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Oil palm expansion in Cameroon: Insights into sustainability opportunities and challenges in Africa

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ABSTRACT

Oil palm production expanded 1.2 million hectares in sub-Saharan Africa since 1990, with expansion accelerating in several heavily forested countries since 2000. Despite a narrative of expansion driven by multinational corporations, we provide evidence of a dynamic non-industrial oil palm production sector linked to a burgeoning informal milling enterprise. Surveys were conducted with oil palm farmers in Cameroon (n = 546), the third largest palm oil producer on the continent with the greatest amount of deforestation due to recent expansion, to determine who is expanding into forest. Seventy-three percent of survey respondents reported clearing forest, the magnitude of which was explained by differences in milling strategies and supply chain integration. Large-scale, non-industrial producers played a disproportionate role in deforestation, many of which were engaged in informal supply chains through the use of non-industrial mills. Farms associated with more clearing tended to use high-yielding seedlings. Even the highest yielding farms, however, averaged only 7.7 tons fresh fruit bunches (FFBs) ha^{-1} yr^{-1}, well below the potential 20 tons FFBs ha^{-1} yr^{-1} yield for Cameroon. We also found a strong relationship between deforestation and land claims. Most farms claimed ownership of their land, although only 5% had official land titles. Conservation challenges in the region arise from land tenure laws that incentivize forest clearing. This study sheds light on the role of informal supply chains in deforestation and highlights the need for strict implementation and enforcement of land use zoning policies.

1. Introduction

1.1. Oil palm expansion in Africa

Oil palm expansion has come under intense scrutiny in recent years owing to its role in tropical deforestation (Carlson et al., 2012; Henders et al., 2015; Gaveau et al., 2016). Although concentrated in Southeast Asia, oil palm production expanded by 1.2 million hectares (ha) in sub-Saharan Africa between 1990 and 2017, with expansion accelerating in several heavily forested countries since 2000 (FAO, 2016; Ordway et al., 2017). Large tracts of unconverted land, an abundance of rural labor and growing domestic demands for palm oil signal potential production growth in the region (Feintrenie, 2014; Rival and Levang, 2014; Byerlee et al., 2017). Despite observed increases in production and demand, it remains unclear which actors are engaged in oil palm expansion in Africa. A recent spotlight on the role of multinational corporations in oil palm expansion globally has led to a narrative emphasizing their role in oil palm expansion in Africa (e.g., Greenpeace International, 2012; Sayer et al., 2012; Carrasco et al., 2014). Yet evidence from existing oil palm production systems in Africa and an expanding medium-scale producer class suggest this narrative is an oversimplification (Rival and Levang, 2014; Nkongho et al., 2014a; Jayne et al., 2014). This paper presents a case-study analysis of oil palm expansion in Cameroon, with two goals: 1) to identify which actors are engaged in non-industrial oil palm cultivation (i.e., small- and medium-scale plantations less than 1000 ha); and 2) to determine what type of farms are expanding at the expense of forest.

An estimated 1.37 billion ha of remaining land suitable for oil palm cultivation is concentrated in 12 tropical countries, with over half already allocated to other uses including protected areas (Pirker et al., 2016). The largest area of suitable land in Africa is located in the Congo Basin. Agricultural production increases across sub-Saharan Africa have primarily been characterized by area expansion rather than yield improvements (Fisher, 2010; Deininger and Byerlee, 2011). This is also

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true of oil palm cultivation (Byerlee et al., 2017). Ten palm oil producing countries in Africa, including Cameroon, are engaged in the Africa Palm Oil Initiative (APOI) under the Tropical Forest Alliance 2020. In response to ambitious palm oil development plans in these countries, the APOI aims to guide the design and implementation of a set of regional principles that will reduce deforestation, encourage smallholder production, and improve livelihoods while promoting socio-economic growth (TFA, 2017). As a result, national principles and action plans are actively being developed in several countries. These efforts highlight the importance of policy in guiding the sector's potential role in both economic development and environmental impacts.

Most policies addressing oil palm expansion to date have targeted industrial-scale practices through supply-chain governance. These include the Roundtable on Sustainable Palm Oil (RSPO) and zero-deforestation corporate commitments. Incorporating non-industrial producers in these agreements and agendas has proven difficult, particularly in developing countries with large areas of remaining forest where economic benefits from resource extraction and extensive land use present direct tradeoffs with forest conservation (Vermeulen and Goad, 2006; Brown and Zarin, 2013). Thus, it is unlikely these approaches will be entirely transferable to sub-Saharan Africa where non-industrial oil palm producers, loosely defined as smallholders, manage far greater total land area than industrial producers. In business operations management, value chain analysis focuses on identifying operations that add utility, value or competitive advantage. Kaplinsky and Morris (2001) emphasize the need to understand all links in the chain, and all activities in each link, to formulate appropriate policies without undermining particularly threatened parties, for example poor, informal operators. A limited understanding of what characterizes "smallholder" oil palm producers and their interaction with industrial-scale production in Africa inhibits the development of appropriate policy.

Industrial-scale oil palm plantations in Africa are comprised of public and private enterprises greater than 1000 ha (Cotula et al., 2009). In contrast, a wide range of definitions exist for smallholders, or non-industrial producers. The RSPO defines a smallholder oil palm farmer as one who relies on family members for labor and cultivates less than 50 ha (RSPO, 2017). Additionally, agriculture is considered to be the main source of income for these farmers. Yet differences in socioeconomic vulnerability, supply chain integration and land use decision-making between a producer cultivating 1 and 50 ha of oil palm can be vast. This heterogeneity among actors engaged in non-industrial oil palm production and its influence on expansion is poorly documented in the literature.

Sub-Saharan African "smallholder" farms are often characterized by their small size, low yields, and limited commercialization (Collier and Dercon, 2014). Differences in access to information, materials, and markets, however, can lead to a variety of production strategies that in turn influence land use decisions and development outcomes (Woodhouse, 2010; Rist et al., 2010). Farm structure provides a concept for characterizing these differences. Farm structure is defined as the arrangement of agricultural holdings including the number and size of farms, ownership and control of resources, the managerial, technological and capital requirements, and the market and institutional arrangements under which a farmer buys and sells (Ruthenberg, 1971; Tweeten, 1984; Knutson et al., 1995; Stanton, 1991).

Recent trends in agricultural investment and expansion across Africa indicate fundamental changes in farm structure that likely influence the oil palm sector. Jayne et al. (2014) provide evidence of more rapid growth in medium-scale agricultural systems compared to small- and large-scale production, where medium-scale refers to 5–100 ha farms. These authors also highlight that increasing agricultural investment by wealthy African nationals is outpacing both foreign and smaller scale land acquisition. Although this type of investment is not new, several studies suggest that rural land capture by national elites and a growing urban middle class is on the rise (Cotula et al., 2009; German et al., 2013; Sitko and Jayne, 2014). At the same time a new generation of African entrepreneurs is emerging, linked to a network of national and pan-African organizations (McDade and Spring, 2005).

