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Tropical forest loss enhanced by large-scale land acquisitions

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Tropical forests are vital for global biodiversity, carbon storage and local livelihoods, yet they are increasingly under threat from human activities. Large-scale land acquisitions have emerged as an important mechanism linking global resource demands to forests in the Global South, yet their influence on tropical deforestation remains unclear. Here we perform a multicountry assessment of the links between large-scale land acquisitions and tropical forest loss by combining a new georeferenced database of 82,403 individual land deals—covering 15 countries in Latin America, sub-Saharan Africa and Southeast Asia—with data on annual forest cover and loss between 2000 and 2018. We find that land acquisitions cover between 6% and 59% of study-country land area and between 2% and 79% of their forests. Compared with non-investment areas, large-scale land acquisitions were granted in areas of higher forest cover in 11 countries and had higher forest loss in 52% of cases. Oil palm, wood fibre and tree plantations were consistently linked with enhanced forest loss while logging and mining concessions showed a mix of outcomes. Our findings demonstrate that large-scale land acquisitions can lead to elevated deforestation of tropical forests, highlighting the role of local policies in the sustainable management of these ecosystems.

Protecting the world's remaining forests is crucial for climate change mitigation, biodiversity conservation, and local livelihoods. However, what were once remote forests are now increasingly embedded in complex networks of local and international actors, increased capital and expanding commodity trade[1,2]. Foreign and domestic investments in land have recently become a key mechanism linking rising global demand with forests and natural resources in the Global South, primarily in Latin America, sub-Saharan Africa and Southeast Asia[3–7]. Since the start of the century, large-scale land acquisitions (LSLAs) (typically defined as being at least 200 hectares)[8] have surged in the Global South, with foreign land investments currently accounting for 76% of all acquired land area[8]. These investments are executed with the goal of generating backflows of natural resources or agricultural commodities to domestic or transnational investors as well as foreign governments[9–11]. Governments in the Global South have often welcomed these investments as a means to potentially facilitate technology transfers and the inflow of capital as well as to promote rural development and local job creation (for example, ref. [12]). To promote these potential advantages, governments have described such investments as particularly suited for improving the utility of 'idle', 'waste', 'unoccupied' and 'marginal' lands and territories. This argument stands in contrast to the realities of informal and traditional land use by local communities[13–15], who often rely on these lands to support incomes[16] and food security[17], and ignores the ecological importance of the natural systems therein. Despite the potential disruption by LSLAs of both informal land use[18] and ecosystem function[20], it remains largely unclear what the socio-ecological impacts of these deals have been to date[19,20]. For environmental outcomes in particular, this lack of understanding persists because spatial information on the location of individual land deals is often not publicly available[21] and because environmental impacts can be a secondary consideration for countries seeking to enhance rural development through direct investments in land[20]. As a result of these limitations, only a handful of studies have been able to evaluate selected environmental impacts of LSLAs, mainly in forests of Southeast Asia[22–26], finding that land deals for oil palm and rubber plantations have indeed accelerated deforestation. Two of these studies[23,24] have also demonstrated the critical need to use proper statistical tools that account for selection bias (that is, the influence of confounding variables on the outcome of interest) when seeking to isolate the effect of LSLAs on environmental outcomes.

These few studies, combined with the fact that most land deals are being granted in countries that occur within the tropics, point to the potential risk that LSLAs pose to the planet's tropical forests, which are of outstanding importance for carbon storage, global biodiversity and other ecosystems services[27]. Large swaths of tropical forests are also used by local communities for supporting livelihoods, food security and cultural identity[28]. Deforestation due to the expansion of other (typically more industrialized) land uses is therefore a major threat to both the environmental assets and the socio-ecological integrity of tropical forests. Yet whether LSLAs are preferentially granted within forests has received limited attention to date[29]. On one hand, forests appear to be a particular focus

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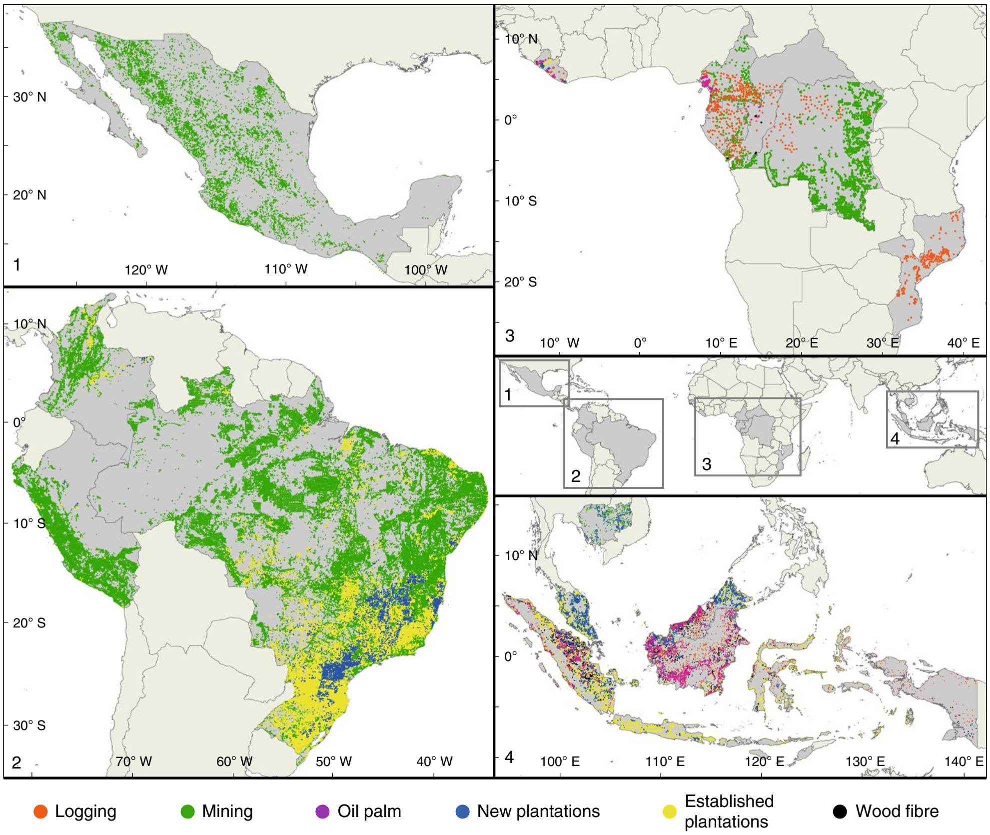

Fig. 1 | Distribution of publicly available LSLAs across Latin America, sub-Saharan Africa and Southeast Asia. Each point corresponds to the centroid of each georeferenced land deal. Points are coloured according to investment type.

of LSLAs, due to factors such as lower land prices, the perceived greater availability of land and economic conditions more favourable for profit than in established agricultural regions[29–31]. On the other hand, such areas typically lack infrastructure, have poorer market access and may be more costly to clear and modify for the intended use[11], which would suggest a preference for land acquisitions located in established agricultural regions or available land in grassland or savannah regions[32,33]. Finally, even if land-based investments target forests, land deals are often highly speculative. This can mean that local communities may be prevented from continued informal use of the land even though the area is never put to productive use by an investor, thereby reducing pressure on forest resources[7]. A comprehensive investigation into the links between land acquisitions and tropical deforestation rates has not yet been conducted, and whether LSLAs are associated with greater deforestation thus remains unknown.

