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LETTER

Deforestation risk due to commodity crop expansion in sub-Saharan Africa

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Abstract

Rapid integration of global agricultural markets and subsequent cropland displacement in recent decades increased large-scale tropical deforestation in South America and Southeast Asia. Growing land scarcity and more stringent land use regulations in these regions could incentivize the offshoring of export-oriented commodity crops to sub-Saharan Africa (SSA). We assess the effects of domestic- and export-oriented agricultural expansion on deforestation in SSA in recent decades. Analyses were conducted at the global, regional and local scales. We found that commodity crops are expanding in SSA, increasing pressure on tropical forests. Four Congo Basin countries, Sierra Leone, Liberia, and Côte d'Ivoire were most at risk in terms of exposure, vulnerability and pressures from agricultural expansion. These countries averaged the highest percent forest cover (58% ± 17.93) and lowest proportions of potentially available cropland outside forest areas (1% ± 0.89). Foreign investment in these countries was concentrated in oil palm production (81%), with a median investment area of 41 582 thousand ha. Cocoa, the fastest expanding export-oriented crop across SSA, accounted for 57% of global expansion in 2000–2013 at a rate of 132 thousand ha yr^{-1}. However, cocoa only amounted to 0.89% of foreign land investment. Commodity crop expansion in SSA appears largely driven by small- and medium-scale farmers rather than industrial plantations. Land-use changes associated with large-scale investments remain to be observed in many countries. Although domestic demand for commodity crops was associated with most agricultural expansion, we provide evidence of a growing influence of distant markets on land-use change in SSA.

1. Introduction

Comparative advantages imply that trade globalization results in a redistribution of the production of goods and services based on efficiency associated with opportunity costs. Markets tend to expand, leading to a displacement of production away from the main centers of consumer demand as it moves to regions where production factors are cheaper [1, 2]. Rapid economic growth and integration of global agricultural markets has led to an increase in trade related cropland displacement [3–5]. Production moves away from consumers in heavily regulated areas or where land becomes scarce, and towards regions with cheaper and more available land, cheaper labor and resources, and often areas with weaker institutions for environmental and natural resource management [6, 7]. Globally, land allocated to crop production for export grew at a rate of 2.1% yr^{-1} from 1986–2000, while cropland for domestically consumed production remained unchanged [4].

Theoretically, a globalized system leads to more efficient crop production [8]. However, land-use changes have social and environmental implications [9–12]. Most land use displacement has been from high-income to low-income countries [13], with

recent expansion of export-oriented commodity crops causing large-scale deforestation in the humid tropics [14–18]. From 2000–2011, 40% of tropical deforestation came from commodity crop production [19]. The proportion of deforestation embodied in export-oriented crop products doubled during this period to over 33% [19]. Brazil and Indonesia accounted for 61% of global tropical deforestation from 2000–2005, largely associated with the expansion of soy production, cattle pasture and oil palm plantations [20–22].

South America, Southeast Asia and sub-Saharan Africa are experiencing the fastest rates of cropland expansion [4]. Yield increases will likely continue to account for most global agricultural production increases in coming years [23]. However, in tropical regions, cropland expansion and intensification have contributed equally to production rises [24, 25]. Research provides evidence of trade related land use displacement in South America and Southeast Asia [6, 19]. However, growing land scarcity and more stringent land use regulations in these regions could incentivize the offshoring of export-oriented commodity crop expansion to SSA, where agriculturally suitable land and labor are abundant and cheap [26–30]. The objective of this study was to explore the extent to which commodity crop expansion is associated with deforestation in SSA.

Since 2015, agricultural production in SSA has grown at the fastest rate globally (2.4%), with cropland predicted to expand more than 10% by 2025 [31]. Commodity crop expansion into forest areas is increasingly associated with industrial, large-scale monoculture production given its technological advantages and operational efficiency, and thus greater profitability, realized with economies of scale [32–34]. Yet, deforestation from agricultural expansion in SSA is often associated with small-scale farmers [35], consisting of subsistence farming and commodity crop production for domestic and international markets. More recently, investments in large-scale, industrial plantations in SSA are on the rise [15, 34, 36]. Large-scale landholders acquired 22.7 million hectares (Mha) of land across SSA since 2005 [30]. From 1980–2000, 95% of cropland expansion in Africa replaced intact or disturbed forest areas [16, 37]. One-half to two-thirds of SSA's remaining agro-ecologically suitable land is currently under forest [23, 38], which represent nearly 30% of tropical forests globally and 25% of tropical forest carbon stocks [12, 39]. Here, we quantify the effects of export-oriented and industrial agricultural expansion on deforestation in SSA. Specifically, we: (i) determined whether export-oriented agricultural expansion is increasing more rapidly in SSA compared to domestic crops and previous years, and the contribution of SSA to expansion of these crops throughout the tropics; (ii) identified countries in SSA at risk of agricultural expansion in tropical forests; (iii) evaluated, based on a case study in Southwest Cameroon, whether deforestation is associated with industrial, large-scale monoculture expansion.

2. Data and methods

2.1. Trends in commodity crop expansion

Commodity crops encompass commercial agricultural commodities for both domestic and export markets. We selected crops classified as, or used to derive, global agriculture commodities [40], and produced across South America, Southeast Asia, and sub-Saharan Africa. Cassava was also included due to its increasing importance as a commodity crop [31, 41, 42]. Country-level data aggregated by region for South America, Southeast Asia, and sub-Saharan Africa were drawn from FAOSTAT [43]. Area harvested, export quantity, and production data for eleven major commodity crops were gathered for 1986–2013. Export-oriented crops were defined as crops with 40% or greater production exported during each study period (figure S1 available at stacks.iop.org/ERL/12/044015/mmedia). To estimate the mean annual rate of area expansion, we quantified linear trends in area harvested in 1986–2000 and 2000–2013 for each crop and region. These two periods were selected to evaluate differences in trends before and after 2000, a year marking noticeable growth in export-oriented agricultural expansion in the tropics [5, 15]. To assess whether export-oriented crops in SSA expanded more rapidly in 2000–2013, we compared rates of expansion to 1986–2000 and to that of domestic crops. We quantified the contribution of SSA to crop expansion that took place in SSA, South America, and Southeast Asia.

2.2. Risk of agricultural expansion in African tropical forests

Risk of agricultural expansion in tropical forests was determined at the country level. We defined tropical SSA countries as those within 23.5° north and south of the equator. Countries were selected if at least 1% of their land area constituted tropical forest biome (figure 1). Biome area was calculated using the tropical and subtropical moist broadleaf (1) and tropical and subtropical dry broadleaf (2) forest biomes from [44]. Risk was defined using a disaster management framework applied in environmental contexts [46]. The framework considers risk to be a function of exposure, vulnerability, and pressure [46, 47]. Exposure is the inventory of elements at risk—i.e. forest area [48]. Vulnerability refers to the proclivity of exposed forest area to suffer adverse effects when impacted by pressures [46–49]. Pressure refers to factors driving cropland expansion causing deforestation. In sum, we clustered twenty-five forest biome countries based on their exposure and vulnerability to deforestation and cropland expansion pressures.