1.2. Focus of the study

This study seeks to discern the diverse actors involved in non-industrial oil palm production in sub-Saharan Africa, and identify whether those differences influence the likelihood of deforestation due to oil palm expansion. It does so through a case-study analysis of Cameroon − the third highest palm oil producing country in Africa, with significant remaining forest cover.

Based on field surveys and key informant interviews in 2014 and 2015, three themes emerged which we explore in this study. First, the development of oil palm production in Africa presents a major sustainability challenge, particularly in regions with high forest cover. With the exception of Gabon, all countries engaged in the APOI rank in the bottom 25th percentile on human development indicators (UNDP, 2017). Countries at this level of economic development rely heavily on resource extraction and land for agricultural expansion. Even where environmental sustainability is a strategic goal, it is a lower ranking priority than poverty alleviation and economic growth. Secondly, a dynamic non-industrial palm oil supply chain, intricately linked to diverse milling techniques, sets Africa apart from the export-oriented formal markets associated with oil palm cultivation in Southeast Asia. Thirdly, land tenure complexities underpin many dimensions of land use decision-making.

Following an overview of palm oil production and the policy landscape in Cameroon, we describe the data and methods used in this study. To identify who is engaged in oil palm cultivation, we first examine farm structure variations. In doing so, we describe the relationship between the palm oil supply chain and different milling strategies. Next, we explore how differences in farm structure are associated with deforestation. We conclude by discussing sustainability challenges and opportunities associated with oil palm expansion relevant to both Cameroon and other producing regions of Africa.

1.3. The case of Cameroon

Originally from West and Central Africa, oil palm cultivation in sub-Saharan Africa takes place at a variety of scales, from wild harvesting to "smallholder", non-industrial farms to industrial plantations. Given recent growth in its oil palm sector, Cameroon provides a useful location to explore questions related to expansion and farm structure. Oil palm was first planted commercially in Cameroon in 1907 in some of the earliest oil palm plantations in Africa (Hoyle and Levang, 2012). Six agro-industrial companies (hereafter referred to as industrial producers) currently operate in Cameroon and produce over half of the country's palm oil. The five top-producing companies—three privately held and two publicly owned—have all been present in Cameroon for over four decades, prior to the global surge in oil palm expansion.

In the 1970s, 90% of oil palm land area was managed by agro-industries, with non-industrial producers accounting for only 10% (Nkongho, 2015). As of 2012, the area cultivated by non-industrial producers constituted approximately 70% of oil palm land area, having increased by 570% since the 1970s (Hoyle and Levang, 2012). An estimated 17% of expansion in Cameroon between 1989 and 2013 came from forest conversion, more than any other top producing country in Africa (Vijay et al., 2016). Similar to many other West and Central African countries, customary and statutory land tenure systems in Cameroon create a complex legal pluralism under which land users operate (Oyono, 2009). As a result of Cameroon's Land Ordinance Laws passed in 1974, the state administers national lands belonging to Cameroonian citizens, and claims ownership of unregistered, un-titled public lands (Assembe-Mvondo et al., 2014). Any lands occupied or used after 1974 require demonstration of use in the form of a draft development project to obtain formal land ownership recognized by the government (Javelle, 2013).

Growth in non-industrial production was stimulated by a government initiated rural financing program from 1978 to 1991 referred to as *Fonds National du Développement Rural* (FONADER) (Nkongho et al., 2015). FONADER, a rural development bank, focused on expanding non-industrial oil palm plantations by providing credit, inputs, and other technical support through relationships with agro-industries (Ngom et al., 2014). Additional expansion in the early 1990s has been attributed to an increase in cash crop farmers switching to oil palm following the crash in cocoa and coffee prices (Frank et al., 2011). In 2003, government assistance was reinstated with the initiation of the *Programme de Développement des Palmeraies Villageoises* (PDPV) to support small-scale producers. The PDPV program aims to increase palm oil production in response to a national vegetable oil deficit, while improving the living standards of farmers by increasing stable revenues from production (Ndjogui et al., 2014; Ngom et al., 2014).

As the number of oil palm producers grew, a non-industrial milling sector emerged. Delayed delivery of fresh fruit bunches (FFBs) from farm to mill gate, delayed payment at agro-industrial mills, difficulties in accommodating FFBs for farms increasingly further away from mills (especially during the rainy season), and an inability to process all FFBs during the peak production season all contributed to a need for additional milling options (Frank et al., 2011; Nchanji et al., 2013). Today oil palm cultivation and processing in Cameroon is carried out across a range of scales of production. Hereafter, we refer to mills owned and operated by agro-industrial companies as industrial mills. All other mills, referred to as non-industrial mills, vary widely in terms of design and operation. However, they can broadly be categorized into two groups that correspond to capacity and crude palm oil (CPO) extraction rates: mechanized systems and fully manual, hand mills.

In Cameroon, palm oil contributes to nearly 80% of edible oil demand, 30% of which is estimated to come from non-industrial mills (Frank et al., 2011). Red palm oil, the most widely consumed form, results from partially refined crude palm oil and is high in Vitamin E and alpha- and beta-carotene (Nagendran et al., 2000). Storage and milling techniques used to process red palm oil result in high free fatty acid (FFA) content, with recorded estimates ranging from approximately 8–15% (De Leonardis et al., 2016). In addition to exceeding the international trade standard of < 5%, high FFA can have negative health consequences (Che Man et al., 1999; Boden, 2008). Top consumers of palm oil globally include Indonesia, Malaysia, India, China, and the European Union, associated with demands for edible oils, cosmetics, biofuels, and other industrial uses (Byerlee et al., 2017). Across producing regions of West and Central Africa, however, nearly all palm oil is consumed locally as food (Carrere, 2010; Ibitoye et al., 2011; Nchanji et al., 2013; Oosterveer et al., 2014).

Household consumption and industrial demands within Cameroon increased dramatically in recent years, due in part to population growth at an average annual rate of 2.1% since 2000 (The World Bank, 2017). Despite long-standing production, increasing domestic demand has led many countries in West and Central Africa to become net importers of palm oil (FAO, 2016). Projections of future demand and the widespread reliance on domestically supplied edible oils has led many African countries to seek production growth strategies (Byerlee et al., 2017). The Government of Cameroon set a target of nearly doubling palm oil production from 250,000 tons in 2015 to 450,000 tons by 2020 (Hoyle and Levang, 2012). In response, a National Strategy is being drafted to identify mechanisms for increasing production in a socially and environmentally sustainable manner.

Without improvements in technology or farming practices, or a commensurate increase in imports, the need to meet growing demands is largely being met through area expansion (FAO, 2016). This expansion has potentially large environmental implications, considering that nearly 50% (approximately 22 Mha) of Cameroon is under forest. Our analysis focused on the Southwest Region of Cameroon, which encompasses the largest area of national oil palm production (40%) and is 86% forested (Fig. 1; MINADER, 2012).