Here we present a systematic assessment of LSLA impacts on forest cover in the Global South between 2000 and 2018. We employ maps of individual land-based investments in oil palm, timber (logging, tree plantations, wood fibre) and mining for 15 countries—covering all of the investment types and countries in the Global South for which georeferenced data were publicly available—in sub-Saharan Africa, Southeast Asia and Latin America (Brazil, Cambodia, Cameroon, Central African Republic, Congo, Colombia, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Indonesia, Liberia, Malaysia, Mexico, Mozambique and Peru) (Extended Data Fig. 1). According to land contracts reported in the Land Matrix database, the land area under contract in these 15 countries currently makes up 51% of the world's LSLA area for all intended uses[8]. In addition, these three regions have been most frequently targeted for land investments since the start of the century[23,34,35] and contain many of the planet's biodiversity hotspots[36] and much of the remaining tropical forests[37]. Further, for the study countries, the investment types included in this study constitute 91% of total reported LSLA area[8]. The resultant database of georeferenced deal boundaries contains 82,403 individual land deals in total for 31 unique combinations of countries and investment types (Fig. 1 and Supplementary Table 1), with the average size of individual investments ranging from 650 ha to more than 100,000 ha (Supplementary Tables 2 and 3). We combine this database on investment location with high-resolution maps of forest cover and annual forest loss[38] (acknowledging that the definition and structure of forests can vary widely from country to country (for example, acacia/eucalyptus in Indonesia, teak/rubber in Cambodia)) and quantify whether different types of land investments have been associated with significant changes in rates of forest loss since the year 2000. We use a covariate matching approach to control for other, potentially confounding, factors that influence forest change (for example, distance to roads, soil fertility)[39], thereby improving our ability to isolate the impacts of LSLAs on forests.

Impact of land deals on deforestation

We find that LSLA areas were preferentially granted in forested areas and that more than half of the examined investments were associated with significant increases in deforestation since the start of the century. Over the study period (2000–2018), rates of annual forest loss rose substantially within those concessions where forest removal was significantly higher than in comparable non-investment areas, and forests in oil palm concessions, tree plantations and wood fibre concessions were particularly affected.

Forest extents varied widely across the 15 different countries and 5 investment types examined (82,403 unique land deals in total (see

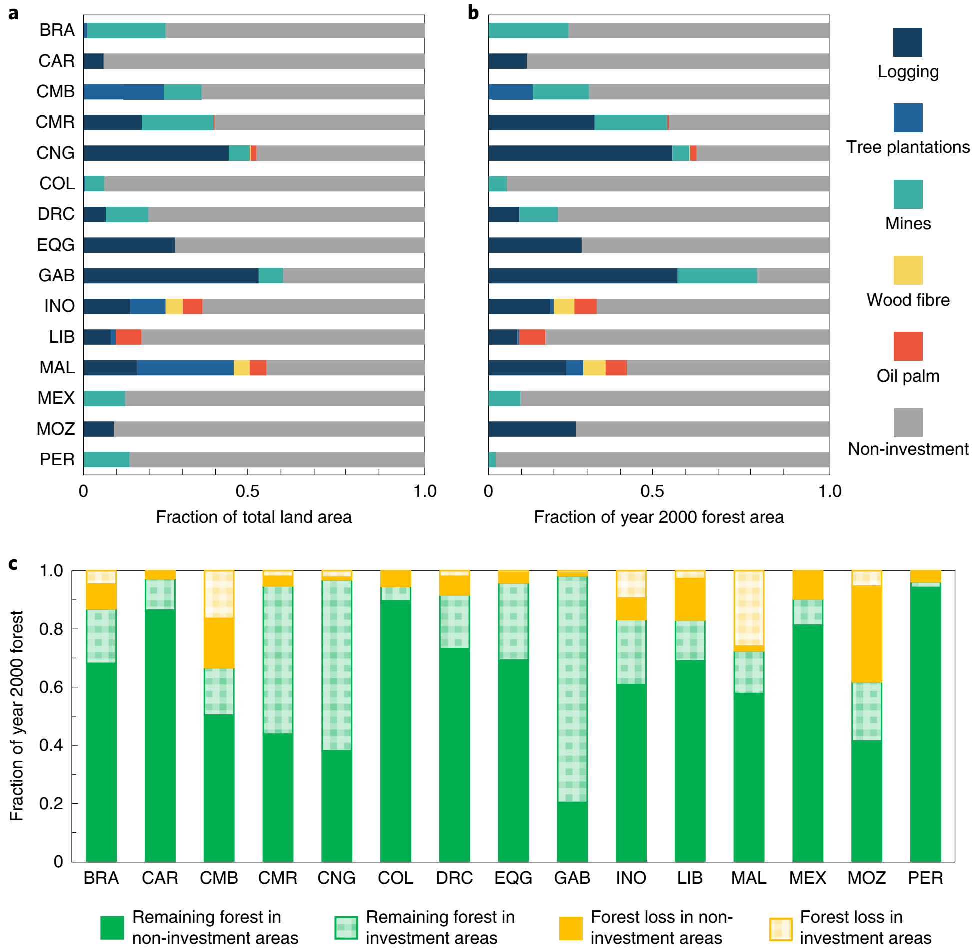

Fig. 2 | Share of land, forests and forest loss within investment areas. a–c, Land area (**a**), year 2000 forested area (**b**) and remaining forests and forest loss located within land-based investment areas (**c**) were calculated as a fraction of total land area, year 2000 forested area and cumulative forest loss through the year 2018 for each study country. Economic land concessions (ELCs) in Cambodia were categorized as 'Tree plantations'. BRA, Brazil; CAR, Central African Republic; CMB, Cambodia; CMR, Cameroon; CNG, Republic of the Congo; COL, Colombia; DRC, Democratic Republic of the Congo; EQG, Equatorial Guinea; GAB, Gabon; INO, Indonesia; LIB, Liberia; MAL, Malaysia; MEX, Mexico; MOZ, Mozambique; PER, Peru.

Fig. 1 and Supplementary Table 1)). LSLAs occupied between 6% (in Central African Republic) and 59% (in Gabon) of each country's land area. In Southeast Asian countries (that is, Cambodia, Indonesia and Malaysia), LSLAs were divided more evenly between investment types, while in other countries a single category of investment dominated acquired land area (for example, logging concessions in Congo and Equatorial Guinea) (Fig. 2a). LSLAs contained anywhere from 2% (in Peru) to 79% (in Gabon) of each country's forested land, as measured in the year 2000 (Fig. 2b). LSLAs contained a disproportionate amount of forested land in 11 of the 15 study countries (Fig. 2b). In other words, in these countries, the percentage of a nation's forested area contained within LSLAs was greater than the percentage of a nation's total land area within LSLAs. Further, in 25 out of 31 cases (or 81%), the percentage of land area that was forested within LSLAs was higher than in non-investment areas (Table 1). On the basis of the countries and investment types examined here, this suggests that LSLAs tend to be disproportionately granted within forested areas. As with forest extents, the rates of forest loss contained within LSLAs varied widely across countries and investment types. Brazil, Cambodia, Indonesia, Liberia, Malaysia and Mozambique lost more than one-tenth of their forests between 2000 and 2018 (Fig. 2c). In nine study countries, average rates of forest loss were higher within LSLAs than in non-investment areas, suggesting that LSLAs may lead to increased forest loss. In Southeast Asia in particular, LSLAs contained 32%–41% of forests in the year 2000 but contributed 49%–94% of cumulative forest loss (Fig. 2c).

