Title: Large-Scale Land Acquisitions as Drivers of Deforestation in Developing Countries

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Abstract

The purpose of this study is to examine the likelihood of deforestation across fifteen developing countries – Brazil, Central Africa Republic, Cambodia, Cameroon, Congo, Colombia, Democratic Republic of Congo, Equatorial Guinea, Gabon, Indonesia, Liberia, Malaysia, Mexico, Mozambique, and Peru – according to different use of natural resources and land-based investments. With the rising demand of natural resources in tension with environmental preservation efforts, large-scale land acquisitions and their effects are crucial to study.

The likelihood that an area will be deforested depends on not only whether the area is located inside a concession area, but also other surrounding factors, such as proximity to waterways, roads, and urban areas. The factors considered in the study are delineated in Table II. To account for these external factors, a covariate matching approach similar to a recent study assessing the effectiveness of protected areas in preventing deforestation and a study that measured the effects of large-scale land acquisitions in Cambodia on the country’s forest loss. This approach matched the covariate distributions of data points located outside of and within each type of concessions for each country. After matching the distributions, areas directly affected and unaffected by concessions were compared to assess the effect of land acquisition on deforestation. To track gains and/or losses in forestation, the land was divided into pixels, with each pixel representing land 30m x 30m. Pixels in protected areas were not considered, and areas that were located in more than one type of concession were also not considered. For each pixel, distance from the nearest road, waterway, railway, urban area (defined as areas with population density greater than 300 people per km^2), and forest edge were determined, along with the pixel’s slope class, soil suitability, and district area. To match the data points located within and outside of concession areas, the “Matching” package was used in R. To account for the possible hidden bias, the sensitivity of the results was found via the Rosenbaum Sensitivity test and McNemar’s test. The overall methodology for this study was based on Davis et. al, 2015 study “Accelerated deforestation driven by large-scale land acquisitions in Cambodia.”

Considering the broader implications of deforestation, the study also assessed leakage. Leakage is the phenomenon in which areas surrounding protected regions undergo deforestation at a significantly different rate than areas farther from the protected regions. This occurs as people and corporations relocate to immediately outside of protected areas due to the restricted access to resources.

Across the 15 countries, there were 9 different types of land concessions: economic, DUATs (right to land), palm oil, wood fiber, mining, forest moratorium, plantations, logging, and forest concessions. In total, there were 33 land concessions granted by countries, 16 of which (48%) had differences in deforestation rates compared to its counterparts. Such differences were significant at the $\alpha = 0.05$ level. Examining individual countries, Democratic Republic of Congo, Equatorial Guinea, Gabon, Mexico, and Mozambique (5 out of 15 countries) did not have any significant differences in deforestation rates across land and non-land concessions across all of their land-based investments.

It is important to examine the effect of large-scale land acquisition policies and various land concessions on deforestation rates because each country in this study has different requirements of concessions, policy enforcement, foreign involvement, and environmental

actions. This study provides insight as to what forms of land concessions have the least impact on the environment.

Introduction

Since the start of the century, there has been a surge in large-scale land acquisitions in the global South. Bioenergy mandates in Europe and the United States have increased demand for crop-based biofuels. Carbon credit initiatives have led to the valuation and acquisition of carbon-rich landscapes. Spikes in food commodity prices in 2008 and 2010 also showed many import-dependent countries their vulnerabilities to distant shocks and their need to increase the natural resources under their control. All of these factors have combined to heighten demand for land and other natural resources and to drive what is popularly referred to as the 'global land rush' (**Deininger, 2013; Davis et al., 2015a**). In response, many developing countries have promoted these investments with a view to facilitate agricultural technology transfers, to promote rural development, and to encourage local job creation and the inflow of foreign capital. In an effort to minimize the impacts of such land deals on rural livelihoods, governments often encourage investments in areas that are broadly categorized as 'pristine', 'unused', 'marginal', or 'virgin' land. While this is a point of ongoing debate – as many communities informally rely on these resources to support incomes (**Davis et al., 2015b**) and food security (**Rulli et al 2014**) – it is also unclear what the environmental impacts of land-based investments have been to date. This uncertainty persists for several reasons. First, spatial information on the location of individual land deals is often not publicly available. Second, environmental considerations can be secondary for countries seeking to enhance rural development through trans-national land investments and so these aspects are often not publicly assessed. Third, in many instances, these land-based investments are speculative, which can mean that local communities may be excluded from the informal use of the land but that the area is not put to productive use by the investor. As a result of these limitations, only a handful of studies have been able to evaluate selected environmental impacts of large-scale land acquisitions (e.g., **Rulli et al, 2013; Davis et al. 2015c**).