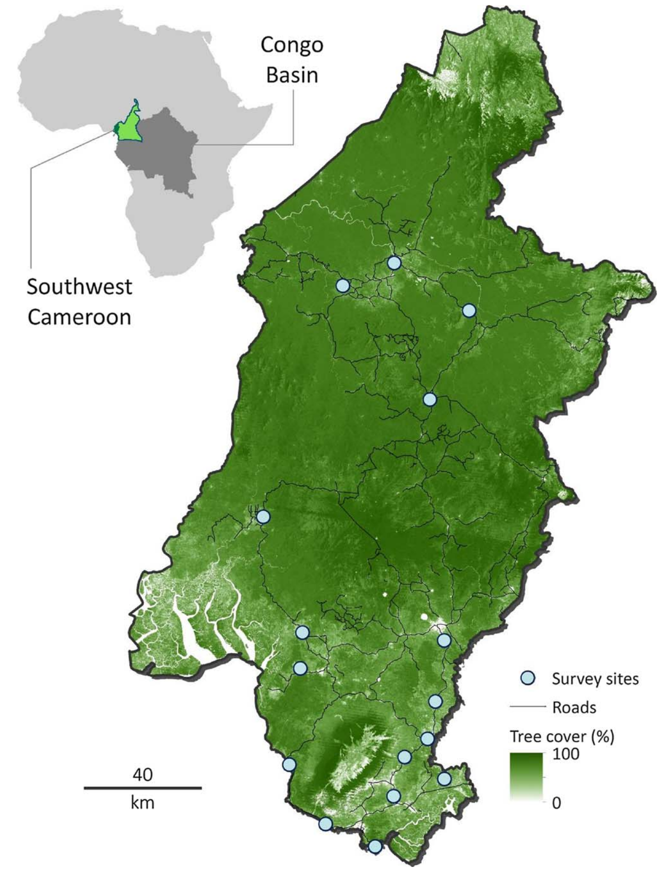

Fig. 1. Study area where surveys were conducted in the Southwest region of Cameroon.

2. Data and methods

2.1. Structured surveys and informal interviews

To characterize who is engaged in oil palm production and identify key factors associated with farms that expanded into forest areas, we developed a formal survey to gather information on farm and farmer household characteristics. At the farm level, we collected data on producer demographics, farm size, labor, milling characteristics, market access, and other sources of income. At the field level, we collected data on land tenure and production and management practices. Field level variables were scaled up to the farm level as fractions of the total farm area. For example, the percent of land owned was calculated as the sum of the area of fields owned divided by the total farm size. Deforestation area was a self-reported measure based on the area of the plot and whether it was forested immediately prior to clearing and planting. Survey questions were aimed at identifying deforestation carried out by the current landowner or plantation manager specifically for the purpose of expanding oil palm cultivation.

A total of 545 oil palm producers were surveyed in the Southwest region from June-August 2015. Participants in the survey were selected from 50 regionally representative villages and towns based on a stratified, multi-stage sampling scheme which included producers from 16 sites varying in population density, and in distance to plantations and mills owned by agro-industries. Sixteen of the region's 25 districts were included in the sample. Producers at each site were identified based on census information provided by the village chief or sub-delegation for agriculture.

Table 1
Farm-level variables considered in the conditional model.

Variable	Mean ± SD	Description
Availability of suitable forest: accessibility constraints		
Distance to mill (km)	1.85 ± 3.56	Farm distance to palm oil processing mill
Distance to household (km)	3.56 ± 5.90	Farm distance to farm manager household
Economic and technological characteristics		
Price index	0.93 ± 0.34	Weighted average calculated from reported FFB and CPO sale prices
CPO sales (liters)	4971 ± 10486	Quantity of crude palm oil sold to consumer
Milling strategy		
Industrial mill	–	Binomial: 1) used industrial-scale mill, 2) did not use industrial-scale mill
Mechanical mill	–	Binomial: 1) used mechanical mill, 2) did not use mechanical mill
Hand mill	–	Binomial: 1) used manual, hand mill, 2) did not use manual, hand mill
Seed type: *tenera* (%)	40.14 ± 48.06	Fraction of oil palm cultivated area planted with higher yielding *tenera* seedlings
Differences in constraints and strategies across scales of actors		
Farm size (ha)	14.20 ± 22.23	Total cultivated area, including all crops
Cocoa production (%)	29.10 ± 34.42	Proportion of crop production area allocated to cocoa
Staple crop production (%)	11.39 ± 23.78	Proportion of crop production area allocated to staple crops
Labor constraint	–	Binomial: 1) hired labor for clearing/planting, 2) relied on household labor only
Credit (USD)	646 ± 4894	Amount of credit or financing received for farm
State titled land (%)	4.72 ± 20.81	Fraction of land with formal state title
Variable costs and benefits of forest clearing		
Owned land (%)*	91.01 ± 25.81	Self-reported fraction of land owned

* Claims to future land rents give farmers an additional incentive to clear land.

The mean number of survey respondents per site was 34 ± 7. A detailed description of sampling methods and data limitations is presented in the Supplementary material. Field level data (n = 1526) were aggregated to the farm level for analysis. Key informant surveys and informal interviews were conducted with mill owners, industrial plantation managers, retailers and traders, Ministry of Agriculture staff, local agronomists, and staff from non-governmental and development organizations over the course of five months in 2014 and 2015.

2.2. Farm-structure typology

To develop a typology of non-industrial farms, with the aim of identifying distinct producer groups based on farm structure, we conducted an unsupervised *k*-means cluster analysis of farms. Variables from the structured survey included oil palm cultivation area, total annual FFB production, on-farm FFB yield, fraction of land allocated to staple crop production, fraction of state titled land, farm distance to palm oil processing mill, type of mill used (i.e., milling strategy), and quantity of palm oil sold. See Supplementary material for a detailed explanation of the *k*-means cluster analysis, including justification of the number of clusters selected and inclusion of categorical variables.

2.3. Deforestation due to oil palm expansion

To determine which types of oil palm cultivation were associated with deforestation in Southwest Cameroon, we compared characteristics of farms that cleared forest for oil palm expansion to farms that expanded on other land cover types. The latter included both managed lands (e.g., cropland) and other types of natural vegetation. Most natural vegetation in the study region, however, is comprised of intact or degraded humid tropical forests (Mertens et al., 2012). Thus, the majority of 'other land cover types' were managed lands. The objective of this analysis was to identify factors that predict both the probability of forest being converted and the relative magnitude of deforestation where conversion occurred. We first selected variables based on conceptual relevance.

Underlying drivers of agricultural expansion resulting in deforestation can include a combination of demographic, economic, technological, institutional and cultural factors (Geist and Lambin, 2002). Deforestation due to commercial agricultural expansion is often associated with the availability of suitable forest, economic and technological characteristics of the agricultural system, differences in constraints and strategies across scales of actors, and the variable costs and benefits of forest clearing (Meyfroidt et al., 2014). Variables considered are described in Table 1. Correlation analyses were performed between explanatory variables to evaluate collinearity in the dataset (Pearson's $r > 0.4$).

