

Cocoa expansion around Ghana's protected areas is associated with food crop displacement and forest loss inside them

Corresponding Author: Dr Thomas Addoah

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Decision Letter:

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Dear Mr Addoah,

First of all, please allow me to apologise for the delay in sending a decision on your manuscript titled "Cocoa expansion displaces food crops into protected forests, but sustainability programmes reduce loss". It has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

In particular, for publication in Communications Earth & Environment, we request that you

(1) provide methodological justification, including choice of time period, sample size, and technique, and explain all definitions used and

(2) discuss the limitations of your approach and provide a deep insight into your findings, including the underlying mechanism and policy insights.

Please submit your point-by-point responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

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may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Fiona Tang, PhD
Editorial Board Member
Communications Earth & Environment
orcid.org/0000-0002-8119-4016

Martina Grecequet, PhD
Senior Editor, Communications Earth & Environment
Consulting Editor, Communications Sustainability

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REVIEWER COMMENTS:

Reviewer #3 (Remarks to the Author):

Manuscript Title: Cocoa expansion displaces food crops into protected forests, but sustainability programmes reduce loss

This manuscript examines how cocoa expansion indirectly drives forest loss by displacing food crops into protected areas and assesses the mitigating role of agroforestry and cocoa-focused sustainability interventions. The study integrates spatial and socioeconomic analyses in Ghana, addressing a highly relevant and timely topic with the potential to make a meaningful contribution. However, some areas require revision to strengthen the manuscript's clarity and methodological rigor.

1. Please include a brief statement on the study's limitations in the abstract.
2. The authors are encouraged to incorporate a concise summary of the existing literature to better situate their research within the broader academic conversation.
3. The analysis spans two distinct periods (2000–2019 and 2022–2024). The justification provided in the methods for excluding the intervening years (2020 and 2021) is unclear. Please clarify this rationale. Furthermore, the authors should explain why alternative satellite data sources covering the entire 2000–2024 period were not utilized so that dynamic effect can be investigated.
4. Survey Methodology (Section 6.2.2): The description of the village-level surveys lacks clarity regarding sample size and sampling technique. This section should be revised to provide these essential details. Additionally, please ensure the methodology clearly distinguishes between the various data collection tools employed (e.g., surveys, focus group discussions, key informant interviews) and explicitly states their respective purposes and target respondents.
5. Results Section (2.2): The content currently presented in Section 2.2 pertains to methodological description rather than results. This part should be relocated to the Methods section.
6. Control variable (Table 1): In the beta regression analysis of the relationship between cocoa saturation outside forest reserves and food crop deforestation/degradation inside reserves (2000–2019), please justify the inclusion of "2020 Population Density" as a control variable, given that the analysis period ends in 2019.

Overall, the manuscript is detailed and well-structured. If the above minor points are addressed, I recommend it for publication.

Reviewer #4 (Remarks to the Author):

This study presents a timely and valuable examination of indirect deforestation resulting from cocoa expansion, addressing a significant gap in sustainability research. To enhance the rigor and impact of the work, the methodology and the discussion of policy mechanisms could be further developed. We suggest that major revisions be undertaken to strengthen these aspects prior to publication.

Major Comments:

1. The results show associations, not strict causality. To strengthen causal inference, future research could consider spatial econometric methods, which are well-suited for analyzing spillover effects. The current analysis may be limited by the sample size and data granularity. Given the valuable field research conducted, integrating a case study approach could offer complementary insights into the socio-economic drivers of land-use change and deforestation.
2. The policy analysis in the Discussion is superficial. It lacks a deep exploration of mechanisms, supported by economic theory, data, or case evidence. For example, the finding on limited agroforestry impact needs a deeper discussion. Was it due to low adoption (statistical power) or ineffective systems? Exploring this would add depth.

Specific Suggestions:

3. The 2000–2019 period is long. Subdividing it could reveal different driving factors for deforestation over time.
4. The current title does not clearly communicate the core study.
5. The introduction is somewhat lengthy and could be simplified. The hypothesis-style writing on page 4 lacks narrative flow.