A comprehensive assessment across targeted countries and across different types of investments is still needed in order to determine if large-scale land acquisitions disproportionately contribute to forest loss and what policies – in certain instances – have prevented an enhancement of forest loss since the start of the century. Here we combine georeferenced maps of land-based investments (for agriculture, timber, mining) across 15 developing countries (Brazil, Cambodia, Cameroon, Central African Republic, Congo, Colombia, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Indonesia, Liberia, Malaysia, Mexico, Mozambique, and Peru) with high-resolution maps of annual forest cover (**Hansen et. al, 2013**) to assess whether large-scale land deals have affected rates of forest loss since the start of the century. We also quantify selected aspects of biodiversity (species richness, total abundance, and rarified species richness) and use land use classifications to develop spatial-explicit maps of these biodiversity metrics and to determine if land investments preferentially occur in areas of relatively higher biodiversity. By identifying those cases where rates of forest loss are low, we can begin to examine policies and regulations that tend to avoid adverse consequences of land-based investments for natural systems.

Methods

We quantified forest loss within eight types of land investments across fifteen countries in sub-Saharan Africa, Latin America, and Southeast Asia and compared rates of forest loss within these land deals 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

Data on land investments was available for fifteen countries: Brazil (BRA), Central Africa Republic (CAR), Cambodia (CMB), Cameroon (CMR), Congo (CNG), Colombia (COL), Democratic Republic of Congo (DRC), Equatorial Guinea (EQG), Gabon (GAB), Indonesia (INO), Liberia (LIB), Malaysia (MAL), Mexico (MEX), Mozambique (MOZ), and Peru (PER).

We consider eight different land investment types 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 fiber concessions came from the World Resource Institute's Global Forest Watch (**2016**). Data on economic land concessions (ELCs) in Cambodia came from Open Development Cambodia (**2014**). Data on forest concessions and Direito do Uso e Aproveitamento da Terra (DUATs) in Mozambique came from the Federal Ministry of Agriculture and Food Security (**2016**). Little information is available regarding the dates that many of the land concessions considered here were either formally contracted or put to productive use. As such, we assume that the land deals considered in this analysis occurred on or after the year 2000, as the global land rush is widely recognized as having commenced after the start of the century (see e.g., **Deininger, 2013; Davis et al., 2015a**).

Data on annual forest loss were from Hansen et al. (**2013**). This dataset provides the initial tree cover in the year 2000 (as a percentage of the pixel area) as well as the year in which a pixel (30m x 30m) gains or loses forest. Following Hansen et al. (2013), we defined a pixel as initially forested if the initial tree cover was at least 50%. 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. Forest gain from 2000 to 2014 was not considered in the calculation of deforestation rates because this was not reported on an annual basis.

Controlling for influences on forest loss

A number of factors can influence the likelihood that an area will be deforested, regardless of whether or not it is located in an ELC. To control for these characteristic covariates, we employed a covariate matching approach similar to that used by Andam et al. (**2008**) – who measured the effectiveness of protected forest areas in Peru – and Davis et al. (**2015c**) – who assessed the influence of Cambodian land investments on forest conversion. The goal of this covariate matching approach is to establish 'balance', so that the covariate distributions of investment and non-investment pixels are 'very similar'. Thus it is then possible to compare investment and non-investment to examine the potential effect of land acquisition on deforestation. To this end, we randomly selected 929,295 initially forested pixels (30m x 30m) – 779,087 of which were located within land investment areas (**Table S1**). Pixels in protected areas and established plantations (and within forest moratorium areas in the case of Indonesia) (**World Resources Institute**, **2016**) were excluded from consideration. For each pixel, we determined covariate information for distance from the nearest road, distance from the nearest waterway, distance from the nearest railway, distance from the nearest urban area (i.e. population density greater than 300 people km^{-2}), distance from forest edge, slope class, soil suitability and district area. Distance from the nearest urban area was calculated using a year 2005 population density dataset from CIESEN/CIAT (**2005**). Classes for median terrain slope and agro-ecological suitability for rain-fed high-input cereals were assigned using data from the FAO/IIASA's Global Agro-Ecological Zones (**2012**).