Seven variables were clustered using *k*-means and Ward's hierarchical methods (table 1). Exposure,

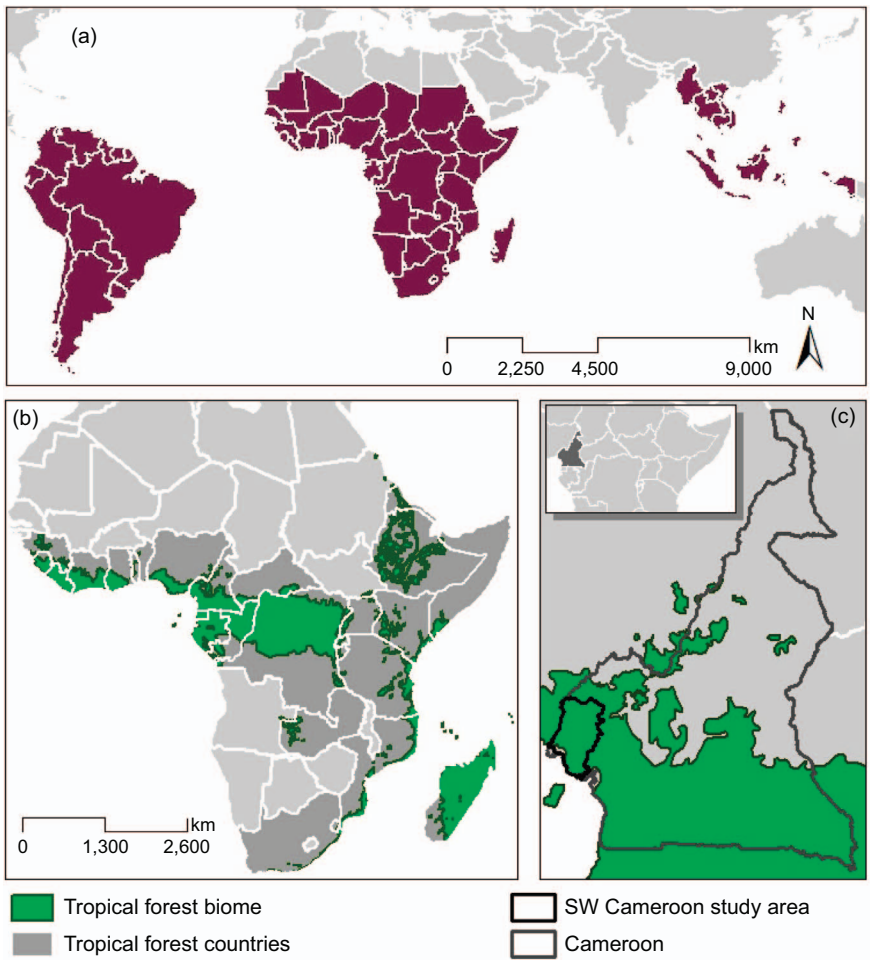

Figure 1. Country-level data were aggregated for South America, sub-Saharan Africa (SSA), and Southeast Asia to estimate commodity cropland expansion (*a*). Risk of cropland expansion in tropical forests was determined for countries in SSA (*b*). A remote sensing analysis was conducted across Southwest Cameroon (*c*).

measured as percent forest cover, was quantified from [49] (table S2, [50]). Two vulnerability variables were included. The proportion of forest biome designated as protected area was calculated from [51] under the assumption that high protected area coverage reduces vulnerability. Potentially available cropland outside forest areas was estimated using data from [41, 52], indicating reduced vulnerability where greater potential cropland is available. Pressure was measured using four variables associated with domestic- and export-oriented agricultural expansion since 2000. Country-level population [35] and income [53] growth rates were proxies for changes in quantity and composition of domestic demand for agricultural products. Domestic- and export-oriented agricultural expansion was measured by the percent change in area for all commodity crops described in section 2.1. Foreign investment in cropland was calculated as the proportion of land area contracted for commercial agricultural production reported by Land Matrix, an open-source global database of land leases and investments greater than 200 ha since 2000 [54]. Hierarchical and *k*-means clustering results were compared to evaluate clustering robustness (see supplementary material). Countries were categorized by level of risk associated with agricultural expansion in tropical forests based on cluster means.

2.3. Case study of agricultural expansion

Deforestation in Cameroon, like most SSA countries, has historically been driven by smallholder cropland expansion. Recent foreign investment in agriculture [26] and a push by the government to increase cocoa and oil palm production provide an opportunity to evaluate whether industrial, large-scale monoculture agriculture is expanding into forest areas. Approximately 17.3 Mha (68%) of Cameroon's land suitable for agriculture is under dense tropical forest [27, 38], that averages the third largest pool of total carbon stocks in Africa at 129 Mg C ha^{-1} [39]. We focused on Southwest Cameroon, a major crop producing region in the Congo Basin spanning 2.5 Mha, 86% of which is forested. The Government of Cameroon set targets to double palm oil production and triple cocoa production by 2035, from 2010 baselines of 230 000 tons and 600 000 tons, respectively. Southwest Cameroon contains the largest area of oil palm production (39% of the national total) and second largest area for cocoa production (29%) in the country [55]. Farm sizes range from less than 1 ha to industrial plantations

Table 1. Risk analysis variables for twenty-five tropical forest countries. Biome: forest biome, forest: forest cover, PA: forest biome under protection, PAC: potentially available cropland, Δ Pop.: population growth rate (1997/99–2015), Δ Income: per capita GDP growth rate (2000–2013), Exp.: commodity crop expansion rate (2000–2013), Invest.: % land area under foreign investment.

