The Economic Dependency of Ghana's Cocoa Sector on Pollination Services

Abstract

The cocoa economy of Ghana depends on insect pollination. We use an economy-wide computable general equilibrium (CGE) model with an explicit representation of the ten regions of Ghana to model a decline in the cocoa pollinator population. Model scenarios are guided by a systematic literature review, supplemented with expert interviews. Changes in pollinator populations affect poor and rural households more than urban and rich households. Substantial income losses and decreased food consumption are observed in the Western region, the major cocoa-growing region. Declining cocoa pollinator numbers lead to an increased production of all other agricultural commodities, which considerably benefits the food processing sector. At the same time, the cocoa processing sector suffers high losses. Apart from activities related to agriculture, substantial changes are observed in the mining and finance industry with both considerably increasing their output if pollinator numbers are on the decline.

Keywords: Pollination services; General equilibrium modeling; Cocoa; Ghana; Smallholder farmers

1. Introduction

Insect pollination plays a crucial role in agricultural systems across the world (Klein *et al.*, 2007). Global declines of insect pollinators threaten ecosystem functions, agricultural production and food security (van der Sluijs and Vaage, 2016; Cardoso *et al.*, 2020). Growing concern about plummeting pollinator populations have led to an increasing number of studies quantifying the economic value of pollination services (Breeze *et al.*, 2016). In these studies, West Africa is often identified as a region that relies strongly on insect pollination, since cocoa, essentially dependent on insect pollination, plays an important role in the economy of Côte d'Ivoire and Ghana (Bauer and Wing, 2016).

Ghana is the second largest exporter of cocoa, contributing about 17% to world supplies (WTO, 2022). Cocoa production adds around 3% to Ghana's gross domestic product (GDP) (Ghana Statistical Service, 2015) and provides income and to some extent food security to more than 800,000 cocoa farming households (Hashmiu, Agbenyega and Dawoe, 2022). The role of the cocoa sector in the future economic development of Ghana has been analyzed by Breisinger *et al.* (2008) who used a computable general equilibrium (CGE) model to evaluate necessary production improvements to become a middle-income country. Income of cocoa farmers in Ghana (and Côte d'Ivoire) has been the topic of much debate for many years and has culminated in the introduction of the Living Income Differential (LID), which has been analyzed by Boysen *et al.* (2023) using a partial equilibrium (PE) model. Wongnaa *et al.* (2021a) investigated the economic impacts of adopting manual pollination for cocoa trees, showing the great importance of adequate pollination.

With this study we want to add to the rich body of pollination economics. There are three common approaches used in the economic valuation of pollination services: the summation of the total crop value produced in a year that depends on pollination, analysis of the social welfare changes associated with vanishing natural pollination and estimating the replacement cost of having to substitute natural pollination (Bauer and Wing, 2016). These widely used methods follow the PE approach (Gallai *et al.*, 2009; Lippert, Feuerbacher and Narjes, 2021), which allows to analyze the value of pollination services for an individual market (e.g. the agricultural sector), but ignore forward and backward linkages to other sectors of the economy. General equilibrium (GE) approaches on the other hand allow for the inclusion of these linkages and thus effects of changes in pollination services on the whole economy of a country. Despite evidence for their potential advantages (Bauer and Wing, 2016), GE approaches have yet to be widely used in the valuation of pollination services.

Against this background, this study aims to use a CGE model for a single country (i.e., Ghana) to identify the effects of changes in the cocoa pollinator population on the economy. A systematic literature review is conducted to identify the most important cocoa pollinators in Ghana, which will help to classify insect families of great importance from a production point of view. Furthermore, the review guides the scenario design, to create realistic, albeit stylized, scenarios. These scenarios are aimed to be closer to reality than the standard scenarios used in most pollination valuation studies, which assume a complete extinction of all pollinators. The effects of decreasing cocoa pollinator numbers on the agricultural sector, other sectors of the economy, disaggregated household accounts and the economy as a whole are analyzed.

To our knowledge this is the first study investigating the economic value of cocoa pollination for a single country.

2. Material and methods

2.1 Model description

CGE models have been commonly used to model and analyze the effects of different policies and economic shocks. While they have seldomly been applied to simulate a loss of pollinators, there exist examples of CGE models used for this exact purpose (Bauer and Wing, 2016). CGE models are roughly composed of two main components: A Social Accounting Matrix (SAM) as a data source and the model code that represents the economic relationships in mathematical formulas. CGE models aim to reflect the entire circular flow of an economy, which can be illustrated by the following example: A household in the Western region of Ghana allocates land, labor and capital to the Western cocoa activity and in return receives a factor income, which is then allocated to consumption, savings, transfers and taxes. The Western cocoa activity pays intermediate inputs and factors, which is financed by selling its output (i.e., cocoa). Therefore, the income of one institution is an expenditure of another institution in the economy.

The CGE model adapted for this study is the single country, comparative-static STAGE 2 model. A detailed description of the model can be found in McDonald and Thierfelder (2015).

The model makes the following major assumptions:

1. Markets are perfectly competitive.
2. Consumers maximize utility.
3. Producers maximize profits.
4. Prices adjust so that markets clear.

Furthermore, the Linear Expenditure System is assumed for household consumption. While consumption of own produce plays a significant role in Ghana, this is not explicitly reflected in the model. Instead, farming households buy their produce at the commodity market. Fixed world prices are assumed, except for cocoa, as Ghana is the second largest producer of cocoa with a significant market share. Land, which is split into cocoa and agricultural land, is assumed to be immobile (i.e., cocoa land cannot be turned into agricultural land). Labor is split into agricultural and non-agricultural labor, and it is assumed that there is no mobility between these two categories (e.g., a cocoa farmer can become a maize farmer but not a doctor).

These assumptions are made due to the short time horizon of the model. Furthermore, we assume that reductions in revenue from one tax source are compensated by another tax (i.e., reductions in the export tax revenue are compensated through an increased direct tax rate.

2.2 SAM and other data

A SAM of Ghana in 2015 that was specifically designed for analysis of the cocoa sector was used and modified as a data source for the CGE model (European Commission *et al.*, 2021). Due to the high level of detail of the original SAM, some accounts were aggregated, leading to a reduction of accounts from 309 to 193. A detailed list of all original SAM accounts and their corresponding new accounts, as well as the corresponding model sets is available upon request.