2.3.1. Conditional model description

As the deforestation data were positively skewed with a large number of zeros (Fig. S1), we used a conditional modeling approach described in Fletcher et al. (2005). First, we modeled the occurrence of deforestation using a logistic regression. We then excluded the non-occurrence data and modeled the logarithm of the area of deforestation when it occurred, using an OLS regression. Lastly, we estimated the area of deforestation by combining the two models.

Two datasets were created. The first indicated whether deforestation occurred or not at each farm (n = 404). The second was restricted to farms where deforestation occurred, with the response being the log-transformed deforestation area (n = 293). Forty-four farms were removed that were not yet harvesting or milling (see Supplementary material for a description of the excluded farms). These two datasets are referred to here as the 'deforestation occurrence data' and the 'log-area data', respectively. All explanatory variables were standardized to compare the magnitude of their influence on the response variable.

The final models for the occurrence and log-area data were combined to predict the expected area of deforestation as follows. Let $Y(x)$ be the area of deforestation when X matrix of explanatory variables equal x set values. Also, let $Z(x)$ be a binary variable, equal to one when deforestation occurs and zero otherwise. The expected value of Y is given by:

$$E(Y) = \Pr(Z = 1)E(Y|Z = 1) + \Pr(Z = 0)E(Y|Z = 0),$$

$$= \Pr(Z = 1)E(Y|Z = 1),$$

$$= \pi m,$$

where $\pi = \Pr(Z = 1)$ and $\mu = E(Y|Z = 1)$. The estimate of expected deforestation is given by (Stefánsson, 1996; Welsh et al., 1996):

$$\hat{E}(Y) = \hat{\pi}\hat{\mu} \quad (1)$$

where

$$\hat{\pi} = \exp(x'\hat{\beta})/\{1 + \exp(x'\hat{\beta})\} \quad (2)$$

and

$$\hat{\mu} = \exp(w'\hat{\theta} + \sigma^2/2) \quad (3)$$

Estimates of π and μ are obtained from the two regression models, where $\hat{\beta}$ is the vector of coefficient estimates in the logistic regression, and x is the corresponding vector of explanatory variables. Similarly, $\hat{\theta}$ is the vector of estimates, w is the vector of explanatory variables and σ^2 is the mean squared error in the OLS model (Crow and Shimizu, 1988).

3. Results

3.1. General characteristics of oil palm producers in Cameroon

Only 5.4% of farms produced palm oil strictly for personal consumption. Nearly all respondents were engaged in either formal or informal markets, where the latter refers to markets that lack formal contracts and government regulation. A key difference lied in whether a producer sold their FFBs to an industrial mill or paid to mill their FFBs at a non-industrial mill and then sold the unrefined CPO (Figs. 2 and 3). Most farmers (72.7%) participated in informal supply chains in which they paid to process their FFBs at non-industrial processing facilities that included manual, hand mills and a range of mechanical mills. These farmers subsequently sold CPO to traders (wholesalers and retailers) and other households. In contrast, only 17.8% of farms were integrated into supply chains associated with formal markets, selling FFBs directly to an agro-industrial (16.4%) or privately owned industrial-scale mill (1.4%), leaving the palm oil sales to milling agents. The 10% of farms that did not mill primarily included immature farms, not yet harvesting, although three farms reported not milling due to an inability to hire labor or pay for transportation costs.

Of the producers actively selling CPO, 17.2% retained some for personal consumption. Farmers generally reported the ability to retain palm oil for consumption or sell to nearby households as a major advantage over other cash crops, including cocoa and rubber. Only 3.8% of farms surveyed were greater than 50 ha, indicating that over 96% of farms fall under the RSPO definition of smallholder (Fig. 4). Despite this, we found a great deal of heterogeneity in farm structure among these smallholders, described in the following section.

3.2. Heterogeneity among "smallholders"

Clustering results yielded six groups of oil palm producers cultivating less than 1000 ha of land (Fig. 3, Supplementary Table S1 and Fig. S2). These clusters explain 70.6% of the total variation in the survey dataset. Producers within groups A, B and C cultivated oil palm on significantly smaller land area than group D ($p \leq 0.009$) and groups E and F ($p \leq 0.004$) (Fig. 4). There was no significant difference in size between groups E and F, or between groups A, B, and C. We refer to groups A-C as small-scale, group D as medium-scale and groups E-F as large-scale. Below, differences in farm structure between and within these size categories are described.

3.2.1. A: small-scale newcomers

Group A (n = 46) was comprised entirely of producers not yet harvesting. Aggregate oil palm area cultivated by these producers amounted to 229 ha. The median year of oil palm plantation establishment was 2013 for this group, indicating that plantations were not yet mature when the surveys were conducted in 2015 (Supplementary Table S3). In many other ways, producers in this group are similar to the other two small-scale producer groups. Likely due to high costs and low returns associated with the early stages of oil palm production, Group A was the most reliant on off-farm income.

3.2.2. B & C: small-scale staple and cash crop diversifiers

The two small-scale producer groups employed a mix of hired and household labor and cultivated the largest number of crops on average. Groups B (n = 35, total area = 174 ha) and C (n = 180, total area = 1127 ha) were also similar in terms of average annual production (25.4 and 23.2 tons FFBs yr^{-1}, respectively) and on-farm yield (5.8 and 5.6 tons FFBs ha^{-1} yr^{-1}, respectively). However, they differed in diversification strategy. Thirty-six percent of Group B respondents, who predominantly cultivated staple crops, explicitly stated that they took up oil palm production to diversify their income. Oil palm producers in