Country	% Biome	Forest area (Mha)	% Forest	% PA	% PAC	Δ Pop.	Δ Income	Exp.	Invest.
Benin	1.3	2	17.1	0.0	2.8	3.1	1.4	59.3	0.37
Burundi	25.3	1	32.4	1.7	0.0	2.7	1.0	25.4	0.00
Cameroon	52.1	26	55.5	7.8	1.7	2.1	1.3	75.2	0.43
Central African Republic	10.4	36	55.6	3.0	9.4	1.8	0.3	10.6	0.01
Republic of Congo	67.7	23	66.5	8.7	2.8	3.0	2.1	49.4	6.02
Côte d'Ivoire	46.4	8	23.3	10.2	1.5	2.0	1.2	36.2	0.51
Democratic Republic of Congo	48.7	167	66.8	5.7	0.6	3.3	0.0	−4.1	0.09
Equatorial Guinea	96.6	2	74.1	20.8	2.7	2.1	13.0	−39.2	0.0
Ethiopia	19.5	16	10.5	2.7	8.8	2.4	3.1	36.6	0.46
Gabon	80.4	19	71.6	13.7	1.7	2.4	1.6	31.7	0.88
Ghana	33.3	5	20.3	6.7	1.5	2.1	5.9	28.9	3.99
Guinea	19.4	9	32.6	1.4	6.5	2.2	0.5	93.1	0.13
Kenya	13.0	4	5.3	2.6	18.0	1.8	2.1	34.0	0.02
Liberia	98.5	7	65.9	12.6	0.3	4.8	1.5	19.0	5.40
Madagascar	79.5	16	27.3	6.2	12.3	2.8	0.9	−12.3	0.07
Mozambique	18.8	34	35.2	2.8	3.6	1.7	1.2	17.5	0.34
Nigeria	13.9	12	13.2	2.3	0.1	2.5	6.9	53.1	0.27
Rwanda	43.2	0.5	16.6	4.1	0.0	2.9	2.1	48.0	0.04
Sierra Leone	64.6	3	36.4	3.5	1.0	3.2	4.1	262.5	6.19
Somalia	4.4	1	1.0	0.0	0.0	3.9	0.0	−28.6	0.00
South Africa	2.6	13	10.0	0.3	6.1	0.3	1.2	−19.9	0.00
Tanzania	12.3	23	19.8	3.2	1.4	2.3	1.9	148.4	0.18
Togo	11.0	1	17.2	1.3	0.0	2.6	1.2	83.4	0.00
Uganda	9.8	5	17.4	2.8	1.0	3.4	1.6	69.1	0.11
Zambia	4.5	29	34.7	0.8	4.4	2.4	4.4	74.5	0.25

averaging 2117 ha. Dominant commodity crops are oil palm, rubber, and banana, produced in monoculture systems, and cocoa, produced in agroforestry and mixed crop systems [55, 56].

We conducted a remote sensing analysis of land-use change across Southwest Cameroon. We used Landsat imagery, topographical data and field information to map land use change and quantify deforestation resulting from agricultural expansion in 1986–2000 and 2000–2015. We classified imagery using Random Forest models, a nonparametric method relatively insensitive to non-normal data distributions [57]. We mapped: 1) forests, 2) mixed crops, 3) immature monocultures, 4) mature banana monocultures, 5) mature oil palm monocultures, 6) mature rubber monocultures, and 7) other (non-agriculture, non-forest). Forest was defined as tree cover greater than 50% over an area of at least 0.09 ha (30 m), and included primary and secondary forests. Monoculture was defined as a single crop agricultural system. Mixed crop was defined as a polyculture system with more than one crop grown in a location at a given time, and crop heterogeneity at or below 30 meters. This includes all combinations of annual and perennial staple and commodity crops.

To assess whether industrial-scale monoculture expansion is associated with deforestation, we quantified the fraction of forest conversion that took place within industrial plantations. We compared this to the proportion of deforestation outside plantations, and in logging concessions, protected areas, and community and council forests. Land use zoning maps were drawn from [58]. To analyze spatial patterns of forest conversion to monoculture systems outside zoned areas, we analyzed relationships between deforestation frequency and accessibility (proximity to roads), local consumption demands (proximity to villages) and commercial agriculture (proximity to plantations).

3. Results

3.1. Expanding commodity crops in sub-Saharan Africa

All commodity crops expanded across SSA during both periods, with the exception of coffee (table 2, figure 2). Cocoa production expanded significantly during both periods, at a higher rate than all other export-oriented crops. Cocoa expanded at mean annual rates of 82 762 hectares per year (ha yr^{-1}) in 1986–2000 ($R^2 = 0.64$, $p < 0.001$) and 132 376 ha yr^{-1} in 2000–2013 ($R^2 = 0.76$, $p = 0.003$). However, crops produced for export generally expanded at lower rates than crops destined for domestic markets (figure 3). In 1986–2013, the proportion of cassava and rice exported from SSA was negligible. Maize exports declined and remained extremely low during this period. Yet these three crops accounted for 85% of commodity crop expansion in the region. Maize and

Table 2. Regional linear trends in commodity crop expansion before and after 2000. Grey boxes indicate relationships that varied significantly in time (Adj.– $R^2 > 0.60$, $p \leq 0.01$). β_1 = mean annual rate of change in area (ha yr^{-1}).

			1986–2000				2000–2013		
Crop	Region	β_1	Robust SE	Adj.-R^2	p-value	β_1	Robust SE	Adj.-R^2	p-value
	sub-Saharan Africa	**25 144**	**14 055**	**0.48**	**0.004**	**15 655**	**2135**	**0.57**	**< 0.001**
Banana	South America	14 414	20 019	0.73	0.485	−2727	400	0.43	< 0.001
	Southeast Asia	407	3609	−0.08	0.912	9459	307	0.95	< 0.001
	sub-Saharan Africa	**252 522**	**33 566**	**0.85**	**< 0.001**	**393 499**	**336 332**	**0.74**	**0.265**
Cassava	South America	−27 574	6002	0.51	0.001	−6817	40 336	−0.04	0.869
	Southeast Asia	−28 637	17 394	0.21	0.126	69 952	5232	0.89	< 0.001
	sub-Saharan Africa	**82 762**	**17 460**	**0.64**	**< 0.001**	**132 376**	**35 959**	**0.76**	**0.003**
Cocoa	South America	4314	6990	0.07	0.549	10 288	71 985	0.26	0.889
	Southeast Asia	30 691	6497	0.66	< 0.001	87 774	5696	0.84	< 0.001
	sub-Saharan Africa	**−58 115**	**6799**	**0.77**	**< 0.001**	**−10 586**	**16 078**	**−0.04**	**0.523**
Coffee	South America	−105 660	39 609	0.69	0.021	−28 151	3398	0.68	< 0.001
	Southeast Asia	40 580	2220	0.97	< 0.001	−4204	2907	0.10	0.174
	sub−Saharan Africa	**148 391**	**160 166**	**0.35**	**0.373**	**864 713**	**96 871**	**0.90**	**< 0.001**
Maize	South America	−79 762	66 719	0.01	0.255	417 406	120 050	0.69	0.005
	Southeast Asia	−66 357	15 480	0.28	0.001	153 414	37 741	0.76	0.002
	sub-Saharan Africa	**88 272**	**26 531**	**0.94**	**0.006**	**37 195**	**5383**	**0.64**	**< 0.001**
Oil palm	South America	13 370	9503	0.97	0.185	24 686	5810	0.90	0.001
	Southeast Asia	233 996	64 528	0.98	0.003	537 300	23 467	0.99	< 0.001
	sub-Saharan Africa	**160 022**	**18 793**	**0.87**	**< 0.001**	**293 761**	**27 263**	**0.91**	**< 0.001**
Rice	South America	−150 783	40 819	0.53	0.003	−49405	25 062	0.21	0.072
	Southeast Asia	524 700	25 053	0.88	< 0.001	637 547	56 229	0.95	< 0.001
	sub-Saharan Africa	**17 747**	**2485**	**0.83**	**< 0.001**	**9236**	**18 163**	**0.69**	**0.620**
Rubber	South America	2230	373	0.71	< 0.001	4400	73	0.97	< 0.001
	Southeast Asia	61 527	2279	0.97	< 0.001	177 252	7246	0.93	< 0.001
	sub-Saharan Africa	**27 278**	**10 838**	**0.34**	**0.027**	**60 032**	**15 395**	**0.82**	**0.002**
Soy	South America	594 300	218 292	0.76	0.019	1934000	163 397	0.92	< 0.001
	Southeast Asia	−5279	30 972	−0.07	0.868	−8507	13 320	0.03	0.535
	sub-Saharan Africa	**4242**	**52 222**	**0.14**	**0.937**	**16 314**	**23 35**	**0.89**	**< 0.001**
Sugarcane	South America	79 684	18 612	0.65	0.001	481 029	17 377	0.96	< 0.001
	Southeast Asia	72 275	21 165	0.89	0.005	38 549	17 864	0.60	0.052
	sub-Saharan Africa	**4139**	**1381**	**0.89**	**0.011**	**8643**	**7634**	**0.95**	**0.280**
Tea	South America	−56	77	−0.05	0.480	−121	67	0.10	0.097
	Southeast Asia	4250	423	0.88	< 0.001	6809	4274	0.85	0.137