Revise these paragraphs to better highlight the study's innovations.

6. The "cocoa saturation" variable is innovative. Please add a clear operational definition in the Methods (e.g., cocoa area as a proportion of total agricultural land within a buffer).

7. The full definition of "AME" (page 6, Table 1) should be provided.

8. Each table needs a self-explanatory note.

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Version 1:

Decision Letter:

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Dear Mr Addoah,

Your manuscript titled "Cocoa expansion, food crop displacement, and forest loss in Ghana's protected areas" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Martina Grecequet, PhD
Senior Editor,
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #3 (Remarks to the Author):

Thank you for giving me the opportunity to review the revised version of the manuscript. I have carefully reviewed the authors' responses and the corresponding revisions made to the manuscript. I am satisfied that they have adequately addressed all of the concerns I raised in my previous review. Therefore, I recommend that the manuscript can be published in its current status.

Reviewer #4 (Remarks to the Author):

The author's response is appropriate, and I have no further comments.

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Manuscript Title: Cocoa expansion displaces food crops into protected forests, but sustainability programmes reduce loss

This manuscript examines how cocoa expansion indirectly drives forest loss by displacing food crops into protected areas and assesses the mitigating role of agroforestry and cocoa-focused sustainability interventions. The study integrates spatial and socioeconomic analyses in Ghana, addressing a highly relevant and timely topic with the potential to make a meaningful contribution. However, some areas require revision to strengthen the manuscript's clarity and methodological rigor.

1. Please include a brief statement on the study's limitations in the abstract.
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3. The analysis spans two distinct periods (2000–2019 and 2022–2024). The justification provided in the methods for excluding the intervening years (2020 and 2021) is unclear. Please clarify this rationale. Furthermore, the authors should explain why alternative satellite data sources covering the entire 2000–2024 period were not utilized so that dynamic effect can be investigated.
4. Survey Methodology (Section 6.2.2): The description of the village-level surveys lacks clarity regarding sample size and sampling technique. This section should be revised to provide these essential details. Additionally, please ensure the methodology clearly distinguishes between the various data collection tools employed (e.g., surveys, focus group discussions, key informant interviews) and explicitly states their respective purposes and target respondents.
5. Results Section (2.2): The content currently presented in Section 2.2 pertains to methodological description rather than results. This part should be relocated to the Methods section.
6. Control variable (Table 1): In the beta regression analysis of the relationship between cocoa saturation outside forest reserves and food crop deforestation/degradation inside reserves (2000–2019), please justify the inclusion of “2020 Population Density” as a control variable, given that the analysis period ends in 2019.

Overall, the manuscript is detailed and well-structured. If the above minor points are addressed, I recommend it for publication.

COMMSENV-25-4426: "Cocoa expansion displaces food crops into protected forests, but sustainability programmes reduce loss

NOTE ON LINE NUMBERS: All **line numbers** refers to line numbers in the clean manuscript text (no track changes).

Reviewer #3

Comment	Response
Please include a brief statement on the study's limitations in the abstract.	We thank the reviewer for this suggestion. We have added a brief statement in the abstract highlighting the causal limitation of the study (lines 14-15)
The authors are encouraged to incorporate a concise summary of the existing literature to better situate their research within the broader academic conversation.	We thank the reviewer for this suggestion. We have revised the introduction to better situate our research within the broader academic conversation on land-use displacement and sustainability standards. See lines 58-79; and lines 85-102 that synthesise the existing literature and clarify our contribution.
The analysis spans two distinct periods (2000–2019 and 2022–2024). The justification provided in the methods for excluding the intervening years (2020 and 2021) is unclear. Please clarify this rationale. Furthermore, the authors should explain why alternative satellite data sources covering the entire 2000–2024 period were not utilised so that dynamic effect can be investigated.	We thank the reviewer for this methodological question. We excluded 2020–2021 to preserve temporal ordering between predictor and outcome measurement: Our cocoa saturation variable is derived from the Kalischek et al. (2023) dataset, which captures cocoa plantations present between 2018–2021 and reflects established farms planted no later than 2019 (due to the time lag required for newly planted cocoa trees to become detectable in satellite imagery). Including forest loss from 2020–2021 would introduce simultaneity bias, as we would be measuring outcomes during the same period in which the predictor is being classified. Additionally, the 2022–2024 period aligns with the agronomic practices and timeline of displacement: farmers typically intercrop food crops with young cocoa for 3-4 years, but once cocoa matures and starts producing (years 3-5), intercropping becomes unviable and food crops must be relocated. The 2022–2024 window therefore captures displacement occurring 3-5 years post-establishment, when pressure peaks. Regarding alternative data, while continuous forest loss data exist (JRC TMF dataset, which we use), the constraint is cocoa