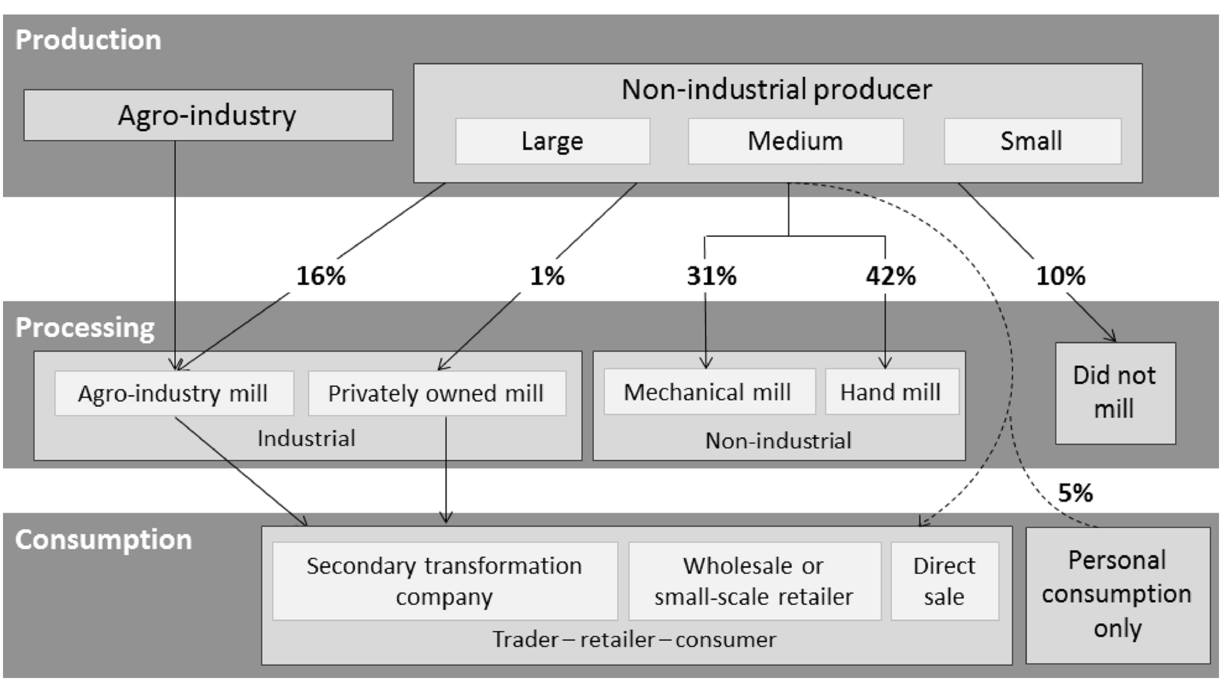

Fig. 2. Schematic of palm oil supply chain in Cameroon. Oil palm producers use different milling strategies at the processing stage that are linked to their role in the supply chain. Percentages indicate the fraction of survey respondents that follow a given milling path in the supply chain. Dotted lines indicate the direct relationship between producers who process at non-industrial mills and consumers.

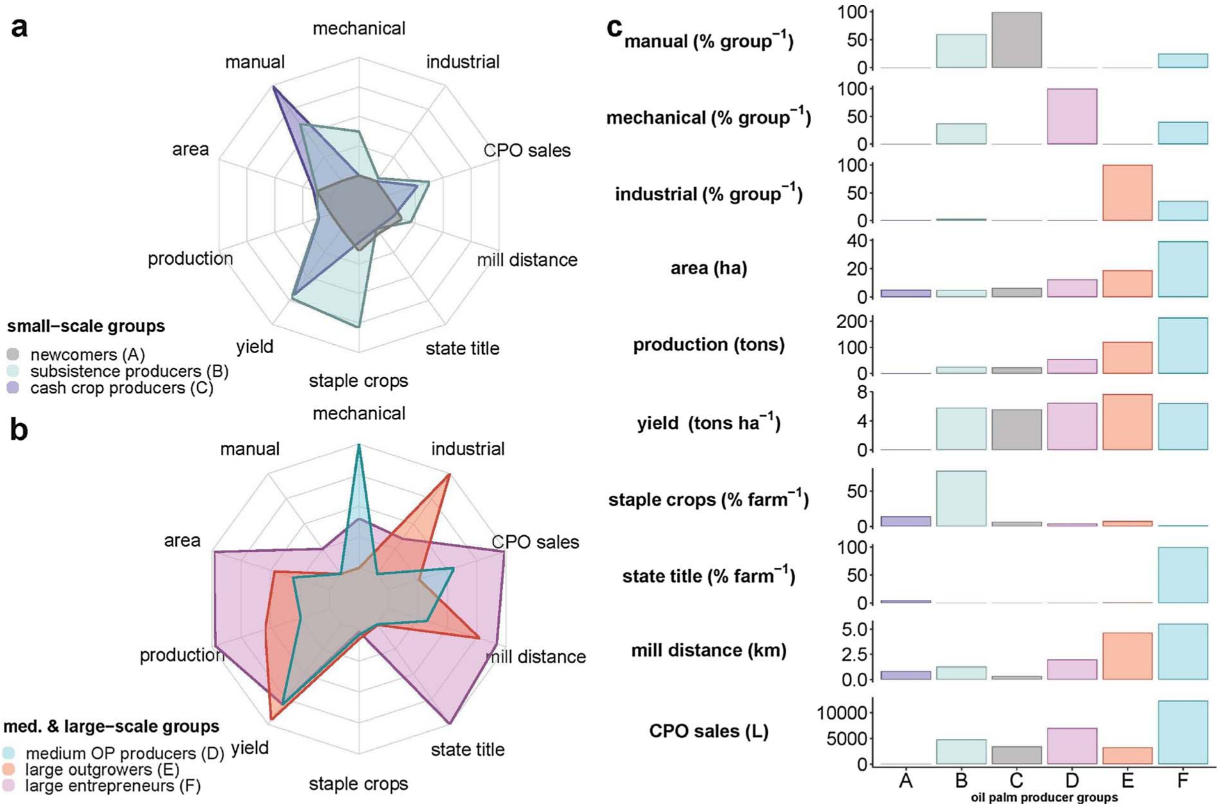

Fig. 3. Farm structure and milling strategy differences for 6 oil palm (OP) producer groups distinguished by color. Cluster means are compared across (a) small-scale producer groups, and (b) medium- and large-scale producer groups, with average values and units for all producer groups in panel (c).

Group C diversified income through greater production of cash crops, namely cocoa. On average, nearly half (42.0%) of all agricultural production on farms in Group C was allocated to cocoa, with cocoa sales averaging 970 kg yr^{-1} (Supplementary Fig. S3).

3.2.3. D: medium-scale oil palm producers

Medium-scale farms (n = 135, total area = 1677 ha) averaged greater production (53.9 tons FFBs yr^{-1}) and higher yields (6.5 tons FFBs ha^{-1}) than small-scale farms (groups A-C). They also typically sold the largest quantities of palm oil (Supplementary Fig. S3). Compared to small-scale farms, medium-scale farms hired more labor and allocated a substantially greater proportion of their total crop production to oil palm (80.9%), often cultivated in monoculture systems.

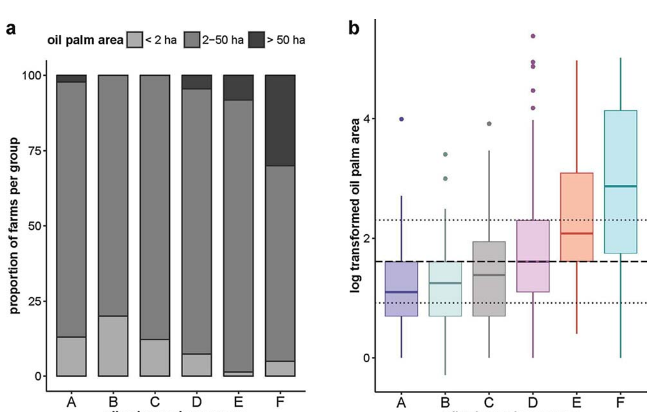

Fig. 4. The proportion of farms that are < 2 ha, 2–50 ha, and > 50 ha for the six clusters with sample size n = 46, 35, 180, 135, 73 and 20 (a). Box plots showing the distribution of log transformed oil palm area per cluster (b). Horizontal dotted lines show Q1 (0.92), median (1.61), Q3 (2.30) values for the original distribution of log transformed oil palm area.