rice expansion accelerated in the 2000s relative to previous years. Maize accelerated by 483% (Wald F-stat = 43.78, p-value < 0.001), faster than any other crop, from 148 391 ha yr^{-1} to 864 700 ha yr^{-1} ($R^2 = 0.90$, $p < 0.001$). Rice expansion accelerated by 84% (Wald F-stat = 15.06, p-value = 0.001). Cocoa, oil palm and soy immediately followed maize, cassava, and rice as crops with the highest rates of expansion during both periods.

Less than 15% of oil palm products and 10% of soy products were exported from SSA in 1986–2000 (figure S1). Although the proportion of production exported remained low, it increased by 171% and 111% for oil palm and soy respectively since 2000. Palm oil exports rose steadily from 2005, while soy experienced a sharp, albeit brief, rise in the late 1980s, with growth reviving in 2008. Thus, most soy and oil palm in sub-Saharan Africa was produced for domestic consumption. Oil palm and soy expanded at rates of 60 032 ha yr^{-1} ($R^2 = 0.64$, $p < 0.001$) and 37 195 ha yr^{-1} ($R^2 = 0.82$, $p < 0.001$) since 2000, respectively.

Globally, SSA accounted for the majority of cocoa expansion during both periods. Cocoa in SSA constituted 57% of global expansion annually in 2000–2013 and 67% of total land allocated to cocoa production by 2013, at 6.3 Mha. Oil palm and soy in SSA contributed far less to the expansion of these crops throughout the tropics. Land area allocated to soy increased across the three regions at an average rate of 2 Mha yr^{-1} since 2000. SSA accounted for only 3% of this expansion. The majority occurred in South America (97%), at a mean annual rate of 1.9 Mha yr^{-1}. In 1986–2000, 26% of annual oil palm expansion in the tropics occurred in SSA. As expansion rapidly increased in Southeast Asia in 2000–2013, where 90% of the growth was concentrated, the contribution of SSA dropped to 6%.

3.2. Agricultural expansion risk in African tropical forests

Hierarchical (figure 4, table 3) and k-means (table S1) clustering methods yielded similar country clusters (table S2). The analysis revealed that four of the six

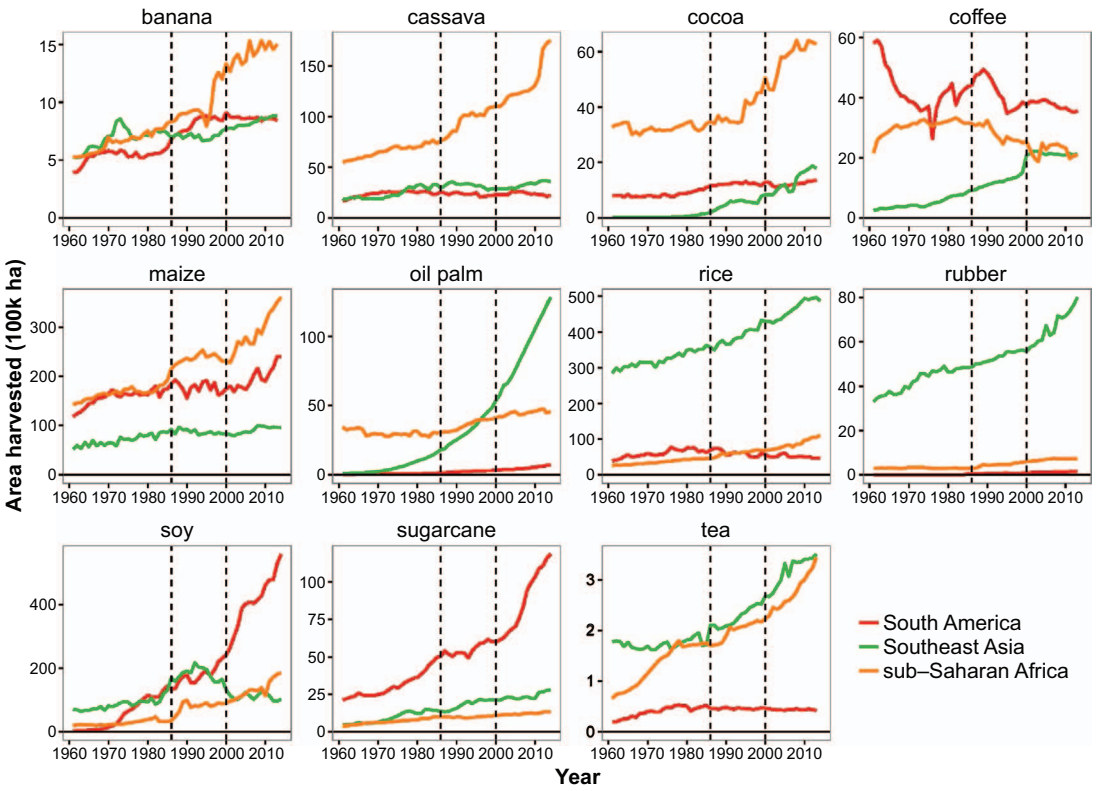

Figure 2. Trends in area harvested for South America, Southeast Asia and sub-Saharan Africa. To facilitate visual comparison of trends, soy area harvested was increased by an order of magnitude in Southeast Asia and sub-Saharan Africa.