Table 1 gives an overview of the aggregated SAM Accounts. The SAM has 43 commodity accounts and 39 activity accounts. Agricultural commodities (crops and livestock) are produced by the 10 regional household activity accounts. They represent the 10 regions of Ghana (e.g., a Volta region household produces maize, sorghum etc.). In addition, the SAM also depicts households as producers of cocoa for the six cocoa-growing regions of Ghana. For the other activities the respective commodity can be directly mapped (e.g., construction activity to construction commodity). The labor factor is separated into agricultural and non-agricultural labor, skilled and unskilled labor and by region. The land factor is separated into agricultural and cocoa land. Lastly, the household accounts are separated into rural and urban and by region. In addition, the household accounts are separated into two groups depending on their per capita expenditure. The first group consists of the first expenditure quintile, while the second group encompasses the other four quintiles.

Table 1 - Adapted Ghana SAM accounts. Source: Based on European Commission et al. (2021).

Commodities	Agricultural (19), Natural Resources (4), Food (8), Industrial (1), Utility (1), Construction (1), Service (9)		
Activities	Household as producer of agricultural commodities (10)[1], Household as producer of cocoa (6)[2], Natural Resources (3), Food (8), Industrial (1), Utility (1), Construction (1), Service (9)		
Factors	Labor	Non-Agricultural, Agricultural	Skilled (20)[1], Unskilled (20)[1]
	Land	Agricultural (10)[1], Cocoa (6)[2]	
	Capital	Crops (1), Livestock (1), Mining (1), Other (1)	
Margins	Trade and transport margin (1), Export margin (1)		
Institutions	Households	Rural, Urban	1st expenditure quintile (20)[1], 2nd – 5th expenditure quintile (20)[1]
	Enterprises (1), Government (1), Rest of the world (1)		
Taxes	Import (1), Export (1), Sales (1), Direct (1)		
Capital	Changes in stocks (1), Savings-Investments (1)		

Note: Numbers in parentheses describe the quantity of accounts (e.g., there are 19 agricultural commodity accounts). [1] Disaggregated for the 10 regions of Ghana. [2] Disaggregated for the 6 cocoa-growing regions of Ghana.

In addition to the SAM, data on factor use was obtained from the Labour Force Survey 2015 (Ghana Statistical Service, 2016). Land use data was drawn from publicly available data of the Ghana Forestry Commission. The original land use data was disaggregated for the 261 districts of Ghana and was aggregated by the author for the 10 regions of Ghana (Ghana Forestry Commission, 2020).

2.3 Systematic literature review

A systematic literature review on cocoa pollination was completed to identify the most important cocoa pollinators and identify realistic scenarios for the economic valuation of cocoa pollination in Ghana. The systematic literature review was conducted using the scientific database Scopus and Google Scholar, following the four stages of the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analysis) framework (Moher *et al.*, 2009). The literature was screened from 04/01/2022 until 09/30/2022. The Scopus database was searched using the following keywords: “cocoa OR cacao OR "Theobroma cacao" AND pollin*”. Google Scholar was screened using the adjusted following keywords: “cacao or cocoa and pollination or pollinator". The Google scholar search was limited to the first 200 results, following recommendations by Haddaway *et al.* (2015). Moreaux *et al.* (2022) similarly applied this restriction while reviewing the pollination of coffee. Scopus and Google Scholar were both analyzed separately, which ensures an additional check for entries that appear in both Scopus and Google Scholar. This is a slight modification to the standard PRISM scheme, where duplicates are removed early on. In addition to the entries from Scopus and Google Scholar, external full-text articles were also included. Furthermore, for the identification of pollinators, abstracts were also included. For all external entries, the initial source was documented. A comprehensive list of all studies and their origin is available upon request. During the screening and eligibility phase of the systematic literature review, either the reason for the removal (i.e., if there is no access to the publication) or the main theme of the publication was documented (e.g., focus of the paper is on genetics and not related to insect pollination). Figure 1 gives an overview of the four phases of the PRISM review process.