3.2.4. E: large-scale outgrowers

Of the 17.8% of farms linked to formal markets, 90.0% were concentrated in group E (n = 73, total area = 1365 ha). These farms all supplied to industrial mills, and averaged greater production at 120.5 tons FFBs yr^{-1}. This group embodies farms involved in outgrower schemes whereby the producer was contractually obliged to supply FFBs to an agro-industrial mill, often in exchange for land and a variety of services, including transportation and the provision of planting materials. Although this group averaged the highest yield at 7.7 tons FFBs ha^{-1} yr^{-1}, productivity was far below the potential 20 tons FFBs ha^{-1} yr^{-1} yield for the region (Nkongho et al., 2015).

3.2.5. F: large-scale entrepreneurs

Although most remaining producers that supplied FFBs to industrial mills (an additional 8.6%) were in group F (n = 20, total area = 784 ha), only 35% of these producers followed the outgrower model. This group was mainly comprised of farms connected to informal markets through non-industrial mechanical milling and selling large quantities of palm oil. Production systems on these farms were often even more commercialized than the large-scale outgrower group, averaging 213.5 tons FFBs yr-^{1}, yields of 6.4 tons FFBs ha^{-1} and the largest farm size (Fig. 3b). Additional characteristics are indicative of entrepreneurial investment in oil palm. These producers traveled farther to mills, similar to outgrowers, despite the lack of transportation incentive from an agro-industry. The allocation of 92.4% of production on average to oil palm cultivation suggests these producers engaged in agriculture specifically to produce the crop. Farms in this group also hired more labor at all stages of production than other groups, and held the highest proportion of state titled land at 99.8%, starkly contrasting the lack of state titles held by farms in all other groups. This land was

Table 2
Unstandardized coefficient estimates, robust standard errors and *p*-values for the explanatory variables in the final logistic and ordinary regression models.

	Logistic regression[a]			OLS regression[b]		
	Estimate	Robust SE	*p*-value	Estimate	Robust SE	*p*-value
Intercept	−0.6249*	0.6409	0.3295	0.3484	0.3120	0.2651
Farm size	0.0161	0.0113	0.1528	0.0245**	0.0070	0.0005
Distance to mill	–	–	–	–	–	–
Distance to household	0.0409	0.0332	0.2180	−0.0022	0.0021	0.9148
Price index	−0.2426	0.3738	0.5163	0.0402	0.1425	0.7780
Palm oil sales	< 0.0001	< 0.0001	0.3921	0.0001	0.0000	0.0934
Industrial mill	0.2095	0.4057	0.6055	0.5496**	0.1477	0.0002
Mechanical mill	−0.1482	0.2777	0.5935	−0.0240	0.0989	0.8082
Hand mill	–	–	–	–	–	–
High-yielding seed	0.0073	0.2861	0.9796	0.3615**	0.0857	< 0.0001
Cocoa production	−0.2087	0.4220	0.6210	–	–	–
Staple crop production	−0.3284	0.5202	0.5279	−0.0956	0.1758	0.5870
Hired labor	0.1012	0.2776	0.7154	0.2143*	0.0994	0.0320
Credit	< 0.0001	< 0.0001	0.9956	< 0.0001	< 0.0001	0.1829
State titled land	−0.7423	0.6280	0.2372	0.0983	0.3860	0.7992
Self-reported land owner	1.6549**	0.4837	0.0006	0.5168	0.3339	0.1228

* Significant at $p < 0.05$.
** $p < 0.01$.
[a] AIC = 477, Residual deviance = 449 on 390 DF.
[b] R^2 = 0.57, $p <$ 0.0001, Residual SE = 0.70 on 280 DF.

more likely to be acquired directly from a chief compared to other groups (Supplementary Table S3). The entrepreneur group highlights two important characteristics of the oil palm sector in Cameroon: large, non-traditional smallholders play an important role in cultivation, and despite more commercialized systems, large-scale farms are engaging in informal supply chains.

3.3. Farm structure influence on deforestation

3.3.1. Most farms cleared forest to expand oil palm cultivation

Findings provide evidence of: 1) widespread forest clearing for oil palm expansion, and 2) a strong association between farms with commercialized production and greater deforestation. Seventy-three percent of farms surveyed cleared forest to expand oil palm cultivation. The probability of deforestation was positively correlated with land ownership (Table 2, $p < 0.001$). For every 1% increase in the area of land reported as owned, the odds of clearing forest were 5.2 ± 2.4 times greater. An average farm in the study area, i.e., approximately 3.6 km from the household, selling 4971 tons CPO yr^{-1}, and claiming ownership of 91% of their oil palm fields, had a 78.7% probability of deforestation (AIC = 477). The probability decreased to 49.2% for farms that claimed ownership of only 10% of the oil palm fields they cultivated, maintaining all other variables at their mean value. Thus, farms claiming 91% ownership were 1.6 ± 0.1 times as likely to clear forest compared to farms that reported owning only 10%. Most farms (87%) claimed ownership of 100% of the land they were cultivating, yet only 5% had a state title. Farms that cleared forest reported owning a greater proportion of their oil palm fields (94.2%) compared to farms that did not clear forest (83.4%, p = 0.001).

Due to multicollinearity, farm distance to mill and hand milling as a strategy were dropped from the logistic and OLS models (Supplementary Tables S5 & S6). The proportion of production area allocated to cocoa was also dropped from OLS. Because surveys were conducted after clearing occurred, results do not identify causal relationships. Rather, regression results inform which types of farms were correlated with forest clearing, in terms of likelihood and magnitude. For ease of interpretation, coefficient estimates, standard errors and *p*-values are reported for results using unstandardized variables, and standardized results are presented in Supplementary Table S7 in the Supplementary material.