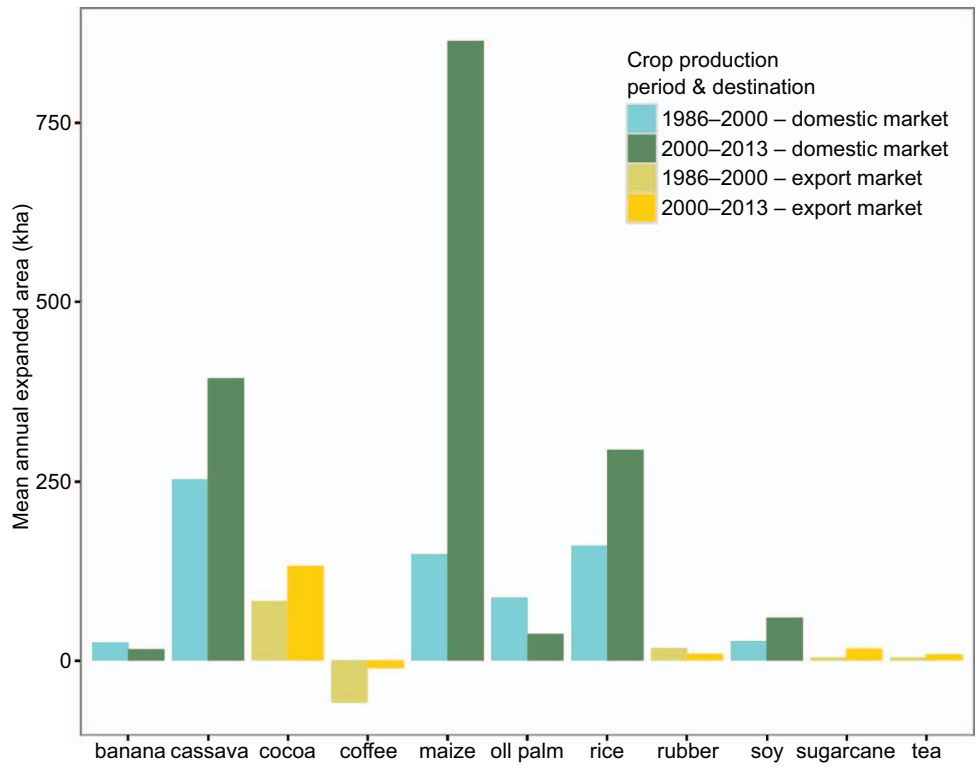

Figure 3. Mean annual expansion in thousands of hectares for domestic- and export-oriented commodity crops in sub-Saharan Africa in 1986–2000 and 2000–2013.

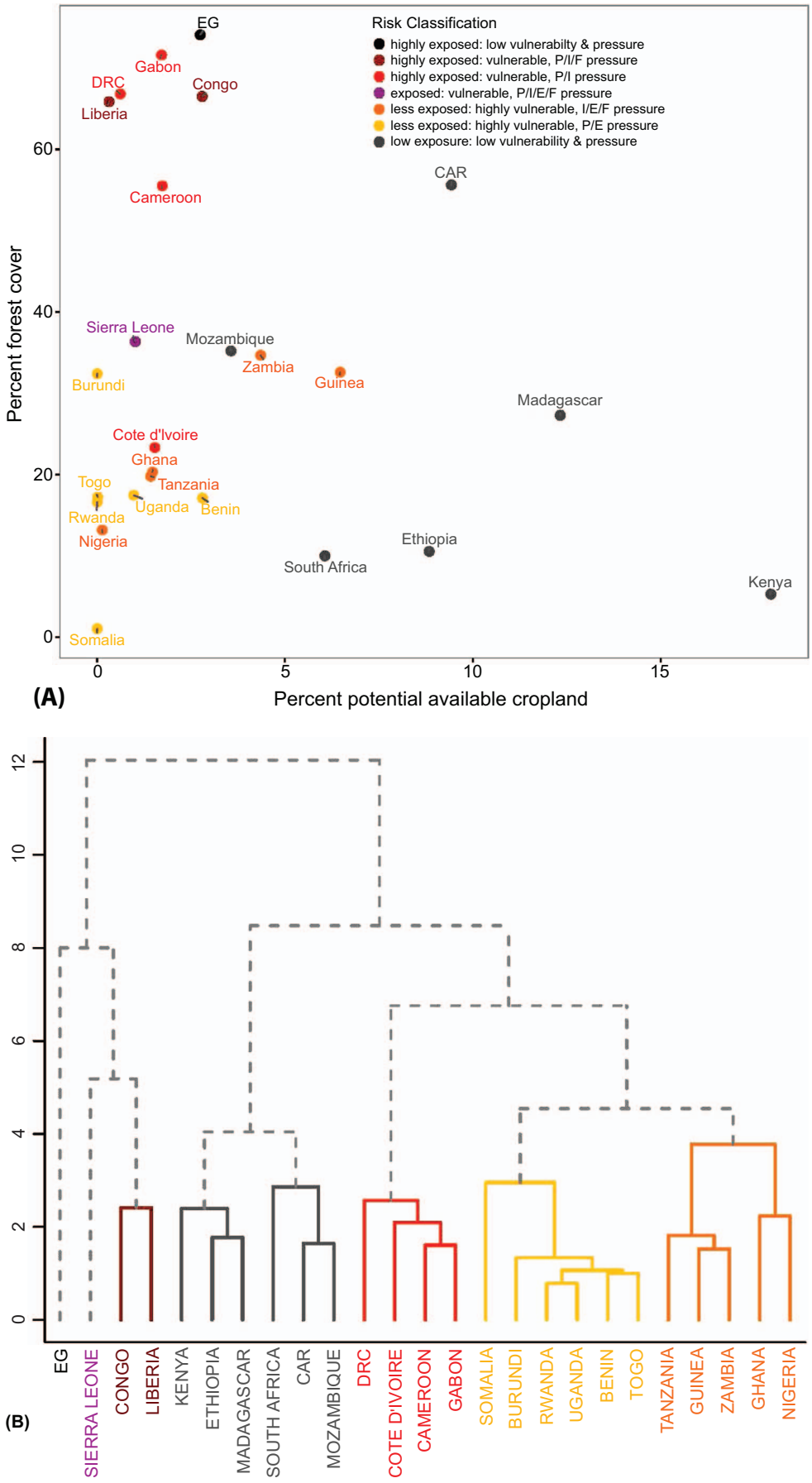

Figure 4. Forest cover and potentially available cropland (*a*) were used to cluster twenty-five countries according to deforestation exposure and vulnerability, and agricultural expansion pressures (*b*). P: population pressure, I: income pressure, E: commodity crop expansion pressure, F: foreign investment pressure.