Controlling for other factors that can influence the spatial patterns of forest loss (that is, selection bias) to isolate the effect of different land investments on deforestation rates revealed that LSLA areas experienced enhanced forest loss within certain policy settings. Of the 31 combinations of countries and investment types that we analysed, 52% experienced rates of forest loss significantly higher than matched non-investment areas (Fig. 3 and Table 2). However, 39% experienced rates of forest loss significantly lower than matched non-investment areas. All other LSLAs (9%) experienced rates of forest loss that were statistically indistinct from those in comparable non-investment areas. As expected, the investments that require complete land conversion to be used productively were the ones that consistently displayed significantly higher rates of forest loss, relative to matched plots. These significantly higher deforestation rates were evident in all countries hosting these specific LSLA types, namely, oil palm plantations, wood fibre concessions and new tree plantations (for example, Fig. 4). This result suggests that these investment types are generally put to productive use shortly after being granted and accords with other recent studies showing that Indonesian oil palm concessions[25,40] and tree plantations in Cambodia[24] experience enhanced forest loss. Conversely, and perhaps surprisingly, of the ten countries that had logging

Table 1 | Ratio of forested fraction within LSLAs to forested fraction in non-investment areas

Country	Logging	Mines	Oil palm	Tree plantations	Wood fibre
BRA	…	1.01[a]	…	…	…
CAR	2.00[a]	…	…	…	…
CMB	…	1.39[a]	…	1.14[a]	…
CMR	2.37[a]	1.33[a]	1.68[a]	…	…
CNG	1.60[a]	1.03[a]	1.57[a]	…	0.86
COL	…	0.95	…	…	…
DRC	1.40[a]	0.93	…	…	…
EQG	1.02[a]	…	…	…	…
GAB	2.10[a]	6.35[a]	…	…	…
INO	1.26[a]	…	1.11[a]	1.12[a]	1.13[a]
LIB	1.06[a]	…	1.02[a]	0.88	…
MAL	1.13[a]	…	1.01[a]	1.02[a]	1.11[a]
MEX	…	0.74	…	…	…
MOZ	3.67[a]	…	…	…	…
PER	…	0.14	…	…	…

ELCs in Cambodia were categorized as 'Tree plantations'. [a]Values greater than 1 indicate cases where the forested fraction (that is, area covered by forests divided by land area) within LSLAs is greater than in non-investment areas.

investments, we generally found a significant, albeit slight, decrease in deforestation in eight of the ten countries containing logging investments, except in the cases of Liberia (no significant change) and Central African Republic (significant increase). Forest loss was significantly higher within mining concessions in three out of nine countries, all occurring in South American countries (Brazil, Colombia and Peru). Four countries (Congo, Democratic Republic of Congo, Gabon, Mexico) saw significantly lower rates of forest loss within mining investment areas. Covariate matching results within oil palm plantations, tree plantations and wood fibre concessions, which were consistently associated with significant enhancements of forest loss within LSLAs, were generally insensitive to hidden bias (that is, the influence of unobserved variables on the outcomes of comparisons between investment and non-investment points) (Supplementary Table 4). However, results for logging and mining concessions, which saw lower rates of forest loss within LSLAs in certain instances, are potentially sensitive to hidden bias. Thus while these types of LSLAs may exercise a small protective effect for forest cover, it is unclear whether their presence or absence is the primary influence on forest loss in areas where these deals are granted. For all comparisons across every country and investment type, covariate balance was improved substantially after matching (Supplementary Tables 5–35), meaning that for each comparison we were able to identify a set of non-investment points with covariate distributions that are nearly identical to those of investment pixels and, in doing so, avoid selection bias and isolate the effect of LSLAs on deforestation rates.

Temporal dynamics of forest loss

Forest loss since 2000 showed differing temporal trends between countries (Extended Data Fig. 2). For example, rates of forest loss in Congolese oil palm concessions were relatively low for both investment and non-investment plots until 2012, when rates of forest loss rose substantially within concessions. In Cameroon and Liberia, rates of forest loss in oil palm investment plots started to exceed that of non-investment plots only after 2008 (see, for example, Fig. 4). Rates of forest loss between oil palm investments and non-investment plots in Indonesia and Malaysia were comparable at the beginning of the period but generally diverged thereafter.

These patterns also varied across different investment types (Extended Data Figs. 3 and 4). Forest loss rates within wood fibre concessions in Congo were moderate (on average around 3%) with substantial interannual variability. For both wood fibre investment and non-investment plots in Indonesia, rates of forest removal were relatively high and showed a general positive trend. Malaysian wood fibre concessions showed trends in forest loss similar to those in Indonesia but with lower average rates. For Liberia, Indonesia and Malaysia, land clearing for new tree plantations produced the most obvious cases of enhanced forest loss associated with land investments. Tree plantations in Cambodia exhibited similar behaviour, with annual rates of forest loss nearing 9% in the second half of the study period. This agrees with recent work showing that, while land investments in Cambodia are often intended for rubber or other tree plantations, they are often indiscriminately logged for timber[41]. According to statistics reported in Land Matrix[8], the timing of forest loss for all of these land deals corresponds with the years during which LSLA contracts were most frequently finalized (Extended Data Fig. 5). In addition, with the exception of mining concessions in Brazil, all cases experiencing a significant enhancement of forest loss from LSLAs have reported contract years that largely occur before or during periods of elevated deforestation rates, thereby strengthening the evidence of causality (Extended Data Figs. 3 and 4). While in most instances, LSLAs appear to precede accelerated forest loss, it is possible that in other cases, LSLAs were granted along active deforestation frontiers. Such temporal mechanisms linking LSLAs and forest loss should be the focus of future investigations.

Potential for evidence-based policies

Our results provide evidence that large-scale land investments in tropical countries have been preferentially granted in forested areas and that more than half of these investments are associated with accelerated forest loss since the year 2000 (Table 2). LSLA-related forest losses were particularly pronounced in Southeast Asia (Figs. 2c and 3) and suggest that if similar investments are granted in other regions they may also result in substantial deforestation. In several countries (for example, Cameroon, Congo, Gabon), LSLAs contain vast tracts of remaining forests, indicating that these areas are at heightened risk of deforestation (Fig. 2c).