Matching was performed in R using the 'Matching' package (**Sekhon, 2011**). We also examined the sensitivity of these results to hidden bias using Rosenbaum's sensitivity test (**Rosenbaum, 2002**). 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. Results were overall insensitive to hidden bias. To determine the potential for leakage (e.g. displacement of forest loss into neighboring forests), we also considered the effect of a 5 km buffer around protected areas and ELCs. In adopting this distance for our analysis, we should note that leakage can occur at various distances and, given the indirect pathways by which it is often driven, can also be difficult to fully quantify.

Results

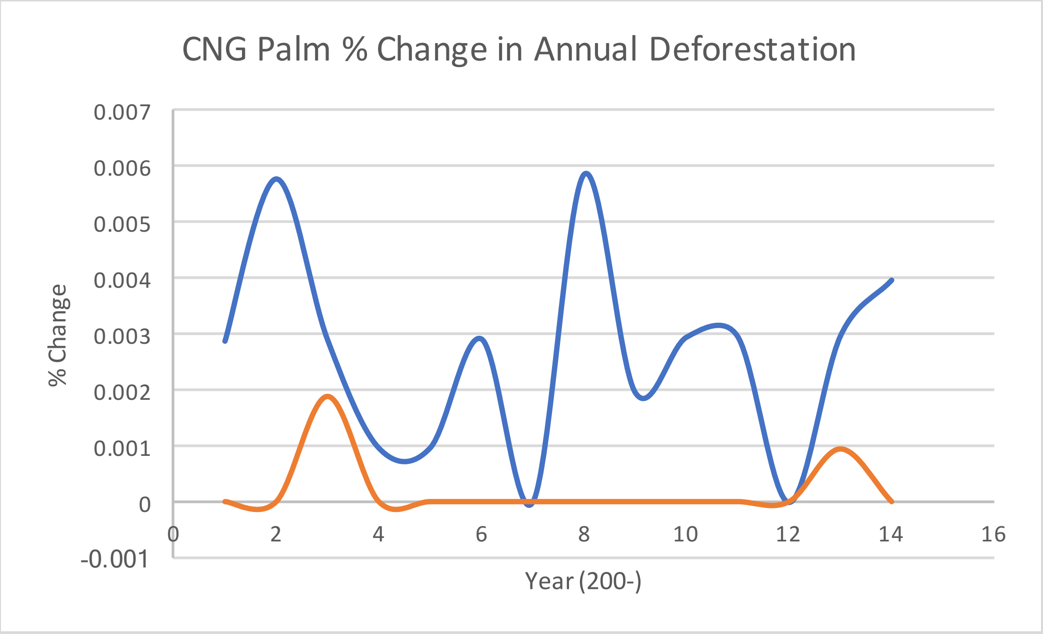
Table 1. P-values comparing rates of forest loss for 'matched' investment and non-investment points. All significant results (in bold) indicate that rates of forest loss within a concession where higher than in 'matched' non-concession areas. A value of N/A indicates that not enough data points were available to perform covariate matching. A value of 0 indicates that a particular country-concession combination did not occur.

Country	ELCs	DUATs	Oil palm	Wood Fiber	Mining	Tree plantations	Logging	Moz Forest Concessions
BRA	0	0	0	0	**0.0201**	N/A	0	0
CAR	0	0	0	0	0	0	**0.0019**	0
CMB	**<<0.001**	0	0	0	1	N/A	0	0
CMR	0	0	**0.0188**	0	0.97	0	1	0
CNG	0	0	**0.0222**	**0.0083**	0.79	0	1	0
COL	0	0	0	0	**0.0080**	0	0	0
DRC	0	0	0	0	1	0	1	0
EQG	0	0	0	0	N/A	0	0.9752	0
GAB	0	0	0	0	0.1061	0	1	0
INO	0	0	**<<0.001**	**<<0.001**	0	**<<0.001**	1	0
LIB	0	0	**<<0.001**	0	0	**<<0.001**	0.9989	0
MAL	0	0	**<<0.001**	**<<0.001**	0	**<<0.001**	1	0
MEX	0	0	0	0	1	0	0	0
MOZ	0	0.979	0	0	0	0	0	1
PER	0	0	0	0	**0.0093**	0	0	0