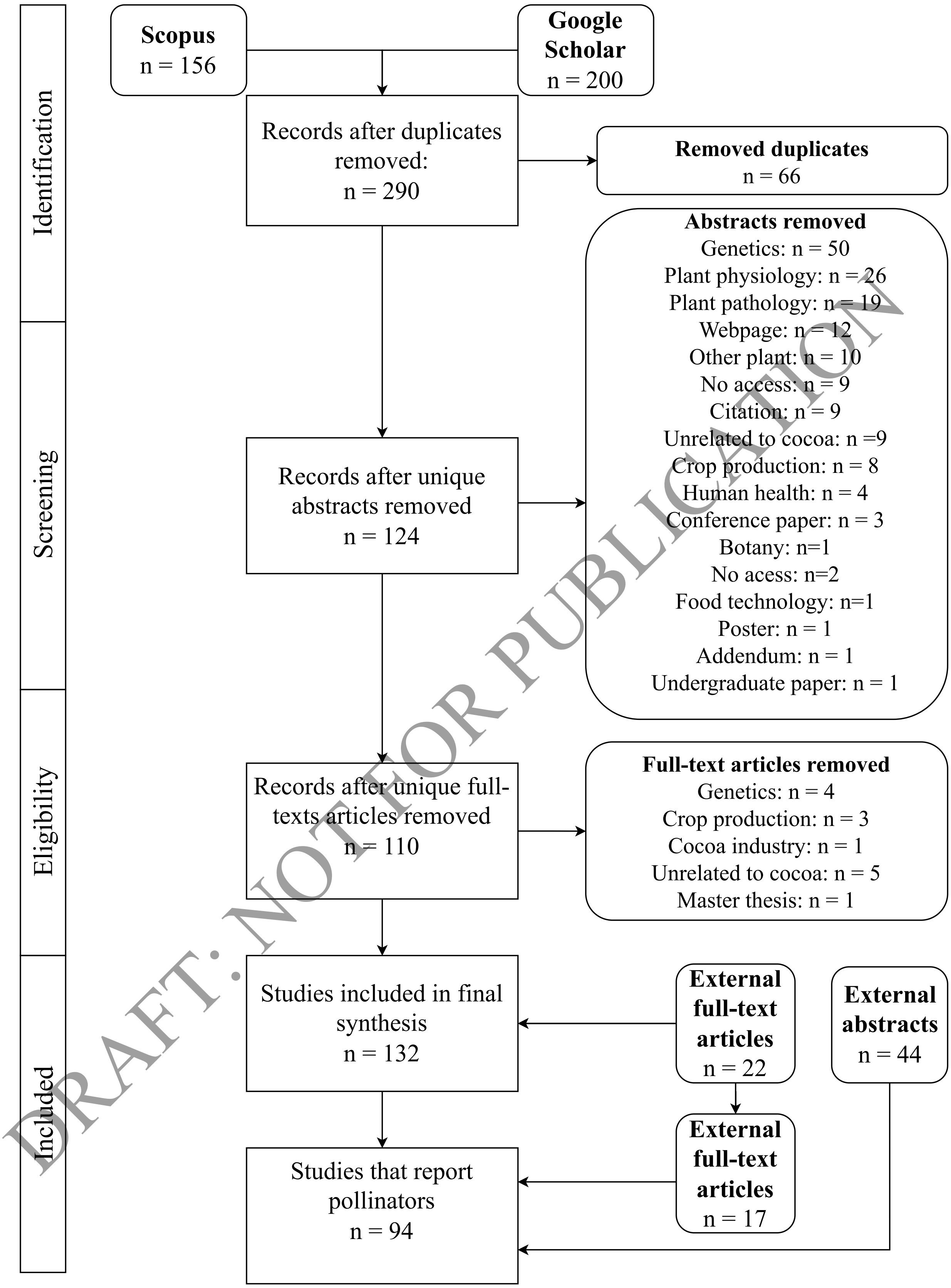

Figure 1 – PRISMA flow chart. Source: Author's own design, concept by Moher *et al.* (2009).

3. Results

3.1 Literature review results and model scenarios

Based on the 94 identified studies, which report pollinators, we were able to identify the most important cocoa pollinators in all cocoa-growing regions (Figure 2), and for Ghana specifically (Figure 3). *Ceratopogonidae* are both globally, and in Ghana specifically the most diverse pollinator family, with *Forcipomyia* midges being the most diverse genus in Ghana. They are not only the most diverse group of pollinators, but also the most important ones in Ghana (Adjaloo and Oduro, 2013). Therefore, from a purely production-oriented viewpoint, they are the most relevant group of insects for this analysis. The focus of the scenario design was therefore on this group of insects.

The systematic literature review showed that currently we are not able to derive a meaningful functional relationship between cocoa pollinator abundance and cocoa yields: Based on the literature, we know that at a pollination intensity of 0%, which is the case if no insects are present and no manual pollination is applied, no pods are forming (Young, 1983; Bos *et al.*, 2007).

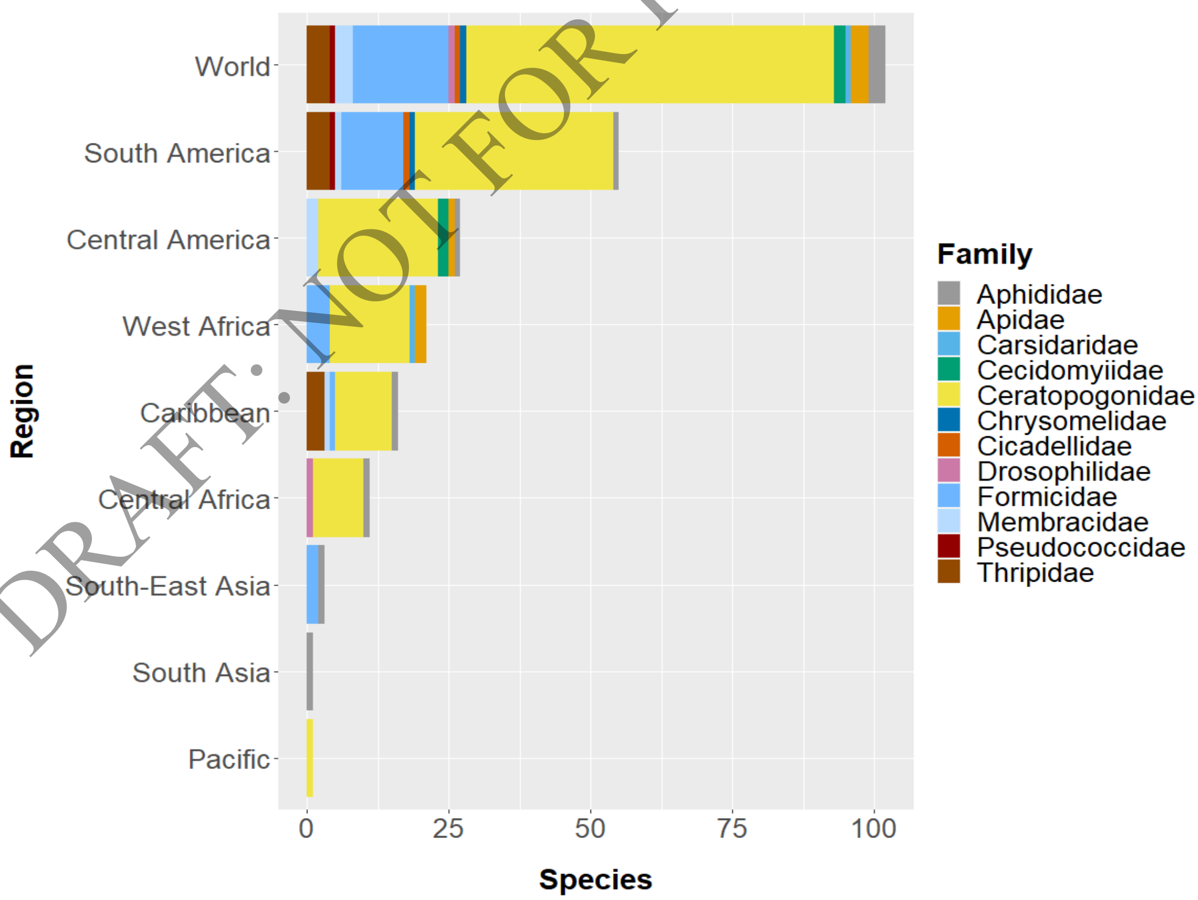

Figure 2 - Global diversity of cocoa flower visitors. Source: Author's systematic review.