Deforestation rates clearly differed among investment types. Investments intended for the production of export-oriented commodities produced the greatest loss rates regardless of region, as these require substantial land conversion to realize their intended use. The effect of other types of investments on forests appeared to be more context specific (for example, mines in Latin America). For mining concessions, these mixed results may be attributable to the fact that the physical footprint of mining operations may vary according to the type of minerals being extracted[42,43], as suggested by a comparison of the results for South American countries (significant increase in forest loss) and for central African countries (significant decrease in forest loss). In logging concessions, where rates of forest loss were relatively low and where we observed consistent, significantly lower deforestation rates within LSLAs, selective tree removal may still lead to forest degradation that is not readily detectable using the remote sensing methods employed in generating the forest loss maps in our study[38]. For other cases where there was not a significant difference in forest loss, it is possible that some of these investments have not yet been implemented and that future assessments may find changes in rates of forest loss in these areas. In addition, for all of the investment types that we studied, our analysis of forest loss did not capture various forms of indirect forest pressure (for example, livestock browsing, collection of forest resources) that may be associated with LSLAs. Similarly, we do not assess how the potential displacement of local communities due to exclusion

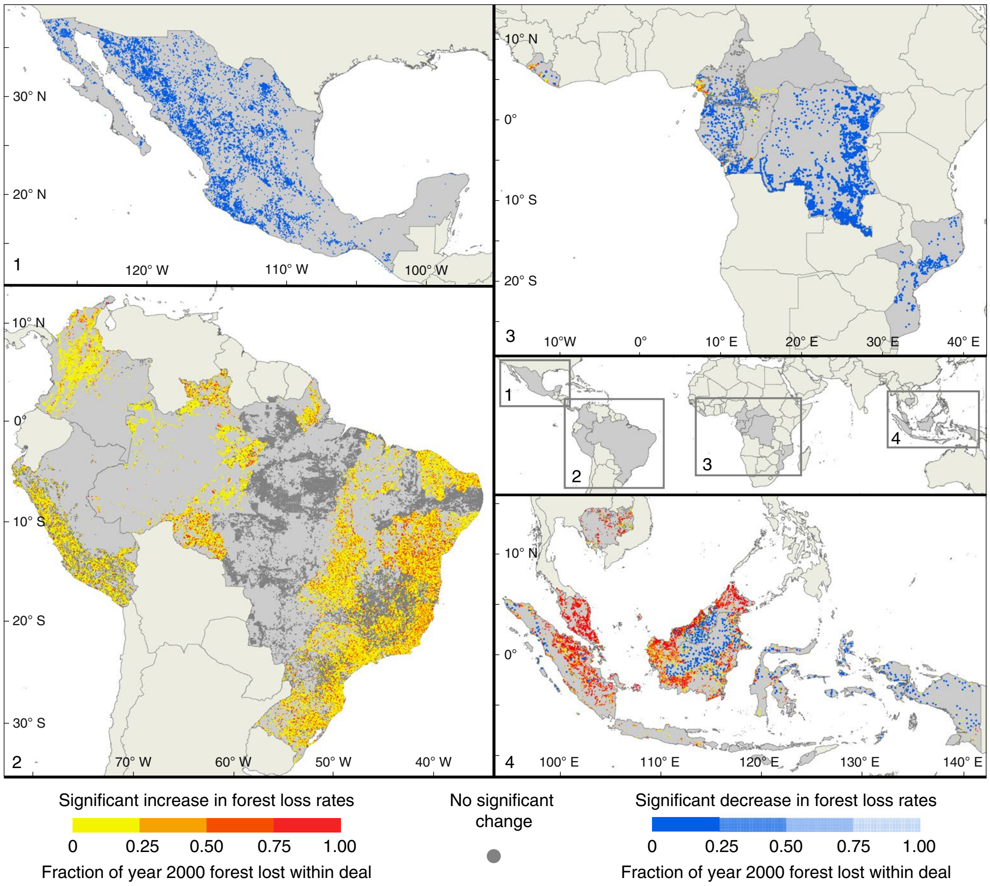

Fig. 3 | Distribution of LSLAs and influence of rates of forest loss. Each point corresponds to the centroid of each georeferenced land deal. Points are coloured yellow to red for a significant increase in rates of forest loss relative to non-investment areas, grey for no significant change in rates of forest loss and blue for a significant decrease in rates of forest loss.

from LSLA areas may also produce forest loss elsewhere. Such displacement effects can exercise important influence on total forest loss[44,45]. Given these considerations, our estimates of the effects of LSLAs on tropical forest cover are likely conservative.

Our study also provides new information regarding the degree of resource use and environmental impacts of LSLAs. The substantial heterogeneity in terms of forest loss rates we find across countries for certain investment types (for example, logging and mining) suggests that the specific regulations and policies, and the wider socio-political and economic contexts, are important for dictating the extent of forest loss within each type of concession. From a policy perspective, this indicates room for nuance in the formulation of forest protection policies by focusing on those investment types at greater risk of triggering deforestation. Decision makers seeking to pursue sustainable development pathways can weigh this evidence of the potential forest loss impacts of LSLAs against other societal objectives (for example, food security, rural development) to determine whether this set of outcomes is in the best interests of the people they represent. This also provides the chance to re-evaluate whether opportunities exist—for example, in relation to the locations where a government could promote or limit certain types of LSLAs through targeted policy mechanisms—to realize co-benefits across multiple dimensions (for example, ref. [33]) and to ensure that LSLAs do not continue to be preferentially granted in forested areas. Developing a more holistic understanding of the likely outcomes of promoting LSLAs in forested areas can also allow policymakers within targeted countries to compare this strategy against other potential interventions to understand which offers the greatest opportunities for realizing local sustainability goals.

Quantifying the environmental impacts of various land investment types is a much-needed step for developing an integrated understanding of the potential socio-ecological trade-offs, impacts and benefits to balance land use with environmental goals, and sustainable development objectives more broadly. Our assessment of changes to forest cover examines only one of the potential impacts engendered by large-scale land investments[20,25]. Better understanding is still required regarding how sudden changes in land use occurring within LSLAs may locally impact hydrological processes, soil erosion, carbon storage and biodiversity. Emerging georeferenced datasets such as those employed here will permit more-detailed future assessments. There is also a need to better quantify forest degradation within targeted countries as such changes can strongly impact biodiversity, ecosystem functioning, ecosystem services and livelihoods[46]. In addition, extending examinations of the changes in forest cover induced by land acquisitions to also include other land cover/use types (for example, rangelands, croplands) as well as other sources of land investment (for example, the urban middle class of targeted countries[47]) will be another key next step.

Our assessment provides new insights into LSLAs as an important influence of forest loss in the Global South and their potential role in altering the environment in targeted areas. The quantitative evidence emerging from our study points towards a land investment nexus within which tradeoffs between economic development and the environment are currently profound and frequent. Future assessments of the potential socio-environmental impacts of LSLAs should seek to adopt integrated approaches that not only understand the causal linkages among the global economy (for example, ref. [48]), investment decisions and outcomes for local communities

Table 2 | Comparison of cumulative forest loss between 'matched' LSLA and non-investment points

Country	Logging	Mines	Oil palm	Tree plantations	Wood fibre
BRA	…	14.9 (13.9)*	…	…	…
CAR	4.2 (2.4)*	…	…	…	…
CMB	…	22.2 (23.4)	…	46.7 (40.3)*	…
CMR	0.9 (2.1)**	5.4 (5.1)	28.5 (19.4)*	…	…
CNG	3 (3.1)	3.8 (7.1)**	5.4 (2.6)*	…	30.5 (17.7)*
COL	…	8.9 (6.6)*	…	…	…
DRC	8.8 (10.6)**	8.6 (14.5)**	…	…	…
EQG	2.5 (3.3)**	…	…	…	…
GAB	0.7 (0.9)**	2.7 (4)**	…	…	…
INO	6.4 (11.5)**	…	31 (24.3)*	86.7 (36)*	29 (23.7)*
LIB	3.9 (6)**	…	22.5 (19)*	72.7 (29.1)*	…
MAL	14.4 (19.1)**	…	40.7 (31.6)*	85.8 (28.7)*	19.5 (15.8)*
MEX	…	2.1 (3.3)**	…	…	…
MOZ	13.7 (15.4)**	…	…	…	…
PER	…	7.1 (5)*	…	…	…

All values are percentages. Values outside parentheses correspond to 'matched' investment areas, and all values in parentheses correspond to 'matched' non-investment areas. ELCs in Cambodia were categorized as 'Tree plantations'. *Forest loss within an investment was significantly higher ($\alpha = 0.05$) than in corresponding non-investment areas after performing covariate matching; **Forest loss within an investment was significantly lower ($\alpha = 0.05$) than in corresponding non-investment areas after performing covariate matching.