We analyzed 33 total land-based investments across 15 different countries and 9 types of investments. Of these, 45% of the concessions experienced rates of forest loss significantly higher than matched non-concession areas (**Table 1**). As expected, the land investments that require the most drastic land conversions in order to be put to productive use were also those that consistently displayed significantly higher rates of forest loss – relative to matched plots – across all countries in which they occurred. Specifically, these types of investments were oil palm plantations, wood fiber concessions, and new tree plantations. Conversely, of the nine countries in which logging investments were reported we only found a significant enhancement of deforestation in Central African Republic. Interestingly, mining concessions in three out of ten countries produced significant results for forest loss, all occurring in South American countries (Brazil, Colombia, and Peru). Also in Mozambique's Zambezia province, neither DUATs nor forest concessions showed significant increases in deforestation despite widespread transnational land investment in that country. Our results for Cambodia also agree with previous findings that economic land concessions (ELCs) in that country have promoted forest removal (Davis et al., 2015c).

In addition to aggregate forest loss over the entire study period (2000-2014), we also examined the temporal dynamics of forest loss in different sets of 'matched' investment and non-investment plots. For instance, annual rates of forest loss for oil palm plantations displayed a variety of trends depending on the country. Rates of forest loss in Congolese oil palm concessions were consistently higher than in matched non-investment plots throughout the measured time periods **(Figure 1)**.

Figure 1: Percentage change in rates of annual deforestation for Congolese oil palm. The blue denotes the rates of investment plots, and the orange denotes the rates of non-investment plots.



In Liberia, rates of forest loss in investment plots only started to exceed that of non-investment plots after 2008, with both following the same pattern of growth and decline and peaking in 2013 **(Figure 2)**. Rates of forest loss between investment and non-investment plots in Indonesia were comparable at the beginning of the time period but have generally diverged thereafter **(Figure 3)**. Conversely, in Malaysia, it appears that only one or two years of pronounced forest removal in oil palm concessions has led to the significant difference in forest loss.

Figure 2: Percentage change in rates of annual deforestation for Liberian plantations. The blue denotes the rates of investment plots, and the orange denotes the rates of non-investment plots.