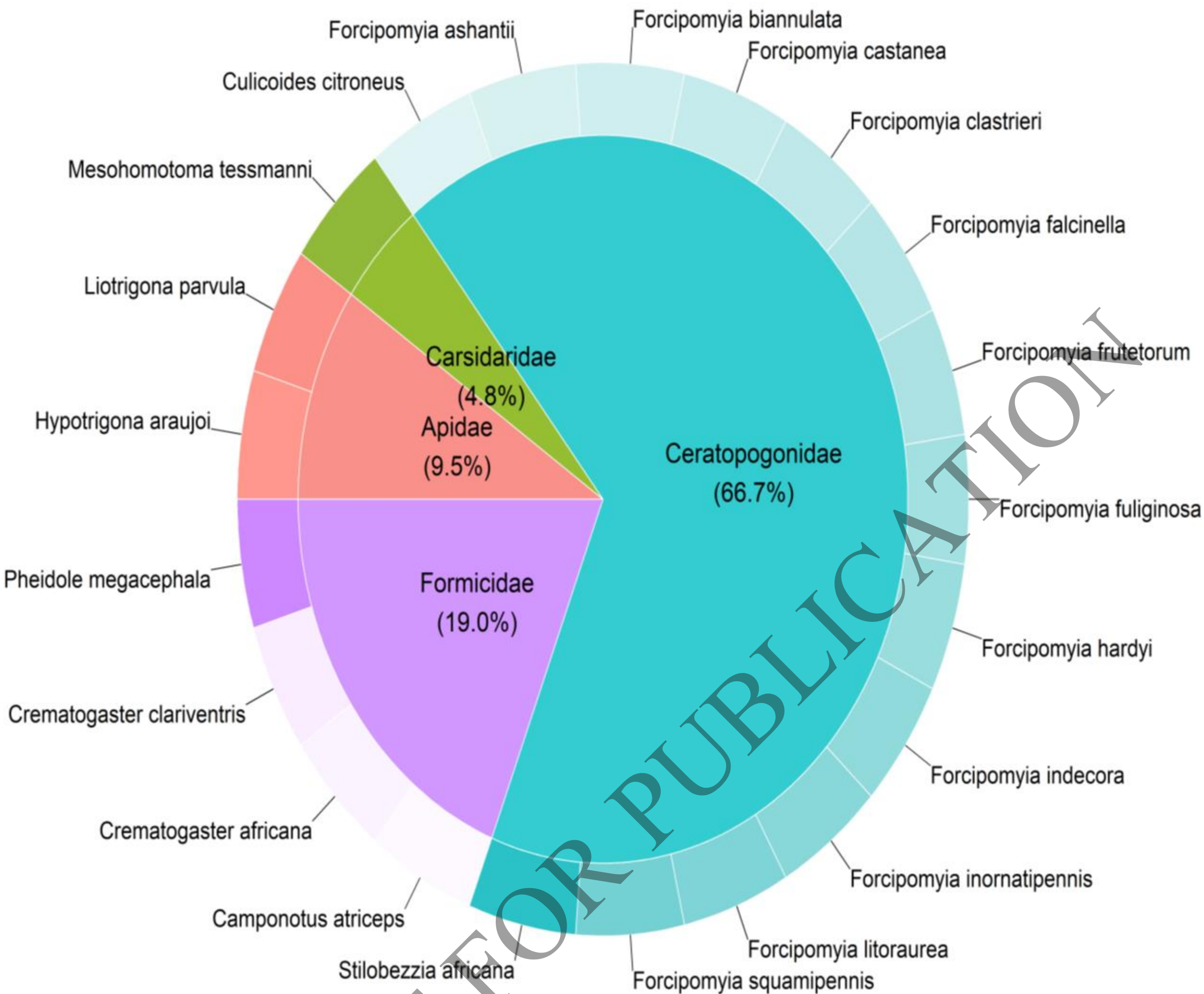

Figure 3 - Ghana's cocoa pollinators. Source: Author's systematic review.

Furthermore, we know that an increase of pollination intensity can lead to higher yields, until a certain pollination optimum is reached (Groeneveld *et al.*, 2010; Forbes and Northfield, 2017). What we do not know is the functional form of this yield function and whether a marginal increase or decrease of pollination intensity, given the current circumstances, would lead to lower or higher yields.

Due to the above-mentioned knowledge gaps in the ecological relationships, working with a stylized pollinator shock is currently the best and only option. Three changes in the pollinator population are modeled. These three changes are a reduction of the cocoa pollinator populations in Ghana by 10%, 30% and 50% (Table 2). Changes of the pollinator population of that magnitude have been observed in Ghana, (Frimpong *et al.*, 2011; Kwapong and Frimpong, 2013), although it should be noted that a decrease of 50% is rather at the extreme end. Such decreases in the cocoa pollinator population could be driven by increased insecticide usage (Kwapong and Frimpong, 2013) or prolonged droughts (Arnold *et al.*, 2018).

For the relationship between pollinator population changes and productivity, a linear relationship is assumed. The changes in cocoa productivity are calculated by multiplying the commonly used dependency ratio of 95% (Bauer and Wing, 2016), which is derived from a study by Klein *et al.* (2007), with the respective change in the pollinator population (i.e. a decrease of pollinators by 10% leads to a decreased productivity of 9.5%) (Table 2). Moreover, it is assumed that ceteris paribus (c.p.) only pollinator populations change, which is a common assumption in the economic study of pollinators (Bauer and Wing, 2010). The stylized scenarios were discussed with cocoa pollination experts in Ghana, which agreed that the population changes are within the realm of possibilities, and as mentioned could be caused by prolonged draughts or an inadequate pesticide application.These three scenarios were then implemented as productivity shocks to all six regional cocoa growing activities.

Table 2 – Pollinator shock scenarios. Source: Author's own calculations using the dependency ratio by Klein *et al.* (2007).

	Pollinator shock 1 (Polli 1)	**Pollinator shock 2 (Polli 2)**	**Pollinator shock 3 (Polli 3)**
%-change of pollinator population	-10.00%	-30.00%	-50.00%
%-change of cocoa productivity	-9.50	-28.50	-47.50%

3.2 Macro model results

The modeled decline of cocoa pollinators leads to a sharp reduction of cocoa production (Table 3), with the Polli 3 scenario causing a production reduction of 63%. The reduced cocoa production in Ghana leads to an increase of the world market price by 11% under Polli 3.

Table 3 - Agricultural production changes. Source: Author's own calculations.