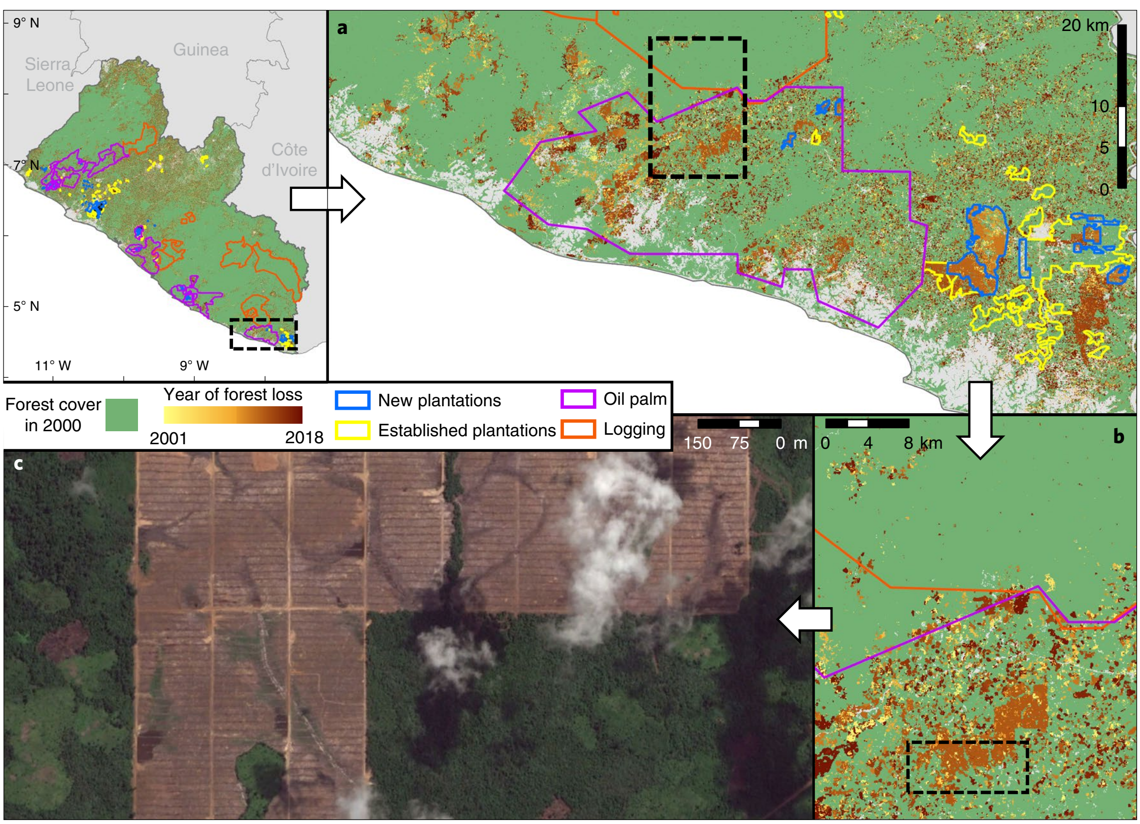

Fig. 4 | Forest loss in oil palm plantations in Liberia. Areas for new plantations of oil palm have been granted near Liberia's coastline. **a**, Patterns of forest loss within oil palm areas and neighbouring new tree plantations display obvious characteristics of agro-industrial activity and stand in stark contrast to patterns of forest loss in outlying non-investment areas, while tree cover within logging concessions remains intact. **b**, Within agro-industrial areas, large patches of forest are removed in a single year, accompanied by widespread removal of smaller patches. **c**, In those patches where forest removal occurred, land is being prepared for oil palm establishment. Adjacent forest patches show the contrast with previous land cover. Credit: satellite image; Google, Maxar Technologies.

and the environment, but also seek to draw broader inferences from individual case studies[49]. Doing so can help in identifying entry points for policy interventions and for understanding their potential cascading effects. This information can also enable policies to incorporate a perspective that accounts for global and local influences on land investments and the potential trade-offs, impacts and benefits that they may engender.

Online content

Any methods, additional references, Nature Research reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41561-020-0592-3.

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Methods

We quantified forest loss within 5 types of land investments across 15 countries in sub-Saharan Africa, Latin America and Southeast Asia—all of the investment types and countries for which georeferenced data were publicly available—for the years 2000–2018. We then compared rates of forest loss within LSLAs with ambient rates of forest loss in non-investment areas that share characteristics that are known to significantly influence the location and extent of deforestation.

Data. Georeferenced data on land investments were available for 15 countries: Brazil, Central African Republic, Cambodia, Cameroon, Congo, Colombia, Democratic Republic of Congo, Equatorial Guinea, Gabon, Indonesia, Liberia, Malaysia, Mexico, Mozambique, and Peru (Extended Data Fig. 1).

We considered five large-scale land investment types. These data were assembled largely from federal ministries and government offices of the respective countries. Information on mining concessions, tree plantations (new and established), logging concessions, oil palm plantations and wood fibre concessions came from the World Resources Institute's Global Forest Watch[50]. New tree plantations were those described as 'Recently cleared' within the dataset. The new tree plantations for which the intended tree species was specified as 'oil palm' were assigned to the analysis for oil palm investments. Data on ELCs in Cambodia came from Open Development Cambodia[51]. Data on forest concessions in Mozambique came from the central office of the Federal Ministry of Land, Environment, and Rural Development[52]. Little information was available regarding the dates on which many of the land concessions were either formally contracted or put to productive use. As such, we assumed that the land deals considered in this analysis occurred in or after the year 2000, the year that is widely recognized as the starting point for a rapid increase in LSLAs in the Global South[7,10,11,53]. We also note that the status of individual land investments can change rapidly. Thus, some of the deals included in our dataset may have been voided, and other deals may have been added, since these data were accessed (January 2020).

Data on annual forest loss came from Hansen et al.[38]. This dataset provides the initial forest cover in the year 2000 (as a percentage of the pixel area) as well as the year in which a pixel (30 m × 30 m) gains or loses forest. Because this dataset does not distinguish between native forest and plantations, we use all georeferenced datasets that are publicly available to differentiate these two land use types. As additional evidence of the presence of native forest at the start of the study period, for each country we randomly selected up to 50 individual 'established' tree plantation deals (that is, plantations not defined as 'clearing/very young plantations' within the World Resources Institute's Global Forest Watch[50] tree plantation data layer) to visually confirm the presence or absence of tree plantations before the year 2000 (Supplementary Table 36). Following Hansen et al.[38], we defined a pixel as initially forested if the initial tree cover was at least 50%. In adopting this threshold, we acknowledge that the definition and structure of forests can vary widely from country to country, that using this product does not allow for an assessment of forest degradation as a result of different uses, and that our analysis probably does not capture vegetation types with lower tree densities (for example, woody savannas). Given these limitations, our estimates of forest loss are probably conservative. For those initially forested pixels that undergo deforestation in a given year, we assume complete forest loss for that pixel in that year and all subsequent years. We did not consider forest gain from 2000 to 2018 in our calculations of deforestation rates because Hansen et al.[49] did not report this on an annual basis and because areas of forest gain in the study countries are much smaller than those of forest loss (see, for example, ref. [24]).