Table 3. Hierarchical clustering results, $k = 8$. Risk cluster descriptions were inferred from cluster means, reported in standardized and unstandardized units. Explained variance is the between-cluster sum of squares (BSS) fraction of the total sum of squares (TSS). P: population pressure, I: income pressure, E: commodity crop expansion pressure, F: foreign investment pressure.

Ward's hierarchical clustering (BSS/TSS = 78%)			% forest	% PA	% PAC	Δ Pop.	Δ Income	Exp.	Invest.
Cluster	**n**	**Risk Cluster**			**standardized units**				
1	1	highly exposed: low vulnerability, low pressure	1.82	3.16	−0.18	−0.53	3.80	−1.39	−0.52
2	2	highly exposed: vulnerable, P/I/F pressure	1.47	1.13	−0.44	1.58	−0.23	−0.19	2.35
3	4	highly exposed: vulnerable, P/I pressure	0.94	0.87	−0.48	−0.12	−0.50	−0.18	−0.28
4	1	exposed: vulnerable, P/I/E/F pressure	0.15	−0.29	−0.56	0.76	0.60	3.52	2.59
5	3	exposed: vulnerable, low pressure	0.02	−0.59	0.63	−1.51	−0.54	−0.71	−0.46
6	5	less exposed: highly vulnerable, I/E/F pressure	−0.40	−0.42	−0.17	−0.30	0.54	0.55	−0.03
7	6	less exposed: high vulnerability, P/E pressure	−0.71	−0.67	−0.65	0.64	−0.43	−0.05	−0.47
8	3	less exposed: low vulnerability, I pressure	−0.83	−0.23	2.13	−0.26	−0.15	−0.43	−0.43
					unstandardized units				
1	1	highly exposed: low vulnerability, low pressure	74.12	20.84	2.74	2.10	12.97	−39.23	0.00
2	2	highly exposed: vulnerable, P/I/F pressure	66.21	10.66	1.55	3.90	1.79	34.23	5.71
3	4	highly exposed: vulnerable, P/I pressure	54.32	9.35	1.40	2.45	1.04	34.75	0.48
4	1	exposed: vulnerable, P/I/E/F pressure	36.36	3.54	1.01	3.20	4.09	262.55	6.19
5	3	exposed: vulnerable, low pressure	33.60	2.03	6.35	1.27	0.92	2.74	0.12
6	5	less exposed: highly vulnerable, I/E/F pressure	24.10	2.88	2.77	2.30	3.94	79.59	0.96
7	6	less exposed: high vulnerability, P/E pressure	16.96	1.65	0.63	3.10	1.24	42.77	0.09
8	3	less exposed: low vulnerability, I pressure	14.35	3.84	13.04	2.33	2.01	19.42	0.18

Congo Basin countries and Sierra Leone, Liberia, and Côte d'Ivoire were most at risk in terms of exposure, vulnerability and pressures from agricultural expansion into tropical forests. The most exposed countries averaged the highest percent forest cover (66% ± 0.46 and 54% ± 21.75) and the least potentially available cropland outside forest areas (1% ± 1.75 and 1% ± 0.53). Additional cropland expansion would thus likely lead to forest conversion.

Except for South Africa, population pressures were consistently high, averaging 2.6% ± 0.9. Foreign investments, recent cropland expansion, and income thus explained greater variation in pressures. Equatorial Guinea was an outlier with high exposure and the highest pressure from income growth, but little pressure from agricultural expansion or investment. Sierra Leone stood out as having the highest pressure from population and income growth, as well as the greatest commodity crop expansion (263%) and proportion of land invested in by foreign companies (6%). Income growth was an additional pressure in Ghana, Nigeria, Sierra Leone, and Zambia.

We examined commodity crop expansion and foreign investments more closely in the six most exposed countries and Sierra Leone. Cocoa, maize, oil palm, rice, and rubber each expanded over 60% in at least three of these countries (table S3). Oil palm expanded in Cameroon (141%), Côte d'Ivoire (70%), and Republic of Congo (Congo, 61%) since 2000, which was a significant acceleration compared to previous years (figure 5). Maize and rubber expansion also accelerated in some countries. Only 2% of foreign investments in large tracts of land in these countries were associated with cocoa production (table S4). Nonetheless, cocoa expanded substantially in Congo (313%), Liberia (150%), and Cameroon (80%). Foreign investments in exposed countries were concentrated in oil palm production (81%), with a median area receiving foreign investments of 41 582 thousand hectares (Kha). Investments in oil palm plantations greater than 100 Kha occurred in Congo, Gabon, DRC, Côte d'Ivoire, and Cameroon. Food crop production amounted to less than 16% of land area receiving foreign investments in these countries. The median investment area for all crops in highly exposed and at risk countries (10 Kha) was nearly twice as large as the median area of investments in less exposed (5.1 Kha) and low risk (6 Kha) countries.

3.3. Monoculture expansion in Southwest Cameroon

Perennial commodity crop monocultures of oil palm, rubber, and banana were spectrally separable at mature stages and as a combined monoculture class at immature stages. Cocoa was undetectable: nearly 92% of cocoa production in Cameroon occurs in shade grown systems under secondary forest canopies or inter-cropped with food crops [56], rendering it spectrally indistinguishable from forest, mixed crop, or monoculture systems at 30 m resolution. Monoculture classes were merged, yielding accuracies of 93%, 92%, and 92% for 2015, 2000, and 1986, respectively (κ = 0.90, 0.89, 0.89, table S9). Forest conversion to agriculture increased 10%, from a rate of 0.08% (15 463 ha) in 1986–2000 to 0.09% (17 050 ha) in 2000−2015 (table 4). The proportion of gross deforestation accounted for by agricultural expansion was constant across the two periods. However, forest conversion to monoculture systems in Southwest Cameroon increased significantly since 2000, from 5441 ha to 9249 ha (1986–2000 $r = 0.03\%$; 2000–2015 $r = 0.04\%$). Conversion to mixed crop systems decreased from 10 022 ha ($r = 0.05\%$) to 7801 ha ($r = 0.03\%$). The 70% increase in forest conversion