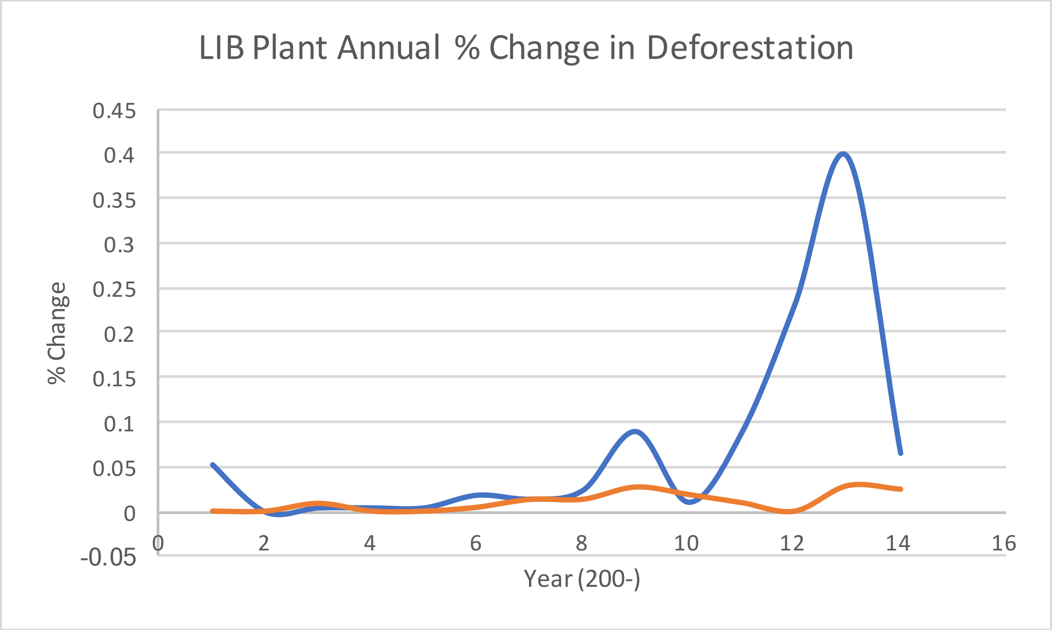
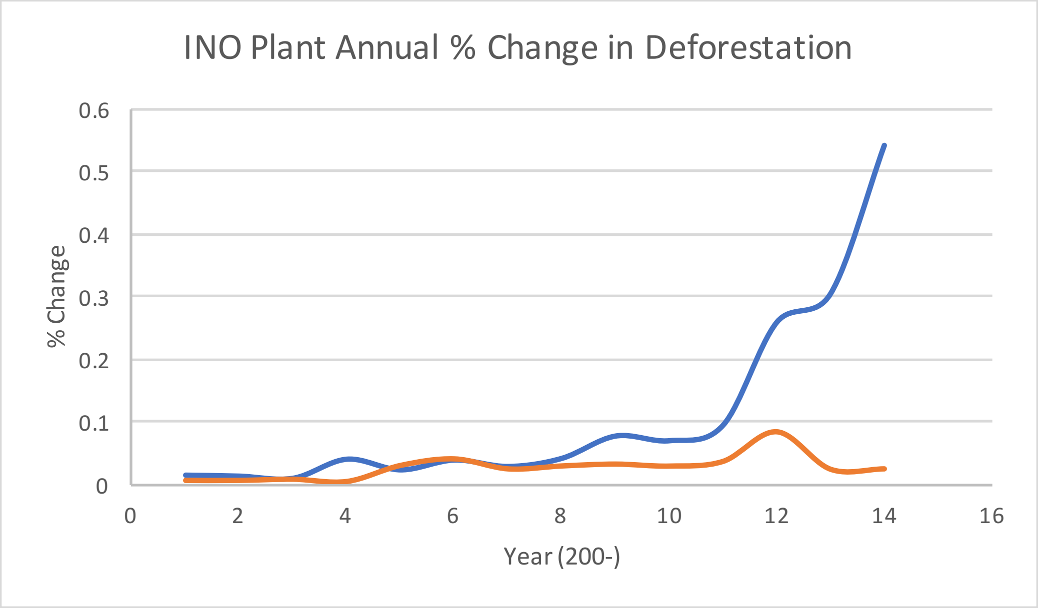


Figure 3: Percentage change in rates of annual deforestation for Indonesian plantations. The blue denotes the rates of investment plots, and the orange denotes the rates of non-investment plots.



Forest loss rates within concessions intended for wood fiber production in Congo were consistently moderate (on average around 2%) with substantial interannual variability. For both investment and non-investment plots in Indonesia, rates of forest removal were relatively higher and showed a general positive trend. Malaysian wood fiber concessions exhibited similar behavior but with lower average rates of forest loss. For Liberia, Indonesia, and Malaysia, the clearing of land to establish new tree plantations produced the most obvious cases of accelerated forest loss as a result of land investments. ELCs in Cambodia exhibited similar behavior, with annual rates of forest loss approaching 8% by the end of the study period.

Discussion

Our results provide important insights regarding pathways that balance objectives of enhancing economic development and preserving natural systems. In some instances, we observed that important tradeoffs have occurred, where land-based investments have occurred at the expense of native forests. For investments like tree plantations and oil palm plantations, we would expect this to be the outcome. However, in these cases, careful land use assessments may help in identifying initially non-forested areas that are still suitable for the intended investment purpose but can avoid impacting areas with such high value in terms of biodiversity and carbon storage.

The specific regulations and policies that are in place within each country are important for dictating whether substantial forest loss occurs within each type of concession. Furthermore, the rigor of law enforcement of such regulations for each country, along with the level of awareness and culture by the general populace are significant factors to consider. For those cases where there was not a significant increase in forest loss, it may be possible to identify practices that can be applied to other situations to promote more protective management of forest resources.

Some of the land investments included in our analysis may have not yet been put to productive use. In these places, it is possible that future assessment may find an enhancement of forest loss when these land deals are actively utilized.