Measuring characteristic covariates. A number of factors can influence the likelihood that an area will be deforested, regardless of whether it is located inside of a land investment. To control for these factors, we employed a covariate matching approach similar to that used by Andam et al.[39], who measured the effectiveness of protected forest areas in Peru, and Davis et al.[24], who assessed the influence of Cambodian land investments on forest conversion. The goal of this covariate matching approach is to identify a set of non-investment pixels with covariate distributions that are nearly identical to those of investment pixels; this serves to avoid selection bias and to isolate the effect of the presence/absence of LSLAs on deforestation rates (Supplementary Tables 5–35). Thus, it is then possible to compare investment and non-investment areas to examine in isolation the potential effect of land acquisitions on deforestation. To this end, we randomly selected over 800,000 initially forested pixels, 30% of which were located within land investment areas (Supplementary Table 37). This represents approximately one pixel every 11 km^2 of the 13.7 million km^2 of forests that we examined. Pixels in protected areas, in established plantations (except Cambodia; Supplementary Table 36), in forest moratorium areas (Indonesia)[50] and in individual deals for which the contract dates were known to be before the year 2000 (logging concession in Indonesia and Malaysia) were excluded from consideration. For mining concessions, pixels that fell within a mining concession and another investment type were also not considered. For each pixel, we calculated covariate information for distance from the nearest road, distance from the nearest waterway, distance from the nearest railway, distance from the nearest urban area (that is, population density greater than 300 people km^{-2}), distance from the nearest forest edge, slope class, agro-ecological suitability and district area. Distance from the nearest urban area was calculated using a year 2005 population density dataset from the Center for International Earth Science Information Network/Centro Internacional de Agricultura Tropical[54]. Classes for median-terrain slope and agro-ecological suitability for rain-fed high-input cereals were assigned using data from the Food and Agriculture Organization/International Institute for Applied Systems Analysis Global Agro-Ecological Zones[55] (Supplementary Table 38). We also reran the analyses excluding random pixels occurring in more than one deal, due to some overlap between datasets of different investments, and found that the outcomes remained consistent.

Controlling for influences on forest loss. Covariate matching was performed in R using the 'Matching' package[56]. We also examined the sensitivity of these results to hidden bias (that is, the influence of unobserved variables on the outcomes of comparisons between investment and non-investment points) using Rosenbaum's sensitivity test[57]. Matched investment and non-investment plots differ in their likelihood of being deforested by an unknown covariate by a factor of Γ, so that $\Gamma = 1$ means that investment plots are equally as likely as their matched non-investment plots to be deforested as a result of hidden bias. The higher that gamma can be increased while the result still remains significantly different from zero, the more robust the results are to hidden bias.

Data availability

The datasets generated and analysed during the current study are publicly available or are available from the corresponding author on reasonable request.

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Author contributions

K.F.D., J.D., P.D., L.J.K., T.K., N.R., M.C.R. and L.E. designed the research; K.F.D., H.I.K., M.K., D.M. and A.d.J.R.P. performed the research; K.F.D., H.I.K., M.K., M.C.R. and M.T. analysed the data; and K.F.D., J.D., P.D., L.J.K., M.K., T.K., N.R., M.C.R., M.T. and L.E. wrote the paper.

Competing interests

The authors declare no competing interests.

