase towards the more suitable Gola rainforest area near the Liberia border. Deforestation in Guinea is concentrated in its forested areas north of Liberia (Fig. S4). A continuation of current deforestation trends in the West African cocoa belt (due to cocoa or other land uses) poses a significant risk to biodiversity and ecosystem services (Figs. 4a and 4b).

The projected conversions from forest to full sun cocoa lead to decreases in the bundle of realised ecosystem services (Fig. 4a) with a spatial footprint similar to where the key land use changes are projected to take place (Fig. S4b). Carbon sequestration rates will be lower in cocoa than under primary forest cover. Water quantity is projected to increase in most areas due to reduced vegetative water use by trees. However, clean water provision reduces as it is assumed runoff from cocoa plantations is more polluted than runoff from natural forest. The results for biodiversity (Fig. 4b) also follow the spatial pattern of projected deforestation but the magnitude of changes is much larger in Sierra Leone, on the border between Guinea and Liberia and in parts of Ghana.

4. Discussion

4.1. Areas at risk

The results show that, throughout the cocoa zone of West Africa, areas of high biodiversity and areas that are important for ecosystem services provision (realised Fig. 2a and potential Fig S2a) are also highly climatically suitable for cocoa (Figs. 3a and 3b). Areas that are highly suitable for cocoa that also show high realised ecosystem services (fuel wood, non-timber forest products (NTFP), carbon, natural hazard mitigation, clean water) are generally found in populated landscapes with relatively high tree cover. These are also the main cocoa growing areas (Schroth et al., 2016). A reduction in tree cover in such areas, including due to the prevailing trend towards low or no-shading in cocoa and other perennial crops (Feintrenie et al., 2010; Vaast and Somarriba, 2014), potentially compounded by increased pressure from loss in suitability for cocoa in other areas (Schroth et al., 2017) would lead to a decline in realised ecosystem services. The most densely forested areas in the region (Fig S1) on the other hand are crucial for the maintenance of potential ecosystem services (including water provision, hazard mitigation and carbon sequestration) and biodiversity (Fig.S7).

Many remaining unprotected forests in West Africa (Fig S5) are highly suitable for cocoa growing (Fig S5, S6) and therefore potentially at risk. Yet, whether cocoa is likely to play a role in driving deforestation in these areas varies per country. In Côte d'Ivoire, a study by Vivideconomics (2020) found that cocoa was the main driver of deforestation in the West of the country (the main cocoa area of the country), with a majority taking place in small unprotected rural forests. These forests likely play an important role in providing local ecosystem services such as fuelwood and other forest products. In Ghana apart from cocoa (WRI, 2019) other factors also play an important role in recent deforestation, such as illegal mining and large-scale agricultural