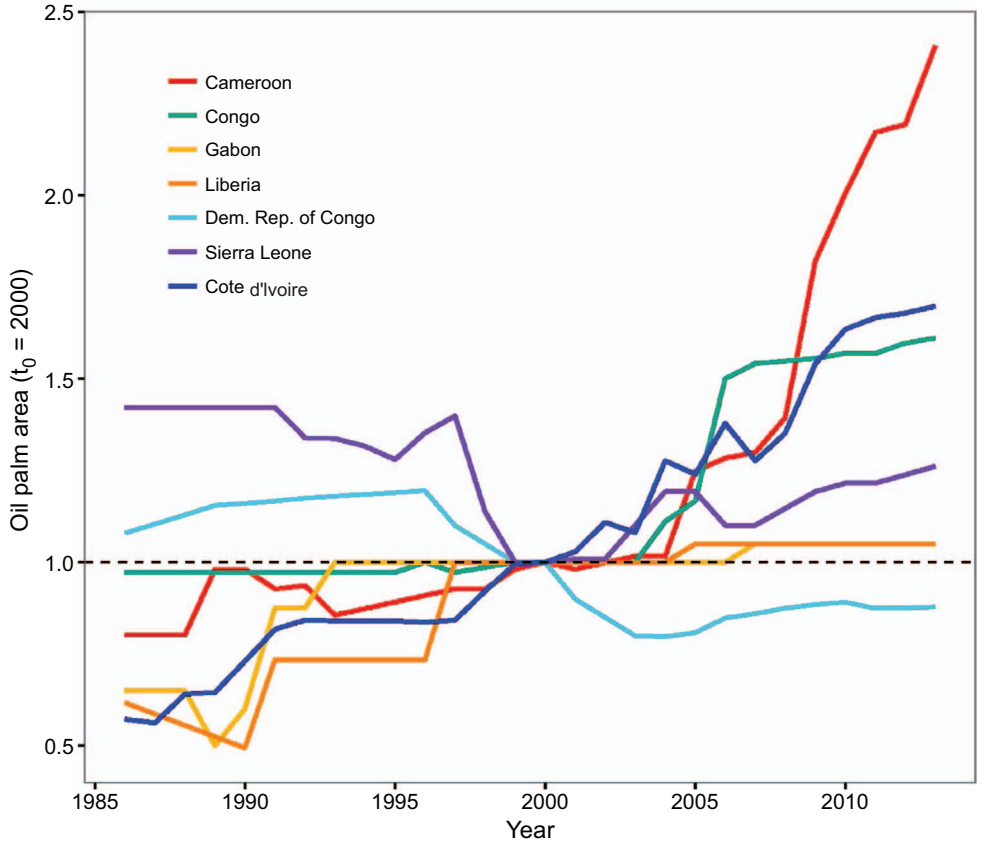

Figure 5. Changes in oil palm cultivated area relative to the year 2000 (dotted line) for seven countries with the greatest deforestation exposure. Cameroon, Congo and Côte d'Ivoire expansion accelerated significantly since 2000.

Table 4. Extent (ha) of forest conversion and farming transitions in SW Cameroon pre-and post-2000.

Transition	1986–2000	rate	2000–2015	rate	Trend
Gross deforestation	18 474	0.08%	19 791	0.09%	+
Gross reforestation	8157	0.04%	8566	0.04%	+
Net deforestation	10 317	0.05%	11 225	0.05%	+
Forest to agriculture	15 463	0.07%	17 050	0.08%	+
Forest to monoculture	5441	0.03%	9249	0.04%	+
Forest to mixed crop	10 022	0.05%	7801	0.03%	−
Mixed crop to monoculture	3367	0.19%	1635	0.08%	−
Monoculture to mixed crop	4457	0.31%	2015	0.08%	−
Monoculture to other monoculture	6155	0.42%	5687	0.23%	−

Table 5. Proportion of deforestation attributed to agricultural expansion.

Land-use transition	% of total deforestation	% of conversion to agriculture	% of total deforestation	% of conversion to agriculture
Forest to Agriculture	83.7%	—	86.2%	—
Forest to Monoculture	29.5%	35.2%	46.7%	54.2%
Forest to Mixed crop	54.3%	64.8%	39.4%	45.8%

to monocultures accounted for 47% of total deforestation in 2000–2015 (table 5, figure S2), previously accounting for only 30%. Mixed crop expansion into forests dropped significantly from 54% (1986–2000) to 39% (2000–2015).

Total deforestation within industrial plantations remained constant between the two study periods: 2658 ha in 1986–2000 and 2953 ha in 2000–2015. This deforestation accounted for only 17% of agriculture-driven deforestation in the study area (figure 6). Field

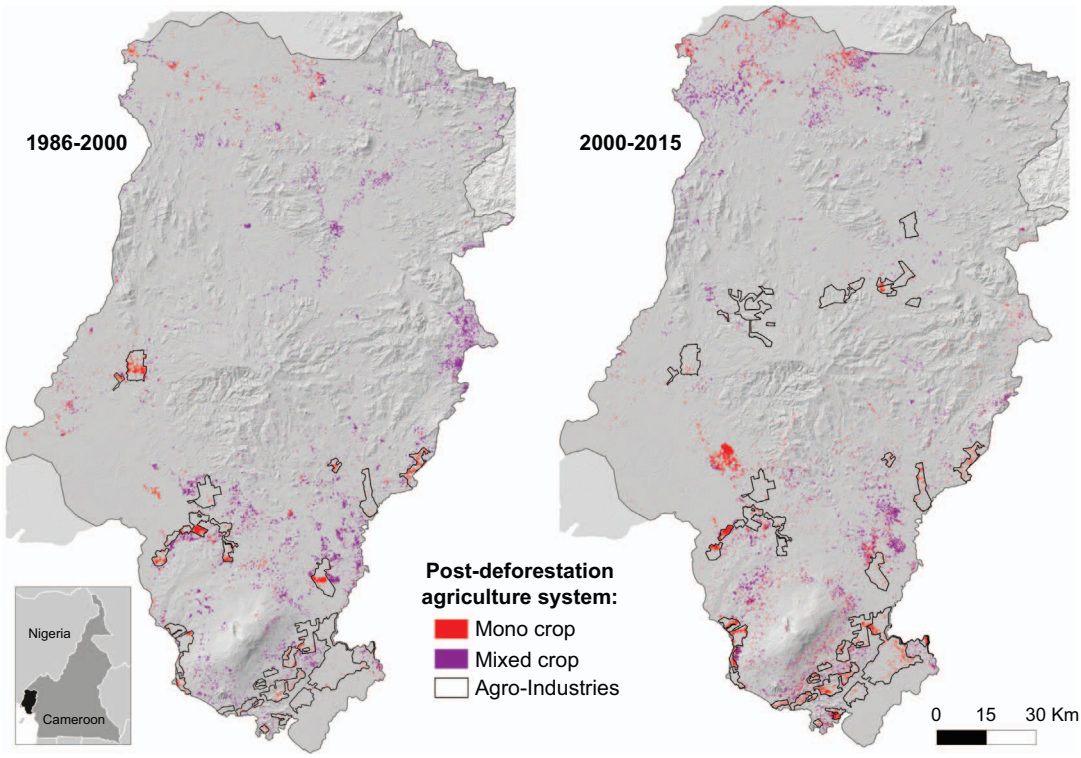

Figure 6. Forest conversion to monoculture (mono crop) systems (red) and mixed crop systems (purple) in Southwest Cameroon, pre- and post-2000. Agro-industrial plantations are outlined in black. Forest conversion to mono crop areas increased in 2000–2015 Most deforestation (83%) resulting from agricultural expansion occurred outside agro-industrial plantations in both time periods.