Additional information

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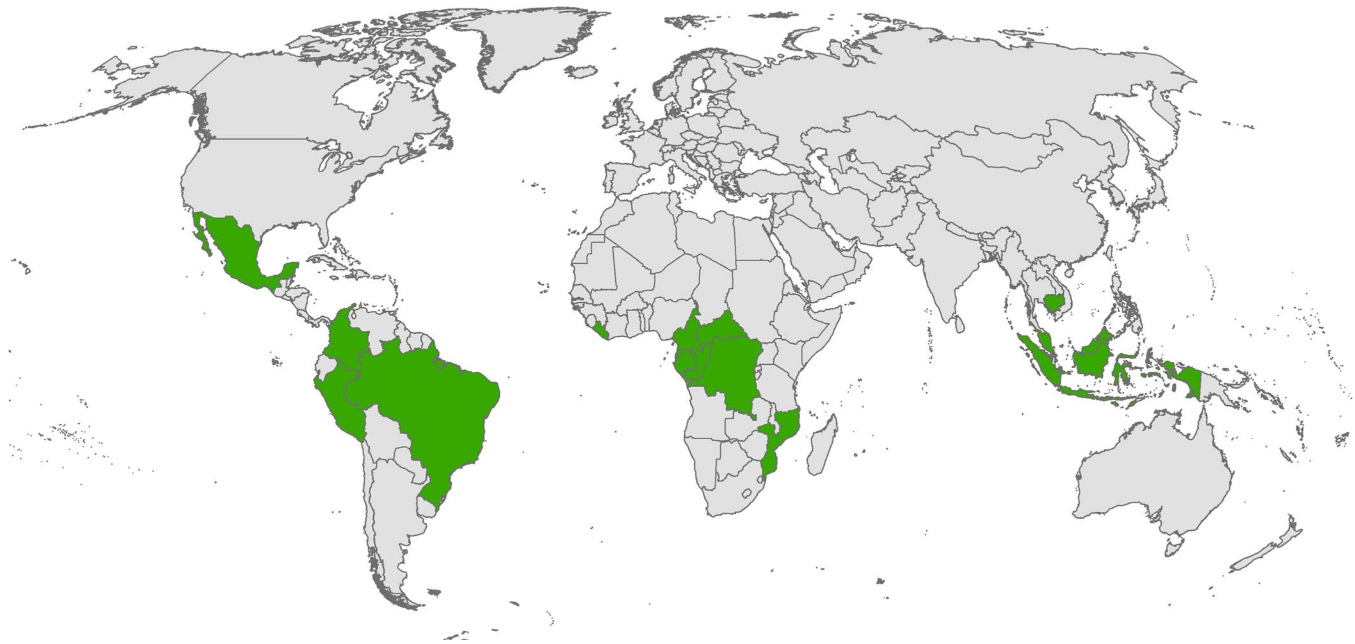
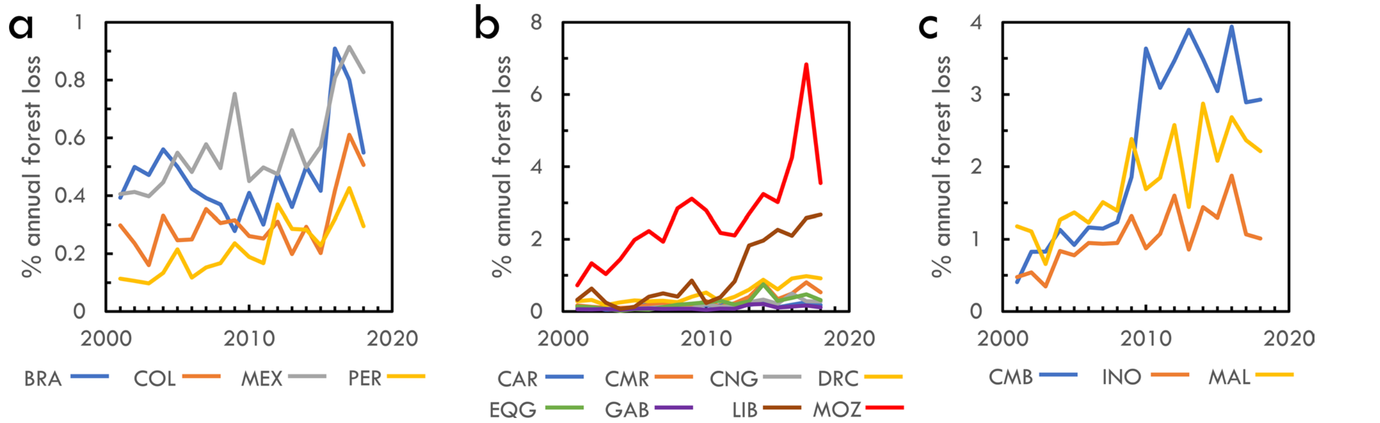
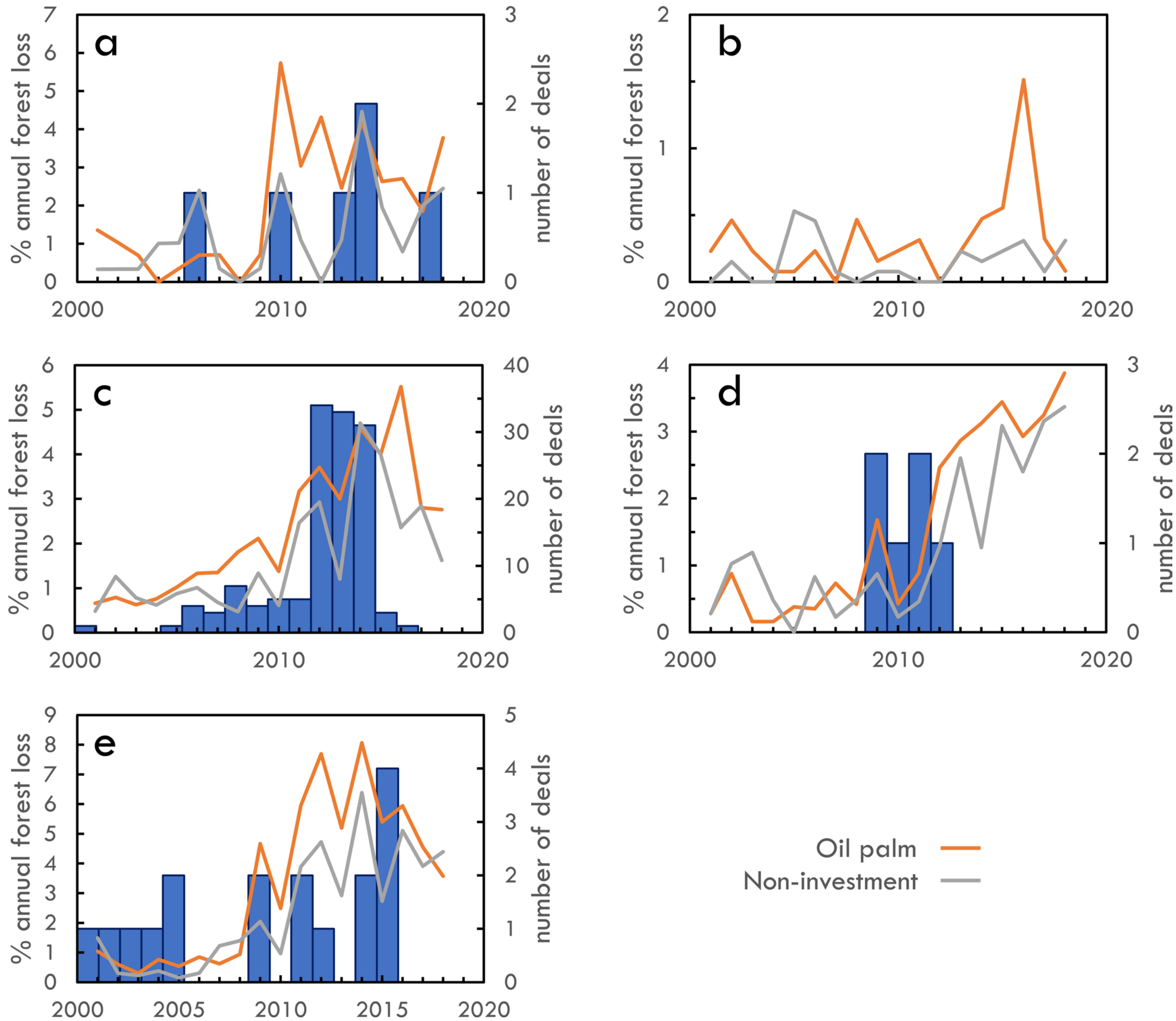


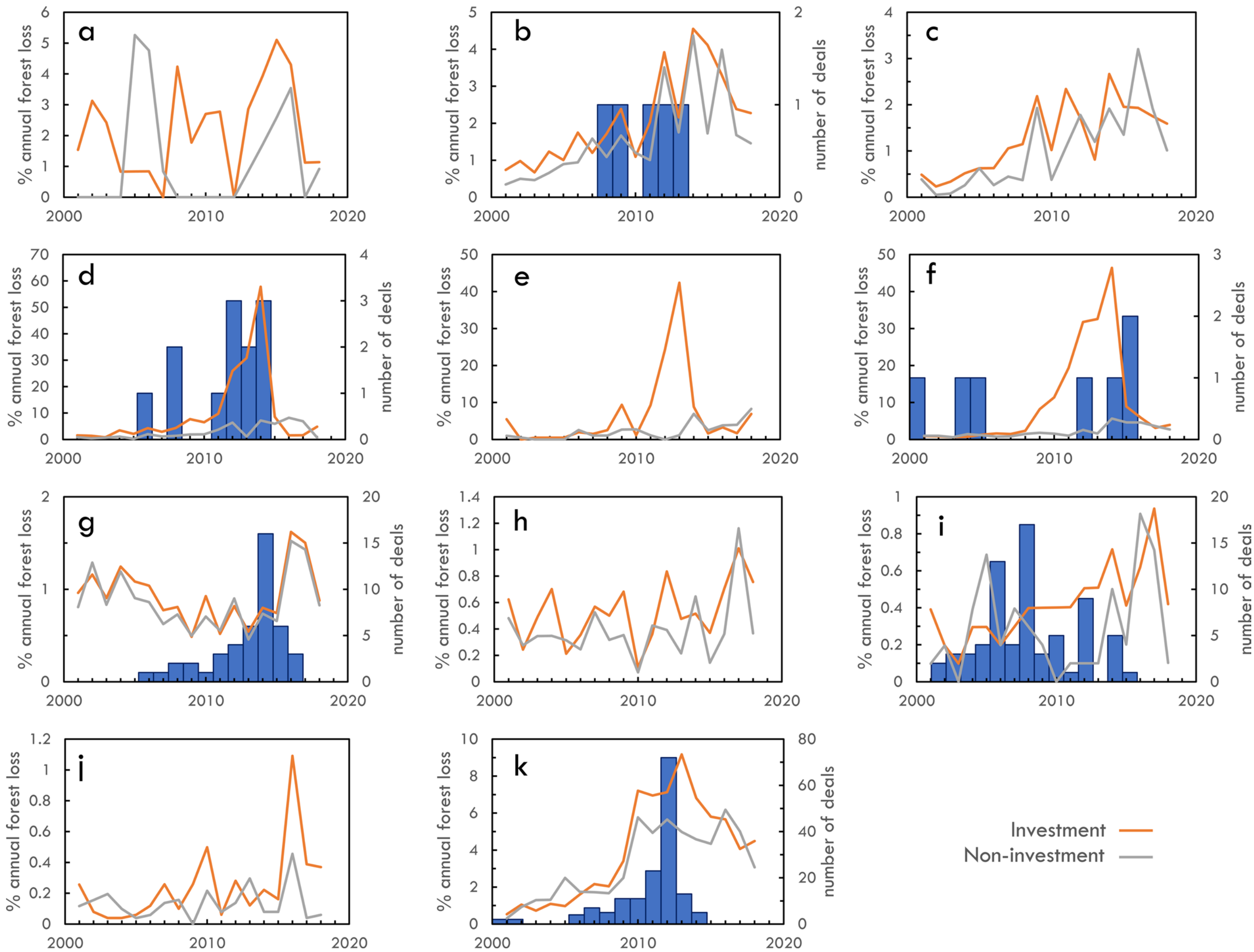
Extended Data Fig. 1 | Map of study countries. Land area under contract in these 15 countries currently makes up 51% of the world's LSLA area for all intended uses[8].