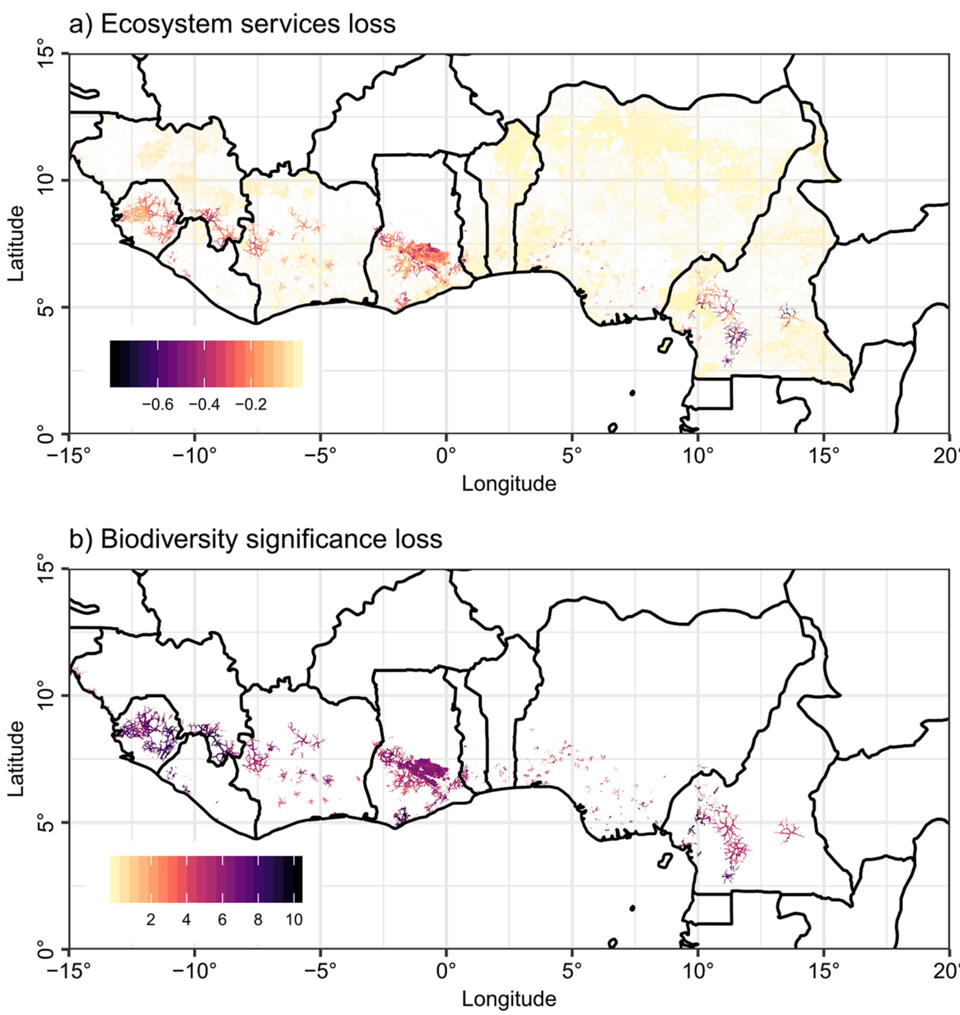

Fig. 4. a) Relative loss in bundle of ecosystem services for deforestation scenario; b) Loss in biodiversity (log10, proportional change in habitat) for deforestation scenario. Darker colours represent greater loss.

expansion for other crops (Satelligence, 2019). In Sierra Leone, until 2013 the largest crop expansion was attributable to cassava, but estimated cocoa area shows a strong increase from 2016 (FAO, 2020; Fig. S8). Countries such as Cameroon or Liberia aim to further develop or revitalise their cocoa sector (Lescuyer et al., 2019; NC3P, 2021). In Cameroon, the government aims to double cocoa production by 2030, which could lead to further expansion: the estimated harvested area for cocoa has already increased 50% in the past 10 years in Cameroon, whilst yields stayed the same (Lescuyer et al., 2019). In the same period, harvested area doubled in Liberia (FAO, 2020; Fig.S8). Detailed investigation by Ordway et al. (2019) on deforestation risk from commodity expansion found that cocoa is the fastest expanding export-oriented crop across SSA (including Cameroon, Côte d'Ivoire, Liberia and Sierra Leone). Shifting agriculture, which includes smallholder cash crops such as cocoa, is by far the largest driver of deforestation in all studied countries (Curtis et al., 2018).

Climate change is expected to reduce the suitability of land for cocoa production in parts of West Africa, including in the main producing countries Ghana and Cote d'Ivoire. Suitability is expected to remain high or increase in important biodiversity and ecosystem services areas in Liberia, Ghana and Cameroon (Schroth et al. (2017) Shifts in cocoa production from areas of declining suitability towards areas that remain suitable may increase pressure on these areas, either through intensification to meet production goals or expansion into remaining forest areas. In addition, declining yields in West Africa (due to management and climate) could lead to a shift in production area into the forested areas of Cameroon and further (de Beule, Jassogne et al., 2014; Schroth et al., 2017), compounding trends of commodity crop expansion into the forests of Central Africa (Ordway et al., 2017). In areas that will become unsuitable for cocoa, a replacement by annual crops would lead to a loss in ecosystem services provided by perennial systems such as cocoa (Schroth et al., 2017).