3.3.2. Higher commercialization associated with greater deforestation

On average, the outgrower and entrepreneur groups accounted for a disproportionately greater area of deforestation (Fig. 5). Results from the OLS regression support the finding that farms with more commercialized production systems were associated with more forest clearing. Among farms that deforested and after controlling for size, farms that used greater fractions of high-yielding *tenera* seedlings and sold FFBs to industrial mills had the strongest association with deforestation area (R^2 = 0.57, $p < 0.001$, Fig. S5, Supplementary Table S7). A 10% increase in the area of oil palm fields planted with *tenera* seedlings was associated with a 3.7% ± 0.3% ($p < 0.001$) greater area of deforestation for a given milling choice, location, quantity of CPO sold, amount of credit received, and tenure arrangement (Table 2). Farms

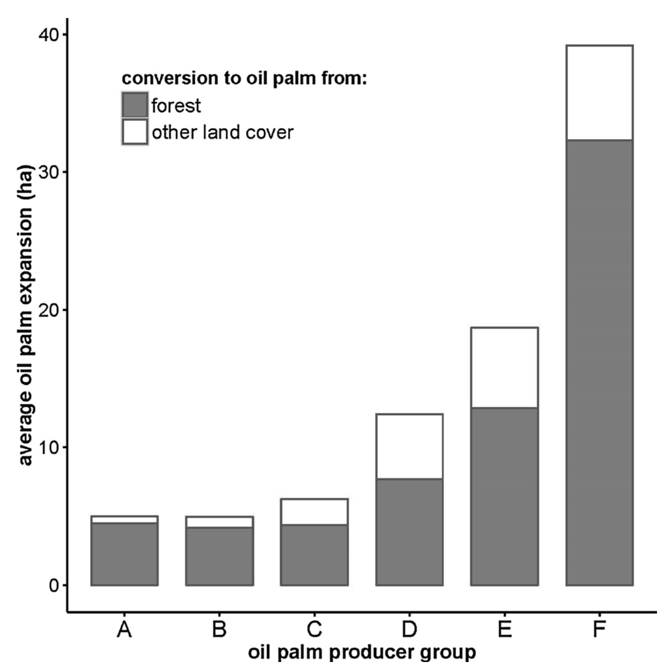

Fig. 5. Average oil palm area expansion per farm for each producer group. The proportion of self-reported forest conversion for oil palm expansion (grey) is compared to conversion of other land cover types (white).

that milled at industrial mills were associated with a 73.3% ± 10.8% ($p < 0.001$) increase in the area cleared compared to farms that milled at non-industrial mills. Similarly, farms that hired labor were associated with a 23.9% ± 2.4% ($p = 0.032$) greater cleared area. Results from the combined model estimates of deforestation area highlight these trends as well as the greater magnitude of clearing associated with larger farms (Fig. S6).

4. Discussion

Oil palm production has been carried out at the commercial scale in sub-Saharan Africa since the early 1900s. Recent expansion in several high forest countries in the region has led to a concern that deforestation rates could increase, similar to trends of rapid forest loss observed in Indonesia and Malaysia. While most attention has focused on the role of international corporate investment, we present evidence of an active, non-industrial oil palm production sector underpinned by domestic investment in land and milling technologies. Case-study results from Cameroon suggest prevalent deforestation is associated with this production, the magnitude of which is marked by differences in a farm's production strategy.

4.1. Milling strategies and supply chains

Nearly all non-industrial oil palm producers were involved in commercial production to some degree, evidenced by our finding that only 5% of farms were producing strictly for subsistence purposes. Significant heterogeneity in the scale of production and supply chain integration among these producers suggests that the broad categorization of smallholders is an oversimplification. Ignoring this variation could lead to misguided policy responses.

For example, only 17.8% of farms surveyed chose to sell FFBs to an industrial mill, suggesting strong incentives for farms to process palm oil at lower capacity mills and sell value-added CPO through informal market structures. This was true even for medium- and large-scale, entrepreneurial farms. The numerous palm oil supply chains intricately linked to non-industrial milling techniques differentiate oil palm production in Africa from the export-oriented markets in Southeast Asia. Since nearly all demand comes from domestic consumers in Cameroon, similar to most oil palm producing regions across the continent, producers are less restricted by quality standards or the need to sell to a select number of export-oriented buyers and traders.

Long distances and poor road conditions between some farms and the few existing industrial mills, as well as late payments and limited access to resources from agro-industries were among the many complaints farmers voiced, which was consistent with previous finding (Frank et al., 2011; Nchanji et al., 2013). Additionally, producer prices are fixed at industrial mills owing to a government regulated price ceiling in Cameroon. At unregulated non-industrial mills, prices fluctuate based on peak and low production seasons, making them more lucrative at certain times of the year. Nkongho et al. (2014b) found that producers who process FFBs at non-industrial mills can accrue greater income than producers selling to industrial mills, especially during the low production season, when the price of locally consumed palm oil is higher given restricted supply. These authors also highlight the tendency of some farms to make use of both non-industrial and industrial mills depending on the season and their scale of production. Other work has shown that non-industrial mills can be a major source of income for rural households (Nchanji et al., 2013).

These findings have several policy implications. Policy efforts focused on incentivizing non-industrial producers to use agro-industrial mills risk overlooking an opportunity to advance the burgeoning non-industrial milling sector. Additionally, the oil palm sector in Cameroon, like most palm oil producing countries in Africa, is driven largely by domestic demands. It is unlikely that domestic consumers with relatively low incomes will be concerned with producers meeting voluntary sustainability standards established by the RSPO or the National Strategy. As a result, the consumer driven incentive to reduce deforestation due to oil palm expansion in places like Indonesia and Malaysia is likely an inadequate motivation for non-industrial producers or informal mills in Cameroon to change their practices.

Further, standards and regulations are often a barrier to entry for small-scale and informal sector producers (Morris et al., 2012). Costs of compliance and the level of preparedness required to meet sustainability standards risk excluding non-industrial producers and the informal milling sector from participation in supply chain improvements. Given their role in deforestation, identifying appropriate incentives and providing support that will allow these actors to engage in standards schemes could yield great environmental benefits. In this way, sustainability standards also offer an effective tool in fostering sustainable development. As policies are developed in Africa that align oil palm production strategies with sustainability pathways, the inclusion of non-industrial producers and the informal milling sector will go a long way in determining the extent to which economic development opportunities can be realized by some of the most economically vulnerable actors.

4.2. Deforestation and differences in commercialization

Although we found that most oil palm farms reported expanding into forest areas, characteristics related to farm structure were important predictors of the magnitude of deforestation. Specifically, farms with more commercialized systems, using high-yielding seedlings and hired labor, were associated with greater clearing (Table 2, Supplementary Figs. S5 & 6). This information, and the substantially larger area cleared on average by the relatively small number of farms in Group F, highlights the disproportionate contribution of entrepreneurial farms to deforestation (Fig. 5). While we also find a strong correlation between deforestation and large farms selling FFBs to industrial mills, the fact that many entrepreneurial farms used non-industrial mills sheds light on the role of informal supply chains in deforestation in Cameroon. Both findings suggest that, in general, larger farms were better suited to take on the high costs of forest clearing over large areas, despite low returns during the early stages of oil palm production.

4.3. Oil palm investment and land tenure complexities

The probability of deforestation across all producer groups was associated with farms claiming greater land ownership of their oil palm fields. Because we were unable to determine whether farms reported ownership prior to clearing, it is impossible to infer from this analysis whether the motivation to own land drives deforestation. However, we demonstrate an important link to land tenure laws that incentivize forest clearing. Determining whether ownership claims are established before or after land clearing is a subject area that warrants further research.