Agricultural sector	Polli 1	Polli 2	Polli 3
Cocoa production	-13.56	-39.55	-63.35
Cocoa - world market price	1.51	5.31	10.93
Agricultural production (excl. cocoa)	0.43	1.38	2.48
Agricultural producer prices (excl. cocoa)	-0.48	-1.47	-2.52
Food exports (excl. cocoa)	2.43	7.84	14.05
Food imports (excl. cocoa)	-0.39	-1.20	-2.03

While cocoa production decreases, all other agricultural production increases, following reduced producer prices, which decrease by 2.5% (Polli 3). This increased agricultural production leads to an increase of food exports, and a reduction of food imports.

Leaving the agricultural sector, and focusing on the macro level effects, a negative impact on GDP, absorption, government consumption and investment is observed (Table 4). The effect on GDP and absorption are minor for all scenarios (less than 1%), but the effect on government consumption and investment is slightly more significant, leading to a reduction by 1.1% and 1.21% respectively in the Polli 2 scenario. Reduced investments at the macro level are explained by reduced household income at the aggregate level which affects their savings and investments negatively.

Table 4 - Macro level changes. Source: Author's own calculations.

GDP Components (Real Macro Totals)	Polli 1	Polli 2	Polli 3
GDP	-0.06	-0.17	-0.23
Absorption	-0.15	-0.45	-0.71
Average household-consumption	0.00	0.03	0.10
Government consumption	-0.36	-1.10	-1.83
Investment	-0.40	-1.21	-2.03
Export	0.36	1.12	1.93
Import	0.03	0.10	0.18
Other macro-level indicators			
Real exchange rate	0.46	1.41	2.38
Purchaser price index	0.19	0.66	1.29
Average household income	-0.08	-0.21	-0.34
Domestic production			
Primary sector	0.16	0.54	1.04
Secondary sector	-0.09	-0.29	-0.52
Tertiary sector	0.12	0.38	0.67
Factor income			
Skilled labor	0.32	1.00	1.74
Unskilled labor	0.32	1.01	1.78
Skilled agricultural labor	-3.09	-9.45	-15.99
Unskilled agricultural labor	-2.35	-7.20	-12.19
Agricultural land	-0.80	-2.46	-4.21
Cocoa land	-11.95	-35.83	-59.11
Capital - crops	-2.18	-6.71	-11.44
Capital - livestock	-0.60	-1.83	-3.10
Capital - mining	1.02	3.10	5.17
Capital - other	0.29	0.90	1.56

Exports are positively affected by decreasing pollinator populations and increase by 1.12% in the Polli 2 Scenario. The increased exports are for the most part driven by increased mining and finance exports, which in the base already contribute 44% and 22% to exports respectively (based on own SAM calculations). Average household-consumption and imports are positively but not sizably affected by decreasing pollinator populations.

The real exchange rate depreciates following the pollination shocks with the Polli 2 scenario leading to a depreciation of 1.41%. Similarly, the purchaser price index increases, while average household income decreases. Domestic production of the primary and tertiary sector is positively affected by decreasing pollinator populations, while the secondary sector is negatively affected. These effects on the three sectors are nevertheless rather minor. Factor income from non-agricultural factors is positively affected by the scenarios simulating a pollinator decline, while the negative effect on agricultural factors is considerable. Factor income from skilled agricultural labor decreases by 9.45% in the Polli 2 scenario and factor income from cocoa land decreases substantially (35.83%) in the Polli 2 scenario.

Focusing on the sectors, that are strongly affected by the scenarios (changes greater than 1% under Polli 3), it can be observed that all food processing activities are benefiting from decreasing pollinator numbers (Table 5).

Table 5 - Major changes in domestic production. Source: Author's own calculations.

Activity	Polli 1	Polli 2	Polli 3
Agricultural processing			
Meat, fish and dairy	4.70	15.27	27.55
Fruit and vegetable processing	2.81	8.95	15.82
Fats and oils	0.49	1.55	2.72
Grain milling	0.37	1.17	2.03
Other foods (incl. cocoa processing)	-6.12	-20.64	-38.46
Oil and mineral extraction			
Crude oil	-0.24	-0.70	-1.16
Other mining	1.98	5.90	9.66
Other activities			
Construction	-0.37	-1.13	-1.88
Accommodation and food services	0.70	2.19	3.80
Finance	0.85	2.54	4.17
Public administration	-0.30	-0.91	-1.52
Education	-0.21	-0.64	-1.05
Health and social work	-0.33	-1.00	-1.67

Cocoa processing on the other hand decreases by 38.46% under Polli 3. The mining and finance industry substantially benefit from decreasing cocoa pollinators, with the former increasing their activity by 9.66% under Polli 3.

Lastly, analyzing the effects of all three scenarios on income, we observe a very slight decrease in income following decreasing pollinator numbers (Figure 4). At the country level all three scenarios lead to a reduction of income. Focusing on specific household groups, we can see that cocoa regions, rural households and poor households suffer income losses while non-cocoa regions, urban households and rich households slightly increase their income, following decreasing pollinator numbers. The greatest decrease in income is observed for rural and poor (expenditure quintile 1) households, which suffer an income loss of 3.7% under Polli 3.