4.2. Methods and assumptions

Since there were no land use data available identifying cocoa throughout the region at the time of analysis, we assess risk from cocoa growing based on climatic suitability, with the assumption that those areas that are most suitable are either already cocoa or highly at risk to become cocoa. We also project past deforestation rates forward, to highlight the risks of a continuation of these trends. We cannot say with certainty that recent deforestation was for cocoa because the small-scale nature of cocoa growing makes it difficult to identify cocoa driven deforestation using satellite imagery. Recently, Vivideconomics (2020) published a map of cocoa growing in Côte d'Ivoire, based on a deep learning method with remote sensing. Such data can enable more refined analysis of risk of expansion, but mapping cocoa, especially agroforestry cocoa, remains challenging due to its similarity to forest from a remote sensing point of view.

We recognise the apparent conflation of climatic suitability for cocoa and the West African rainforest zone, and thus the potential risk of cocoa-related deforestation, in our study. Indeed, the lack of spatial data on cocoa growing areas and expansion is an important limitation. On the other hand, much recent and projected future deforestation takes place outside the most suitable and densely forested areas (near settlements and in remaining smaller rural forests, in the forest-savanna transition zone). In Cameroon, cocoa production is promoted in non-cocoa areas, including the savanna transition zone to increase production, carbon sequestration and avoid deforestation (Government of Cameroon, 2021). Despite the data limitations, we believe that adding insights on vulnerability to future climate change, country specific recent cocoa area production and deforestation trends allows for making reasonable inferences about potential deforestation risks due to cocoa production.

Other factors than climate may also affect the suitability for cocoa growing and potential productivity, such as soils and management practices (e.g. soil fertility management, shading) which vary within the region and within countries. Including these could help refine the identification of areas with higher risks for conversion now and in the future. Next steps will build on this work to incorporate further understanding on climate-associated risks, including from shifts in cocoa production due to climate change, the potential role of different adaptation strategies and their implications for biodiversity and ecosystem services in the region.

We did not consider cocoa or other crops grown within the cocoa production system as (provisioning) ecosystem services. It is evident there is a trade-off between these production related ecosystem services and the informal fuelwood and NTFP provisioning services that benefit more local beneficiaries. Our analysis suggests that increased conversion of natural land to full-sun cocoa would result in an overall loss of (non-cocoa) ecosystem services provision, though this was not analysed in economic terms. Increased cocoa production may yield important (short term) economic benefits but these are likely benefiting fewer people and risk the loss of important services such as carbon sequestration and hazard mitigation.

In this analysis, we used only comprehensively assessed terrestrial groups for West Africa (i.e., all terrestrial vertebrates). Thus, areas of importance for plant and invertebrate taxa are not represented, apart from where they overlap such areas for vertebrates. The species' ranges have errors of omission and commission (Brooks et al., 2019), and although refinement to AOH can reduce some commission errors, these uncertainties should be considered when interpreting the results.

4.3. Implications of the study

Understanding where the risks are is crucial to prioritise or target actions to tackle deforestation in the cocoa sector. Zero-deforestation initiatives generally prohibit deforestation in High Conservation Values or High Carbon Stock (HCV/HCS) areas (Proforest, 2014). The assessments required for such approaches are costly, but their prioritisation could be informed by considering those areas most at risk as highlighted through this study.

The results showcase the need for context specific action, and to prioritise action. We found two broad types of risk which call for different strategies to help maintain forests, biodiversity and ecosystem services in the cocoa producing region of West Africa.