validation of remote sensing results confirmed that 83% of agricultural expansion into forest areas was associated with non-industrial actors. An increasing amount of forest conversion to monocultures was also concentrated outside plantations, growing from 51% to 68% between study periods. In zoned areas, the percent of total monoculture expansion that occurred within logging concessions rose from 3.6% to 10.9% (table S10). Although agricultural conversion in logging concessions was primarily forest conversion to mixed crops, the proportion of forest conversion to monocultures increased to 39% after 2000, compared to 22% in previous years. The frequency of deforestation due to monoculture expansion across the landscape was most correlated with proximity to roads and villages (table S11), occurring within less than 4 km. As deforestation due to monoculture expansion in plantations decreased post-2000, forest conversion near agro-industrial plantations grew. In 1986–2000, 75% of monoculture expansion occurred within 74 km of plantations. This distance decreased to 74% within 19 km in 2000–2015 We observed increased correlation between the frequency of forest converted to monoculture and proximity to plantations within 2 km (R^2= 0.50, figure S3).

4. Discussion and conclusions

The influence of international markets on deforestation in SSA was until now largely unexplored. Lower deforestation rates in the region offer an opportunity to anticipate shifting drivers of land-use change. We explored the extent to which the offshoring of land use change is affecting SSA by evaluating trends in domestic- and export-oriented commodity crop expansion across the region and the risk posed to tropical forests. We found that domestic demand for commodity crops was associated with most agricultural expansion in SSA in recent years, which includes soy and oil palm. This is in contrast to Southeast Asia and South America, where soy and oil palm expansion driving deforestation is strongly linked to global markets [59]. However, our finding of growth in the export of these two crops, the high concentration of foreign land acquisition for oil palm production in heavily forested countries, and the expansion of export-oriented cocoa production offer evidence of increasing influences of distant markets on land-use change throughout SSA.

Across the tropics, oil palm and soy expansion remain concentrated in Southeast Asia and South America, respectively. Still, both soy and oil palm expanded across SSA; exports of both crops are increasing; and land-use changes associated with large-scale investments, particularly for oil palm production, remain to be observed in many countries. By contrast, SSA accounted for the majority of cocoa expansion globally since 1986. Cocoa expanded more rapidly compared to other export-oriented crops across SSA, with rates of expansion surpassing several crops for domestic markets. Although foreign

investment in land for cocoa production was limited, significant area expansion occurred in 1986–2013, including in several highly exposed countries. An expected shortage of cocoa in the next 20 yr due to increasing demand, largely coming from Asia [60], will likely stimulate efforts to increase production. This has several implications given our finding that cocoa is the major export-oriented crop expanding in SSA. The dominance of shade-grown cocoa systems under secondary forest in SSA could incentivize conservation of forest cover [56, 61]. Yet existing remote sensing techniques are insufficient to accurately detect cocoa production. We faced limitations in mapping commodity crops like cocoa, due to these agroforestry and intercropping practices. FAO statistics indicate that cocoa expanded in Cameroon at a rate of 28 Kha yr^{-1} in 2000–2013. We thus likely underestimated deforestation and forest degradation. Remote sensing has become an important tool for monitoring, reporting and verifying deforestation and degradation, a more feasible task when forest is converted to monocultures like oil palm or soy. As countries are held accountable for land use-based CO_2 emissions, further research is needed to understand impacts of cocoa expansion. Research programs aimed at improving yields in West and Central Africa emphasize the development of low shade/full sun hybrid cocoa systems [56]. Given the current extent of cocoa and rapid rates of area expansion, conversion of shade- to sun-grown systems could have large aggregate effects on tropical deforestation in SSA [62]. Alternatively, possible synergies have been suggested when investments in cocoa production are combined with forest conservation strategies (e.g. REDD+) [63]. This is particularly salient in light of expanding monoculture systems, which can have far greater impacts on forest ecosystem productivity than mixed-species stands [64].

Our case study results from SW Cameroon provide evidence that monoculture commodity crop expansion—for domestic markets in the case of oil palm—is increasingly expanding into forest area, accounting for nearly half of all deforestation since 2000. Large-scale oil palm investments are concentrated in tropical forest countries with little potentially available cropland outside forests, namely the Congo Basin, where expansion is accelerating. Yet, the case study also demonstrates that the majority of recent forest conversion for monoculture farming did not occur in industrial plantations, pointing to growing monoculture expansion by non-industrial actors. A pattern of deforestation around commercial plantations could indicate an influence of the private sector on smallholder land use practices. Rapid cocoa expansion, despite less foreign investments in large tracts of land, also suggests expansion of smallholder, export-oriented agriculture. The term smallholder, however, encompasses a notably heterogeneous group that includes subsistence farmers and farmers cultivating commodity crops [65]. Further, Jayne *et al* [66] record a rapid rise in medium-scale farmers, who now cultivate more land than small-scale famers in some African countries. Medium-scale producers often cultivate tens to hundreds of hectares, and can be linked to urban political elites investing in land for commodity crop production [66]. Determining the role of small- versus medium-scale farmers in deforestation was beyond the scope of this study. Future research in this area can improve our understanding of causal mechanisms driving these dynamics.

Despite evidence of export-oriented commodity crop expansion, SSA has not reached rates observed in other tropical regions. Export-oriented commodity crops in SSA are also expanding over significantly smaller areas than crops for domestic markets, suggesting agricultural expansion in the region remains largely associated with domestic demand [14]. This is likely due to land accessibility constraints, both in terms of infrastructure and land tenure complexities. Most unexploited land in SSA is far from markets, limiting the profitability of its conversion [38]. Pervasive land tenure complexities across SSA linked to discrepancies between customary and statutory tenure, among other issues, present major impediments to both forest regulation and large-scale investments in land for agriculture [67]. Still, mechanisms in some areas are being established to facilitate foreign investments in commodities like soy [29]. Our observation of large land investments and the high concentration of oil palm contracts in highly exposed tropical forest countries suggest that these impediments may be overcome.

Our findings contribute new information on commodity crop expansion in SSA during a time of globalized market influences on land use displacement and deforestation in the tropics. We provide evidence that commodity crops are expanding in SSA, placing increased pressure on tropical forests. Domestic demand across SSA continues to drive most agricultural expansion, although export-oriented cocoa expansion and foreign investments demonstrate increased influence of distant markets. We highlight challenges and potential synergies associated with cocoa expansion that differ from oil palm and soy. Results also suggest that commodity crop expansion in SSA is largely being carried out by non-industrial actors. Commodity crop expansion can follow multiple pathways with very different outcomes for tropical forests [18]. This research presents new information on commodity crop expansion dynamics in SSA and underscores a growing influence of distant markets on land-use change in the region.

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