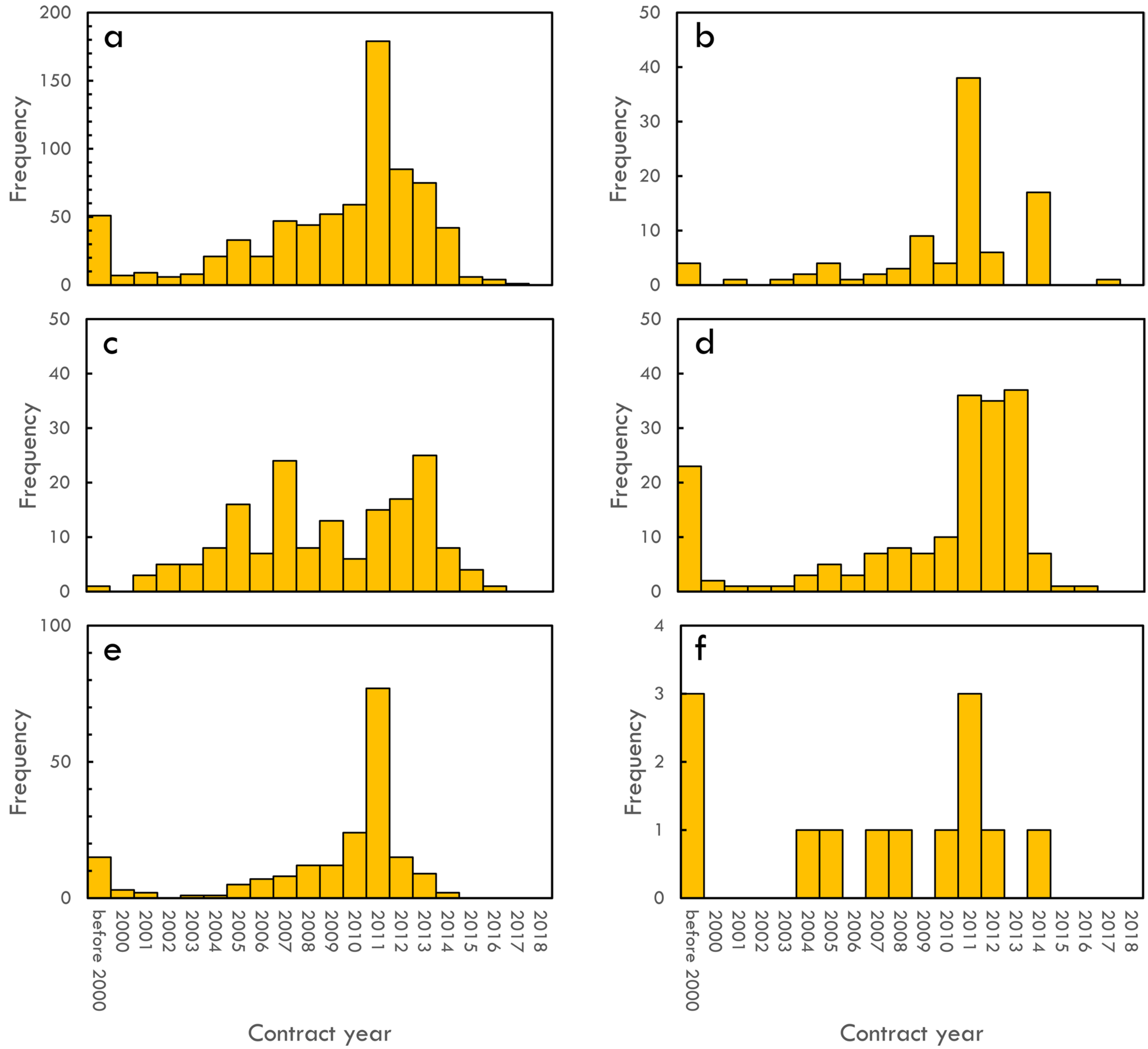
Extended Data Fig. 2 | Annual rates of forest loss. Forest loss plots are separated by region between Latin America (**a**), sub-Saharan Africa (**b**), and Southeast Asia (**c**).



Extended Data Fig. 3 | Annual rates of deforestation for random pixels within oil palm concessions and 'matched' non-investment pixels. Significant enhancements of forest loss within oil palm concessions were observed in (**a**) Cameroon, (**b**) Republic of Congo, (**c**) Indonesia, (**d**) Liberia, and (**e**) Malaysia. Data on contract year (blue histograms) came from the Land Matrix19. For Cameroon, Indonesia, and Malaysia, 1, 1, and 21 oil palm deals, respectively, had reported contract years before 2000 (not shown). Insufficient data on contract year were available for oil palm concessions in Republic of Congo. Y-axes scales vary between panels.



Extended Data Fig. 4 | Annual rates of deforestation for random pixels within investments and 'matched' non-investment pixels. Significant enhancements of forest loss within investments were observed in: wood fiber concessions in (**a**) Republic of Congo, (**b**) Indonesia, and (**c**) Malaysia; tree plantations in (**d**) Indonesia, (**e**) Liberia, and (**f**) Malaysia; mining concessions in (**g**) Brazil, (**h**) Colombia, and (**i**) Peru; logging concessions in (**j**) Central African Republic; and economic land concessions (ELCs) in (**k**) Cambodia. Data on contract year (blue histograms) came from the Land Matrix19. Insufficient data on contract year were available for panels (**a**), (**c**), (**e**), (**h**), and (**j**). Y-axes scales vary between panels.



Extended Data Fig. 5 | Contract year of LSLAs in study countries. Frequency distribution of contract year reported by Land Matrix[19] in all countries for (**a**) all investment types, (b) logging investments, (**c**) mining investments, (**d**) oil palm investments, (**e**) tree plantation investments, and (**f**) wood fiber investments.