	data. The Kalischek et al. dataset which is the most accurate available (validated by CIAT and the World Cocoa Foundation) is cross-sectional, not time-series. Developing annual cocoa maps for 2000–2024 was beyond the scope of this study. Our two-period design (2000–2019 for long-term patterns, 2022–2024 for recent dynamics) addresses temporal variation while maintaining methodological rigor. We have clarified this in Methods (Section 6.1; lines 436–455).
Survey Methodology (Section 6.2.2): The description of the village-level surveys lacks clarity regarding sample size and sampling technique. This section should be revised to provide these essential details. Additionally, please ensure the methodology clearly distinguishes between the various data collection tools employed (e.g., surveys, focus group discussions, key informant interviews) and explicitly states their respective purposes and target respondents.	We thank the reviewer for this important comment. We have substantially revised Sections 6.1, 6.2.2, and 6.2.3 to clarify sample size, sampling technique, and data collection methods. Village sampling: The 77 villages were drawn from 298 villages with boundaries both inside and outside forest reserves. The 298-village universe was constructed using Thiessen (Voronoi) polygons around village locations, as official boundaries do not exist (Supplementary Fig. S1). The 77 villages were selected as part of a broader research project involving fieldwork during June–September 2022. While not randomly selected, they are geographically distributed across 14 forest reserves and 8 districts. Balance tests confirm representativeness: no significant differences from the 298-village population in cocoa saturation ($p=0.645$), shade cover ($p=0.439$), or other key variables (all $p>0.05$; Supplementary Table S3). The availability of detailed qualitative data from these villages, including company presence, sustainability programmes, and farmer perspectives on land-use dynamics, makes them particularly valuable for linking spatial patterns to on-the-ground processes. Data collection methods and their purposes: We employed two distinct data collection approaches: 1. <i>Village-level group meetings</i> (N = 77 villages, conducted June–September 2022): These meetings brought together cocoa-buying clerks, village leaders (chiefs, assembly members), and where available, COCOBOD and company extension officers. Each

	meeting had two components: a) Structured survey component where participants systematically identified all cocoa-buying companies active in the village during the five years prior to 2022, reported which companies implemented sustainability programmes (e.g., agroforestry promotion, forest protection, livelihood support, productivity interventions), and confirmed village participation in the Modified Taungya System. This information was triangulated with informal interviews with district company staff and publicly available company documents to construct the village-level exposure variable used in our regression analysis. b) Qualitative discussion component. Following the structured questions, meetings transitioned to open discussions on broader issues including local livelihood challenges, land-use decisions, deforestation dynamics, food crop displacement into forest reserves, forest protection efforts, and perceptions of cocoa companies' deforestation policies. These discussions provided valuable qualitative insights into the mechanisms linking cocoa expansion to food crop displacement, which complement and contextualise our quantitative spatial analysis. 2. <i>Key informant interviews</i> (N = 6, conducted virtually in 2024): Semi-structured interviews with government officials, scientists, and NGO representatives working in Ghana's cocoa sector. These interviews explored broader sector-level perspectives on the relationship between cocoa expansion and food crop deforestation, focusing on push and pull factors driving displacement into forest reserves. These provided expert contextualization of observed patterns and informed our interpretation of results.
Results Section (2.2): The content currently presented in Section 2.2 pertains to methodological	We thank the reviewer for this observation. We have moved methodological details from Section 2.2 to Methods (Sections 6.1 and 6.3).