The process of titling lands can be lengthy and expensive, and often requires navigating layers of corruption. Only 2% of the rural land in Cameroon was registered or titled as of 2008 (AfDB, 2009). Instead, most land users, especially in rural areas, claim ownership through customary tenure systems whereby the chief or local authorities sanction customary titles. As a result, Cameroon's Land Ordinance Laws encourage the establishment of visible signs of use, including forest clearing and cultivation of otherwise fallow land, to demonstrate land rights. This is consistent with our finding that, although 87% of farms claimed ownership of all the land they were cultivating, only 5% had a state title.

State titles were restricted to large farms with highly commercialized production systems (i.e., large-scale entrepreneurs group). These farms were also more likely to acquire land directly from a chief rather than from other villagers, suggesting strong rural political ties among these producers. From personal communication and informal interviews in the field, we learned that a sizeable number of medium- and large-scale oil palm producers were political elites or wealthy business men and women engaged in oil palm cultivation as an investment opportunity. Many had familial or political connections to rural villages. One respondent, who owned several hotels, decided to invest in land for oil palm cultivation due to her knowledge of the crop from family history and easy market access. Investment in mills by entrepreneurs and elites was also not uncommon. For example, a mechanical, non-industrial mill in the study area was managed locally, but owned by an accountant living 120 km away in a major city.

In contrast, recent foreign investment in land for oil palm production demonstrates potential conflicts that can arise from the legal pluralism of customary and statutory land tenure systems. Sithe Global Sustainable Oils Cameroon, Ltd. (SGSOC), a subsidiary of Herakles Farms, was allocated a 99-year lease to 73,000 ha of land already inhabited by over 14,000 people in Southwest Cameroon in 2009 (Mousseau, 2013). After opposition from local community members and international conservation organizations, the lease was suspended and then reduced to 20,000 ha in 2013. The land was still only partially developed in 2017. This suggests that, while land tenure complexities serve as a constraint on foreign companies' ability to acquire large-tracts of land, they offer an opportunity for African investors who can navigate the complexities of accessing land while avoiding conflicts with local communities.

4.4. Deforestation in primary and secondary forests

Our finding that most oil palm farms reported expanding into forest merits an important caveat. Depending on the forest type being cleared, deforestation can have different impacts. The degree to which a forest is intact can influence, for example, the quality of habitat lost or the amount of biodiversity at risk (Barlow et al., 2007; Gibson et al., 2011). Distinguishing between primary and secondary forests was beyond the scope of this study. Remote sensing analyses that reliably separate forest types using multi-spectral data require long and dense time series. These were not available in our study area due to persistent cloud cover. In a landscape like Southwest Cameroon, which has a long history of human occupation, high human population density, complex topography, and spatial variability in soil types and landscape configuration, these analyses are made even more difficult. Additionally, owing to the many definitions of forest (Chazdon et al., 2016), we could not expect survey respondents to reliably report differences between primary and secondary forests. For this reason, forest was broadly defined in the survey instrument as continuous, natural tree cover.

Previous research found that 67% of the oil palm cultivated by smallholder farmers in Cameroon occurred at the expense of secondary forests, compared to 4% in primary or intact forests (Nkongho et al., 2014a). The authors noted that primary forests were often degraded by timber companies or agro-industries, while smallholder farmers were more likely to develop oil palm plantations in secondary forests. Similarly, Ndjogui et al. (2016) found that 71% of smallholder oil palm plantations in Cameroon expanded into secondary forests, and 5% into intact forests. These findings suggest that non-industrial oil palm developments have a lesser impact on primary forests. Secondary forests, which include selectively logged and degraded forests, forest areas recovering from fires, and forests regenerating from past agricultural land use, account for approximately 65% of total global forest cover, and an estimated 64% of Congo Basin forest cover (FAO, 2015, 2011). Given their conservation value and critical role in ecosystem service provisioning (Chazdon et al., 2009; Baccini et al., 2017), oil palm expansion at the expense of secondary forests has also major ecological impacts.

4.5. Sustainability challenges and opportunities

Countries with high forest cover and developing economies, like Cameroon and other Congo Basin countries, present a major conservation challenge. In these countries, millions of people directly and indirectly rely on forests for their livelihoods. However, efforts to increase food security and poverty reduction initiatives in agriculture-based economies increasingly compete for land. This is particularly true given that limited technology adoption has often resulted in production increases from agricultural expansion rather than intensification.

In Cameroon, we found that on-farm oil palm yields averaged 5–7 tons FFBs ha^{-1} throughout the study area and across producer groups, well below the 20 tons FFBs ha^{-1} potential yield for the country (Nkongho et al., 2015). The large yield gap points to a major opportunity to increase production on existing oil palm fields. Similarly, the widespread use of low capacity, non-industrial hand mills and mechanical mills with low extraction rates presents an opportunity to increase palm oil yields at the processing stage. Whether intensification slows cropland expansion or increases deforestation depends on economic and policy factors (Rudel et al., 2009). The incentive to clear more land as yields improve and profitability increase, referred to as the Jevons Paradox (Jevons, 1865), underscores the need for strict land use policies. Byerlee et al. (2014) argue that technology-driven intensification more often results in a net sparing of land, while market-driven intensification at agricultural frontiers generally leads to further expansion.

Increasing domestic demand for palm oil in Cameroon provides a stable market for oil palm producers, which differs from the volatility of markets for other cash crops like cocoa and rubber. Diversification strategies, land acquisition, and economic returns on investment were widely reported as reasons to invest in oil palm production in the study area, while the use of technology and inputs was limited. Where yield increases took place, through the use of inputs and higher yielding seed varieties, deforestation still occurred. This is demonstrated by the positive relationship between adoption of high-yielding varieties and forest area cleared, although we are unable to claim causation due to the lack of data prior to clearing.

5. Conclusions

We conducted a case study analysis of oil palm expansion in Cameroon, the third largest palm oil producer with the greatest amount of recent expansion resulting in deforestation on the African continent. Of the oil palm producers surveyed for this study, nearly three-quarters cleared forest to expand cultivation. Most references to the emergence of oil palm expansion in sub-Saharan Africa highlight the role of international corporate investment. Our results rather provide evidence of a dynamic non-industrial oil palm production sector, with great heterogeneity among producers that are often referred to as "smallholders". This heterogeneity is linked to varying economic and land tenure incentives to clear forest, and associated with an expanding informal domestic market and milling enterprise. Low crop and milling yields and limited technological capacity mean that deforestation is occurring with production benefits well below their potential. Intensification strategies to increase on-farm and milling yields will likely need to be complimented by adequate conservation policies to prevent deforestation. Although deforestation rates remain low relative to other tropical regions, pressures are mounting from economic development and domestic consumption demands, which is associated with population growth and urbanization. This study highlights the role of the customary land tenure system in land use development, and the need for strict implementation and enforcement of land use zoning policies.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.gloenvcha.2017.10.009.

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