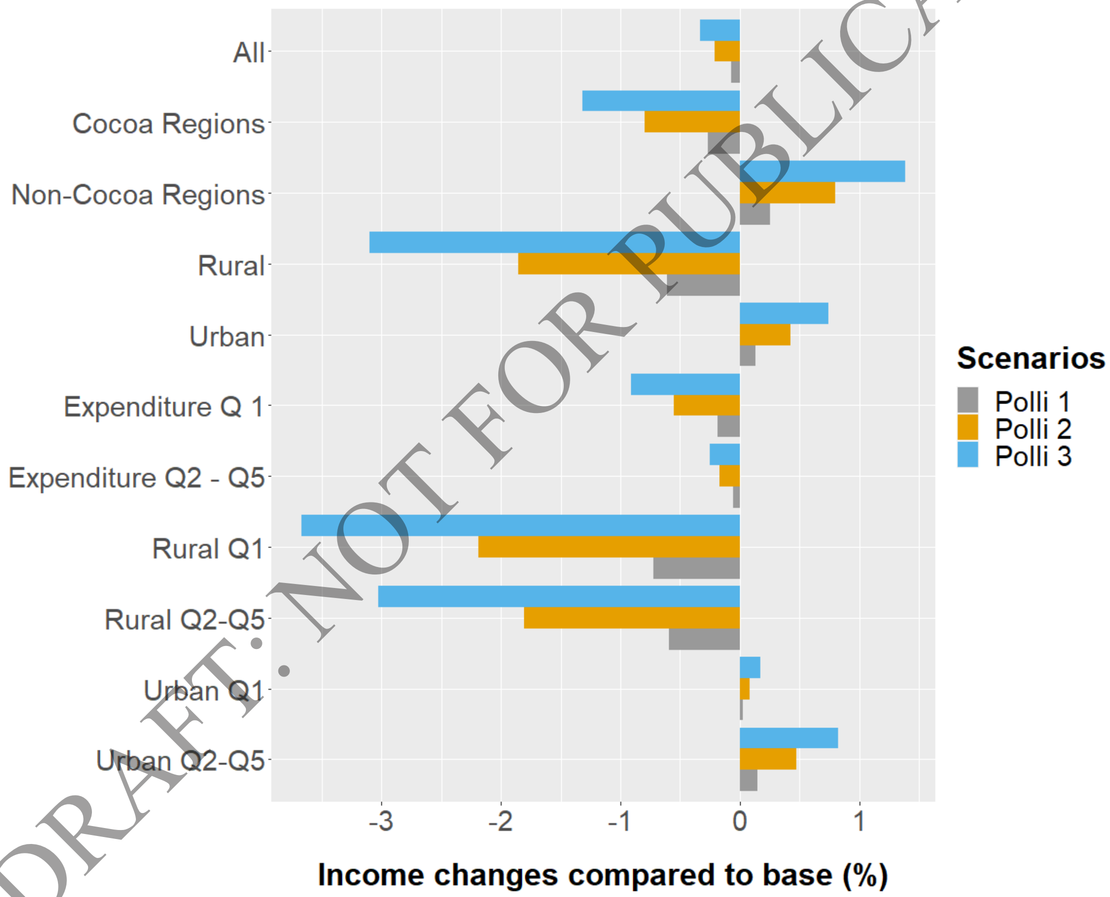

Figure 4 - Income changes of different household groups. Source: Author's own calculations.

3.3 Regional results

Since cocoa production only takes place in certain regions, and predominantly in the Western region, it makes sense to also highlight the regional effects of these three scenarios. The decline of pollinators leads to a sharp reduction of cocoa production in all cocoa-growing regions by more than 60% under Polli3 (Figure 5). While cocoa production decreases, all other agricultural production increases, as labor and capital are freed from cocoa production. Magnitude of these results are highly regional, with cocoa-growing regions experiencing the greatest increase in agricultural production.

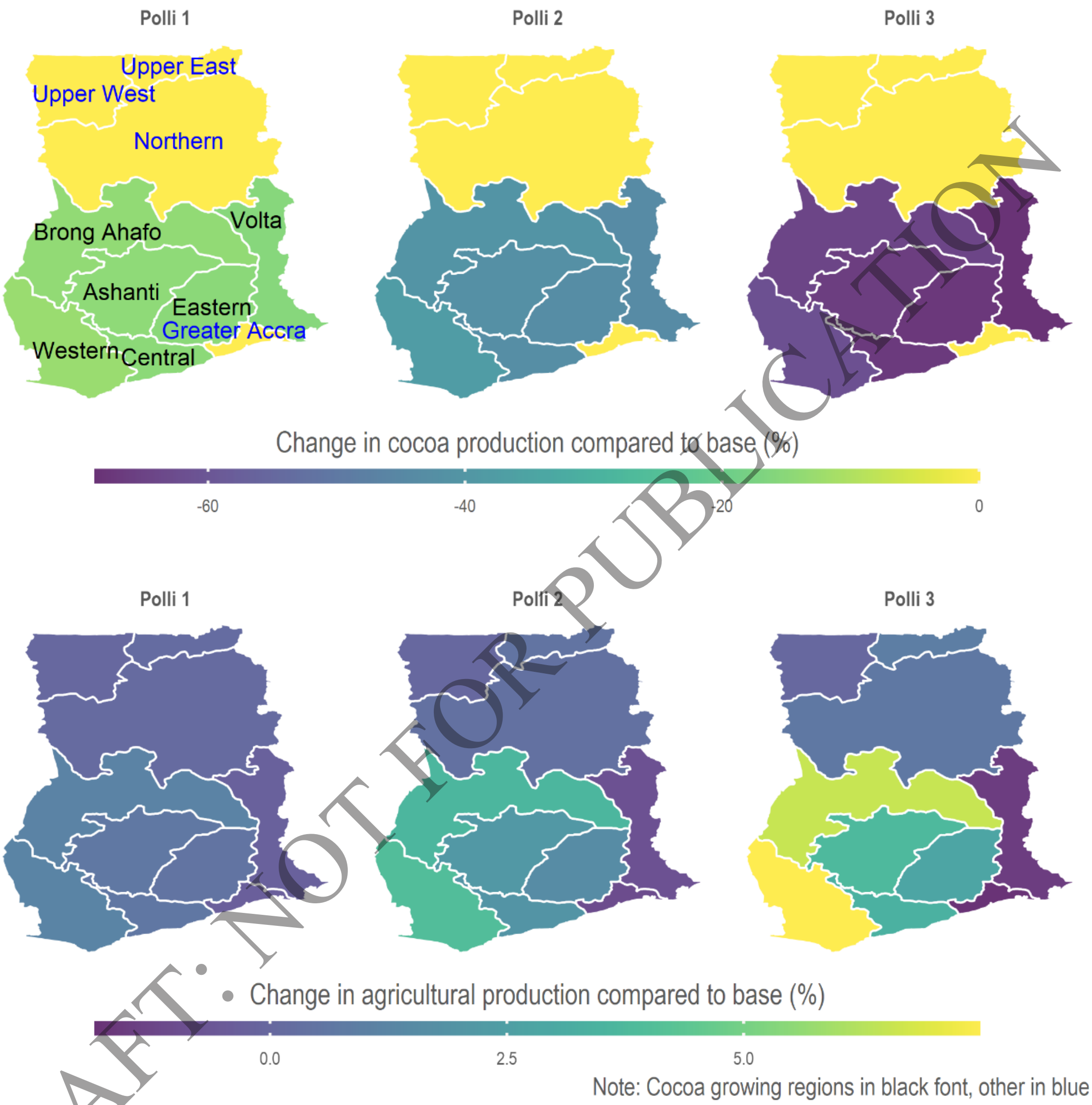

Figure 5 - Regional cocoa and agricultural production changes. Source: Author's own calculations.