description rather than results. This part should be relocated to the Methods section.	However, we retained a brief introductory paragraph in Section 2.2, lines 143-148 , explaining the two-period design, as is standard in Nature portfolio journals, where Methods appear after Results. This minimal framing orients readers without duplicating Methods content.
Control variable (Table 1): In the beta regression analysis of the relationship between cocoa saturation outside forest reserves and food crop deforestation/degradation inside reserves (2000–2019), please justify the inclusion of “2020 Population Density” as a control variable, given that the analysis period ends in 2019.	We thank the reviewer for this observation. We revised the 2000-2019 analysis to use 2010 population density (midpoint of study period, Ghana census year) instead of 2020, addressing the temporal ordering concern. For 2022-2024, we use 2020 population density. Our models also control for distance to district capital and roads, capturing additional population-related accessibility pressures. Results for our main variables of interest remain substantively unchanged.

Reviewer #4

Comments	Response
This study presents a timely and valuable examination of indirect deforestation resulting from cocoa expansion, addressing a significant gap in sustainability research. To enhance the rigor and impact of the work, the methodology and the discussion of policy mechanisms could be further developed. We suggest that major revisions be undertaken to strengthen these aspects prior to publication.	We are grateful for this feedback on the timeliness and value of our work while providing constructive feedback on strengthening methodology and policy analysis.
The results show associations, not strict causality. To strengthen causal inference, future research could consider spatial econometric methods, which are well-suited for analysing spillover effects. The current analysis may be limited by the sample size and data granularity. Given the valuable field research conducted, integrating a	We thank the reviewer for this important observation. We fully agree our study is correlational and cannot establish strict causality from an econometric perspective. We have revised the manuscript to ensure claims appropriately reflect this limitation. However, our integration of qualitative insights

case study approach could offer complementary insights into the socio-economic drivers of land-use change and deforestation.

from the case study analysis provides additional evidence to triangulate and improve confidence around the conclusions drawn. To address this concern, the following changes have been made:

Framing and language: Throughout the manuscript, we now consistently use associative language ('associated with,' 'linked to,' 'corresponds with', 'correlated with') and have revised the title to avoid causal implications. In the Abstract, we have added a sentence to clarify this limitation.

Strengthened Limitations section 4.0: We now explicitly address causal inference constraints, noting that while spatial patterns, temporal alignment, and farmer interviews converge to support displacement, unobserved village characteristics (land tenure history, governance capacity, market access) could confound results. We acknowledge that establishing stricter causal claims would require panel data, spatial econometric methods, or quasi-experimental designs beyond our current scope, and note that future research could employ in-depth case studies to trace decision-making processes. See lines (373 -376)

Discussion framing: We revised key sentences to acknowledge correlational design while maintaining the strength of triangulated evidence. These revisions ensure acknowledgement of the constraints of our method/design while presenting our valuable empirical contribution: the first village-scale quantitative evidence linking cocoa patterns to

	food crop forest loss, supported by convergent qualitative evidence.
The policy analysis in the Discussion is superficial. It lacks a deep exploration of mechanisms, supported by economic theory, data, or case evidence. For example, the finding on limited agroforestry impact needs a deeper discussion. Was it due to low adoption (statistical power) or ineffective systems? Exploring this would add depth.	We thank the reviewer for this constructive criticism. We have substantially revised and expanded Section 3.2 to provide deeper mechanistic analysis grounded in economic theory and empirical evidence from our fieldwork. Key additions: 1. We distinguish between statistical power limitations (low adoption, narrow variation) and substantive barriers to effectiveness, noting that 14.7% median shade coverage falls far below thresholds (30-65%) identified in other tropical systems. 2. Drawing on village meeting discussions, we highlight a perverse institutional arrangement relating to lack of tree tenure where naturally occurring on-farm trees belong to the state. Farmers reported that state's Forestry Commission grants permits allowing external contractors to harvest trees from their farms, often damaging cocoa. This creates strong disincentives for tree retention and undermines agroforestry promotion, a critical barrier absent from existing policy discussions. 3. We clarify that our shade cover data capture all trees in cocoa areas (not only programme-promoted trees) and that most corporate agroforestry promotion began in recent years post 2017, likely