First, in traditional producer countries such as Ghana and Côte d'Ivoire, much of the suitable areas have already been converted. The most biodiverse areas and areas important for global ecosystem services, such as carbon sequestration but also landscape level hazard mitigation and clean water provision (Fig.S3), are now found mainly in or near protected forests that are sometimes highly degraded. (Fig S1 and S7; Vivideconomics, 2020). Conservation and restoration should be a major focus to maintain ecosystem services provision from these areas (Nijmeijer et al., 2019), as is indeed planned in the REDD+ programmes of countries such as Côte d'Ivoire and Ghana and the Cocoa and Forests Initiative (GFC, 2016; IDH, 2017; Republic of Côte d'Ivoire, 2017; Republic of Ghana, 2018). In existing cocoa growing areas, tree cover should be maintained or increased where possible, including through agroforestry as an alternative to full sun systems to support the delivery of ecosystem services (Fig. 3a) as also argued by Schroth et al. (2011), based on empirical analysis. Cocoa agroforestry can help maintain significant biodiversity in agricultural landscapes (Clough et al., 2011; Maney et al., 2022), support local and global ecosystem services (Vaast and Somarriba, 2014) and play a role in maintaining landscape connectivity (Schroth and Harvey, 2007).

Second, in areas where land highly suitable for cocoa overlaps greatly with high biodiversity values (i.e., Liberia and Cameroon, see Fig. 3b) and where (unprotected) forests are still relatively intact, there is a need for systematic land use planning to limit potential impacts of cocoa development on forests and other areas of high conservation value. Schroth et al. (2011), proposes that in such potential "frontier" areas, focus should be on minimising forest conversion by intensifying production. However, in countries with large areas of remaining forests and that depend on agriculture as a major source of income and foreign exchange to develop their economies (Ordway et al., 2017), some expansion into remaining unprotected forests (e.g., in Cameroon's "non-permanent forest domain"), may be unavoidable and a combination of approaches balancing different objectives (economic development, livelihoods, biodiversity and global and local ecosystem services) in the most land-efficient way is required.

The results of this study can support planning for such developments. For example, by identifying forest areas that are relatively more important for biodiversity and/or potential ecosystem services than they are suitable for cocoa and should therefore be prioritised for conservation (pink to purple colours in Fig. 3b and S3), or by helping to prioritise areas for HCV/HCS assessments in unprotected areas that are highly suitable and support high biodiversity and potential ecosystem services (dark blue areas in Fig. 3b and S3). The approach used in this study, in combination with other criteria such as for example population, infrastructure and access to markets, can support (national level) spatial planning for sustainable cocoa or other commodity developments.

The risks to biodiversity and ecosystem services from cocoa expansion and intensification in West Africa are likely to be compounded by climate change Therefore, adaptation strategies on a large scale may need to be developed over the coming decades to avoid the loss but also improve the conservation of biodiversity and provision of ecosystem services across the region. At the local scale, context adapted climate smart agroforestry systems can potentially support this adaptation, whilst at the same time increasing biodiversity, ecosystem services and farmer resilience in current cocoa growing areas (Vaast and Somarriba, 2014; Niether et al., 2020).

Finally, these results highlight that throughout the cocoa growing region of West Africa, sustainable, climate resilient intensification approaches for cocoa should be promoted to increase and support productivity on existing land over the longer term, so that the historical expansion and associated deforestation seen in some countries in the past are avoided where there are still large amounts of relatively intact forests (see also Gockowski and Sonwa, 2011). Furthermore, any expansion (in forested of degraded areas) should entail cultivation systems that maximise benefits for livelihoods, biodiversity and local and global ecosystem services (e.g., global climate change mitigation goals).

5. Conclusions

Mapping areas of risk to biodiversity and ecosystem services from expansion and intensification of cocoa production in the cocoa belt of West Africa can be used to prioritise sustainability efforts and plan for sustainable cocoa (and other commodity) development. Risks vary spatially and over time and require different strategies for action, from the protection of remaining forests, prioritising areas for conservation in forested landscapes where agricultural development is to take place, to supporting the maintenance or increase of tree cover in existing cocoa landscapes informed by local agroecological and socio-economic contexts. Finally, the results highlight the need to increase the productivity and resilience of cocoa systems on existing land over the longer term. We hope this work contributes to help guide policy and planning as well as further prioritise action to support the sustainable development of cocoa production into the future.

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Declaration of Competing Interest

The authors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2022.106142.

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