Looking at the income and consumption expenditure of rural and poor households specifically, who are the most affected by decreasing cocoa pollinator numbers, we observe regional differences. Poor and rural households in the Western region suffer considerable income losses of 5.4% and 9.1% for Polli 2 and Polli 3 respectively (Figure 6). Income changes of the same household group in the Ashanti and Central region are not as considerable as in the Brong-Ahafo or Eastern region despite similar economic cocoa output. The Volta and Upper West regions are negatively affected by decreasing pollinator populations. Decimated pollinator populations slightly increase the income of poor and rural households in the Northern, Upper East and Greater Accra regions.

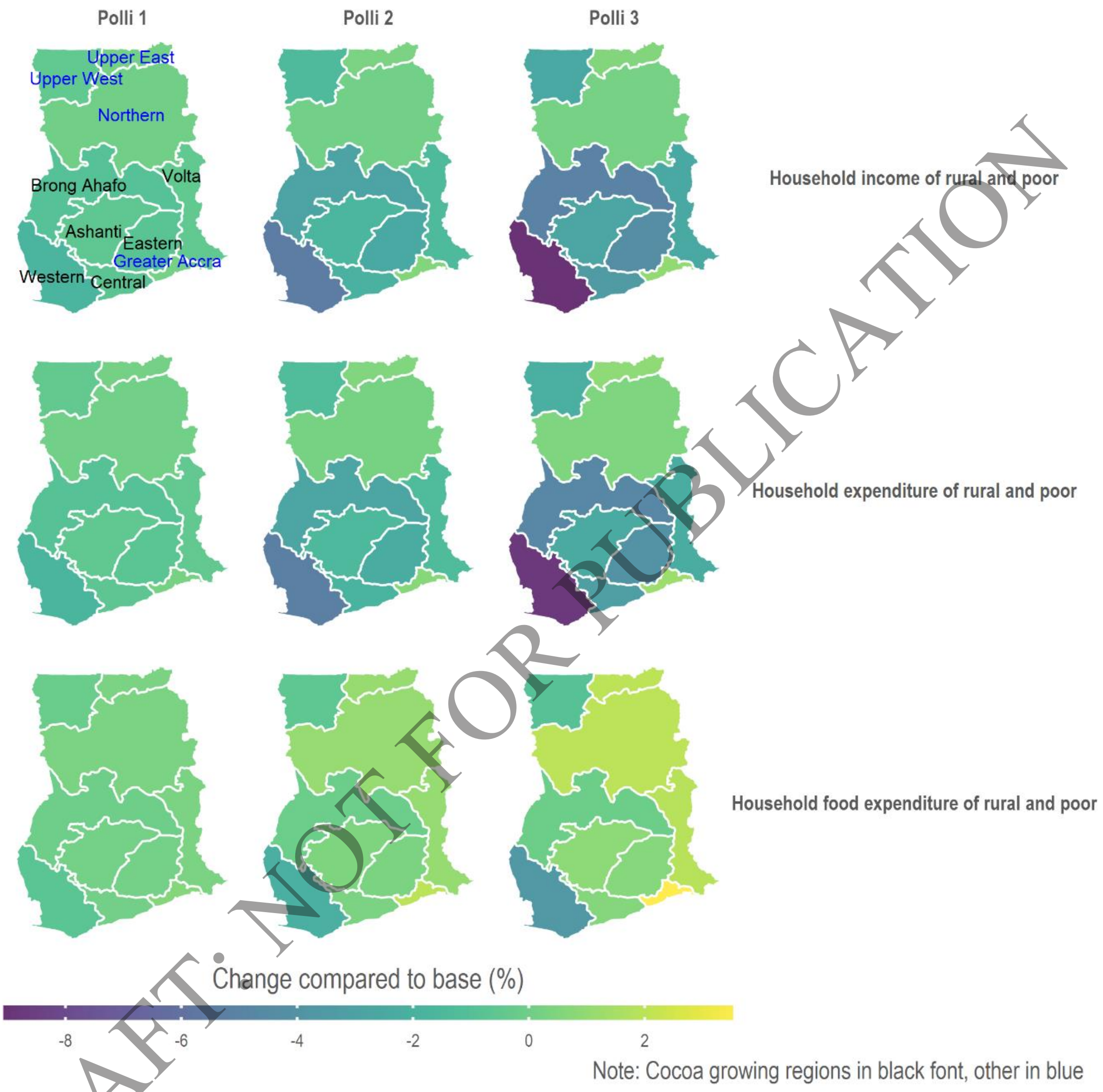

Figure 6 – Regional changes of rural and poor households. Source: Author's own calculations.

The decreasing household income leads to a general reduction in household expenditure, which follows a similar trend as income, with households in the Western region reducing their expenditure by 8.8% under Polli 3 (Figure 6).

Analyzing the effects of changing cocoa pollinator populations on food consumption of rural and poor (Q1-expenditure) households at the regional level, we can see that most regions increase their food consumption (Figure 6), if pollinator decreases are simulated. The only exceptions being the Western and Upper West regions, where the effects are flipped. Food consumption in Brong-Ahafo, a cocoa-growing region, is not substantially affected by changes in the cocoa pollinator population (neither positively and negatively). Interestingly, food consumption in the Upper West region decreases if cocoa pollinators decrease, despite not being a cocoa-growing region. This might be explained by the decreased prices for crops, as agricultural production increases, which has a negative impact on income in the Upper West region. As their income decreases, so does their food consumption. The most substantial changes are observed in the Western Region and in the Greater Accra Region. Pollinator declines of 50% could lead to reduced food consumption in the Western Region by 3.67%, while in the Greater Accra Region it would lead to increased food consumption by 3.51%.

4. Discussion

While there exist a multitude of studies that evaluate the economic consequences of declining pollinator numbers, there has only ever been one using the CGE approach. Bauer and Wing (2016) used a highly aggregated multi-region CGE model to assess the economic consequences of declining pollinator numbers across the world and identified Western Africa as a region highly dependent on insect pollinators. A direct comparison of the model results with the study by Bauer and Wing (2016), or with other studies for that matter, is difficult, as the simulated scenarios differ considerably in their order of magnitude. Most studies assumed the complete extinction of all pollinators, whereas this study modeled more conservative shocks that only affect cocoa pollinators. Nonetheless, Bauer and Wing (2016) report significant linkages between the agricultural sector and other sectors of the economy. Such linkages have also been observed in this analysis, where considerable losses in cocoa exports are compensated by increased mining and finance activities. Changes in the cocoa pollinator population modeled in the three scenarios did not substantially affect most macro level indicators, which might be explained by the fact that, despite cocoa's general importance as a source of foreign exchange earnings, it still "only" contributes around 3% to the GDP of Ghana (Ghana Statistical Service, 2015).