	too recent for satellite detection of newly planted trees. 4. We explain low adoption through short-term yield-shade trade-offs, tenure insecurity (especially for migrant farmers), and misalignment between programme-promoted timber species and farmer-preferred fruit trees. 5. We identify specific reforms needed particularly tree tenure reform, payments for ecosystem services, and landscape-level integration, to enable agroforestry to achieve conservation potential. We believe this expanded discussion addresses the reviewer's concern about superficial policy analysis on agroforestry findings
The 2000-2019 period is long. Subdividing it could reveal different driving factors for deforestation over time.	We thank the reviewer for this suggestion. We analysed 2000-2019 as a single period for three reasons: First, our cocoa saturation predictor is cross-sectional (circa 2019). Without time-series cocoa data, subdividing the outcome period would not reveal different driving factors, as the predictor remains constant. Second, the full period captures cumulative displacement relationships. Shorter sub-periods would reduce statistical power (N=77) and introduce noise from year-to-year fluctuations unrelated to underlying land-use pressures. Third, our two-period design already addresses temporal dynamics: 2000-2019 captures long-term patterns, while 2022-2024 assesses recent dynamics including sustainability interventions. We acknowledge that future research with annual cocoa time-series data could examine finer

	temporal variation and have added this to the Limitations section 4.0, lines (380 -382)
The current title does not clearly communicate the core study.	We thank the reviewer for this important observation. We recognise that our original title used causal language ('displaces,' 'reduce') that overstates the strength of inference possible from our correlational study design. We have revised the title to: <i>'Cocoa expansion, food crop displacement, and forest loss in Ghana's protected areas'.</i>
The introduction is somewhat lengthy and could be simplified. The hypothesis-style writing on page 4 lacks narrative flow. Revise these paragraphs to better highlight the study's innovations.	We thank the reviewer for this constructive feedback. We have revised the introduction to improve narrative flow, particularly in the final paragraphs describing our study's objectives and innovations. See lines 103-111. However, the other reviewer asked for more literature review, so we have not been able to shorten the introduction overall.
The "cocoa saturation" variable is innovative. Please add a clear operational definition in the Methods (e.g., cocoa area as a proportion of total agricultural land within a buffer).	We thank the reviewer for this positive feedback on our cocoa saturation variable. We agree that a clearer operational definition would improve clarity. We have made two revisions: In the Introduction (lines 103-104), when first introducing the term, we now provide a brief parenthetical definition: 'cocoa saturation outside reserves (the proportion of non-reserve land under cocoa)' In the Methods (Section 6.2.1; lines 472-476), we provide the full operational definition with formula: Cocoa Saturation = (Area of cocoa plantations outside reserves) / (Total land area outside reserves within village polygon)

	This variable ranges from 0 (no cocoa) to 1 (all non-reserve land is cocoa), with higher values indicating greater land-use pressure from cocoa expansion.
The full definition of "AME" (page 6, Table 1) should be provided.	We thank the reviewer for this observation. While we define AME (Average Marginal Effects) in the Methods, Section 6.3; lines 614-616, the acronym appears in Table 1 before readers reach that definition. We have made the following revisions: 1. Added to Table 1 note: 'AME = Average Marginal Effects, representing the average change in the predicted outcome (forest loss proportion) for a one-unit change in the predictor, averaged across all observations. AMEs facilitate interpretation of beta regression coefficients on the original proportion scale.' 2. First mention in Results (line 154): Changed to 'The Average Marginal Effects (AME) results show...' to spell out the acronym at first use.
Each table needs a self-explanatory note.	We thank the reviewer for this suggestion. We have revised all table notes to be self-explanatory, providing sufficient context for readers to understand each table independently. The revised notes include: (1) brief description of the dependent variable and analysis period, (2) explanation of key variables, (3) definition of statistical terms (e.g., AME, beta coefficients), and (4) interpretation guidance.