Increased exports under the Polli 1 – Polli 3 scenarios are fueled by growing mining and finance activities, with both benefiting from the depreciation of Ghanaian cedi. While it is still debated whether increased exports lead to economic growth in the short or long run, there has been growing evidence in the case of Ghana, suggesting that increased exports actually lead to economic growth (Yennu, 2018; Kollie, 2020). Therefore, an increase in mining and finance activities, could potentially lead to economic growth in the long run, and compensate for lost cocoa productivity.

The increased production and factor demand of the mining sector as a consequence of decreasing pollinator populations, could have negative effects on the environment (Aryee, Ntibery and Atorkui, 2003; Emmanuel, Jerry and Dzigbodi, 2018) and human health (Bansah, Yalley and Dumakor-Dupey, 2016; Stemn, Amoh and Joe-Asare, 2021). Artisanal mining has been a hot topic in Ghana for many years and is a significant contributor to the livelihoods of many people (Worlanyo, Alhassan and Jiangfeng, 2022), but efforts by the government to both improve the current mining practices in terms of sustainability, as well as to stop illegal mining have not been successful (Teschner, 2012; Osei *et al.*, 2021; Ros–Tonen *et al.*, 2021). An increase in galamsey (small-scale mining) could also have specific negative effects on the cocoa production itself, as it could lead to labor shortages, flooding and competition for land (Osman *et al.*, 2022). In the long run this could potentially further reduce the productivity of the Ghanaian cocoa sector.

The incomes of rural and poor households were affected the most by changes in the pollinator population. Decreasing pollinator numbers lead to considerable income losses in cocoa-growing regions, with the Western region suffering the greatest income losses. These income losses could force cocoa farmers to become increasingly dependent on child labor, as small incomes and poverty are still the root cause of child labor in the cocoa sector (Luckstead, Tsiboe and Nalley, 2019). Moreover, these income losses could also force farmers to expand their cocoa land to compensate for lost income. Deforestation remains a major problem in Ghana and expansion of cocoa land has been identified as one of the factors fueling deforestation (Acheampong *et al.*, 2019; Brobbey, Agyei and Osei-Tutu, 2020; Kyere-Boateng and Marek, 2021).

We observe neutral or positive changes to food expenditure in most regions of Ghana, fueled by increased agricultural production. At the same time, a significant food expenditure reduction of poor and rural households in the Western region is reported by the model. This could be particularly harmful in some parts of the Western region, where pockets of food insecure areas exist (Ghana Statistical Service, 2022). The effects on food security could be significantly worse considering that the model does not account for seasonality, which might be an important aspect for further analysis (Kleemann *et al.*, 2017).

The changes in cocoa productivity and cocoa world market prices not only influence the economy of Ghana, but other economies as well. These effects are not explicitly modeled, but it is reasonable to argue that increased cocoa world market prices, as a consequence of declining cocoa pollinator numbers in Ghana, will benefit other cocoa producing countries such as Côte d'Ivoire or Indonesia (Murphy *et al.*, 2022). Moreover, these changes in cocoa productivity not only affect cocoa producing countries but also the cocoa importing countries. The economies of countries which import pollinator dependent crops like cocoa, can be negatively affected even if pollinator shocks would only occur in the exporting countries (Murphy *et al.*, 2022). Therefore, protection of cocoa pollinators in Ghana is not only a concern of Ghanaian stakeholders, but for every stakeholder in the cocoa economy.

A potential limitation of our study is that we only modeled changes to cocoa pollinators. This enabled us to do a very detailed analysis focusing on the cocoa sector. Nevertheless, future studies should further investigate how changes to other pollinators affect the economy of Ghana.

One thing that has not been mentioned so far is the potential response of the Ghana Cocoa Board (COCOBOD) to these changing pollinator numbers. COCOBOD controls most aspects of the Ghanaian cocoa sector and determines the producer prices (Bymolt, Laven and Tyszler, 2018). These prices are determined at the beginning of the cocoa season and usually maintained for one year, although they are sometimes adjusted to avoid smuggling to neighboring Côte d'Ivoire (Bymolt, Laven and Tyszler, 2018). The model uses the data from the Ghana 2015 SAM (European Commission *et al.*, 2021), which reflects the fixed cocoa price at the time, and reports changes in the cocoa world market prices, but a fixed producer price in Ghana is not explicitly modeled. Therefore it cannot currently be assessed whether the fixed producer price is higher than the changed cocoa world market price, which would benefit cocoa farmers, or lower, which would be negative for Ghanaian cocoa farmers and could potentially lead to increased cocoa smuggling (Benneh and Anaman, 2022). In addition, the recently implemented LID is also not explicitly reflected in the model, which has the goal of ensuring a living income for cocoa farmers by setting a minimum price for cocoa. This policy might buffer some of the negative effects of decreasing pollinator numbers, but there remain many uncertainties regarding the policy and implementing it into a model is a complex issue by itself (Boysen *et al.*, 2021). Similarly manual pollination of cocoa could in the long run substitute some amount of natural pollination (Wongnaa *et al.*, 2021b), but that technology is still emerging and its long term effects need further analysis.

Conclusion

This study makes the following contributions to the literature: First, the combination of an economic analysis with a systematic literature review makes it possible to show which insects (i.e., *Ceratopogonidae)* have a high economic value in Ghanaian cocoa production. This additional information can guide policy makers, as they do not have to deal with vague terms (e.g., insects in general), but rather with specific groups of insects that are of particular interest to the cocoa sector. Second, using a CGE model, enabled us to show that a reduction in cocoa pollinators increases activity of the mining sector, which can have considerable impacts on the environment. Third, using disaggregated household accounts, made it possible to show that rural and poor households in cocoa-growing regions depend strongly on adequate cocoa pollination. These findings allow for a more holistic impact assessment and are thus potentially better suited to inform policy makers on the effects of changing pollinator numbers.

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