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ANNEX I

Supplementary Tables

Table S1. Number of random points occurring within concession areas. 0 denotes the absence of the concession variable in the country. The different values in the columns denote the number of data points that fall within the concession category. ** denotes that the difference between concessions and non-concessions is significant at the α = 0.05 level, whereas *** denotes that the difference is significant at the α = 0.01 level. N/A denotes that significance levels were not available because the corresponding sample size was too small.

Country	ELCs	DUATs	Oil palm	Wood Fiber	Mining	Tree plantations	Logging	Moz Forest Concessions	Total random points
BRA	0	0	0	0	**19607****	<100	0	0	80083
CAR	0	0	0	0	0	0	**4953*****	0	44327
CMB	**3763*****	0	0	0	4479	212	0	0	24455
CMR	0	0	**319****	0	21170	0	18351	0	59031
CNG	0	0	**1045****	**141*****	13951	0	37423	0	51449
COL	0	0	0	0	**2932*****	1	0	0	59293
DRC	0	0	0	0	14702	0	11763	0	118415
EQG	0	0	0	0	<100	0	13316	0	39864
GAB	0	0	0	0	13197	0	29779	0	46998
INO	0	0	**4962*****	3964	0	581	10534	0	54683

LIB	0	0	**3527*****	0	0	**227*****	3959	0	41345
MAL	0	0	**2589*****	**4387*****	0	**2347*****	10811	0	52508
MEX	0	0	0	0	10481	0	0	0	42145
MOZ	0	6706	0	0	0	0	0	1180	26654
PER	0	0	0	0	1040	0	0	0	37837

Supplementary Figures.

Figure 1: Percentage change in rates of annual deforestation for Congolese wood fiber concessions. The blue denotes the rates of investment plots, and the orange denotes the rates of non-investment plots.

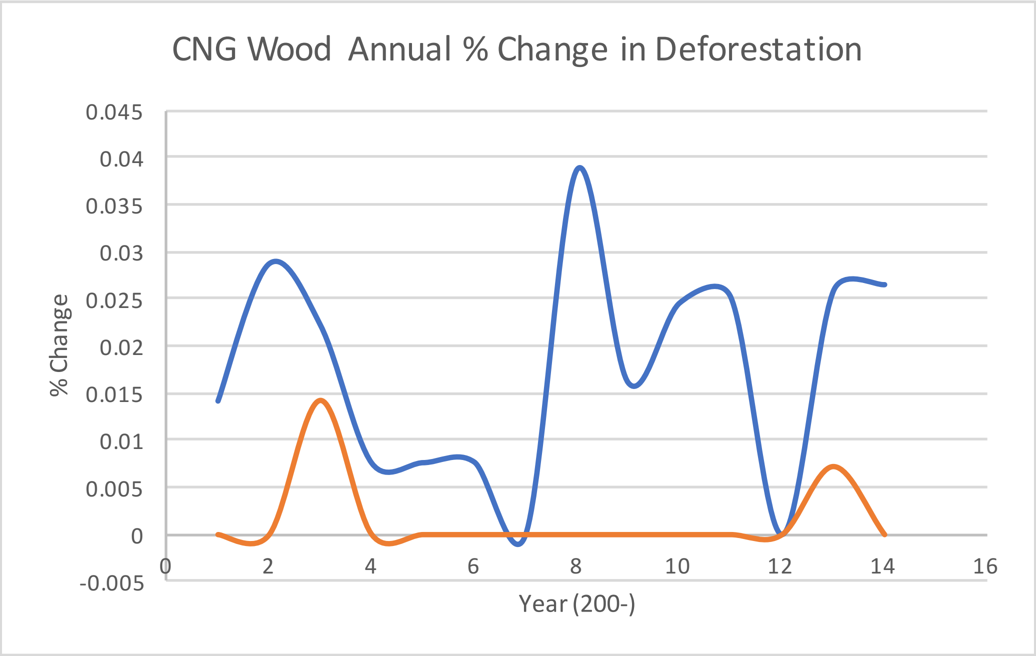

Figure 2: Percentage change in rates of annual deforestation for Malaysian wood fiber concessions. The blue denotes the rates of investment plots, and the orange denotes the rates of non-investment plots.

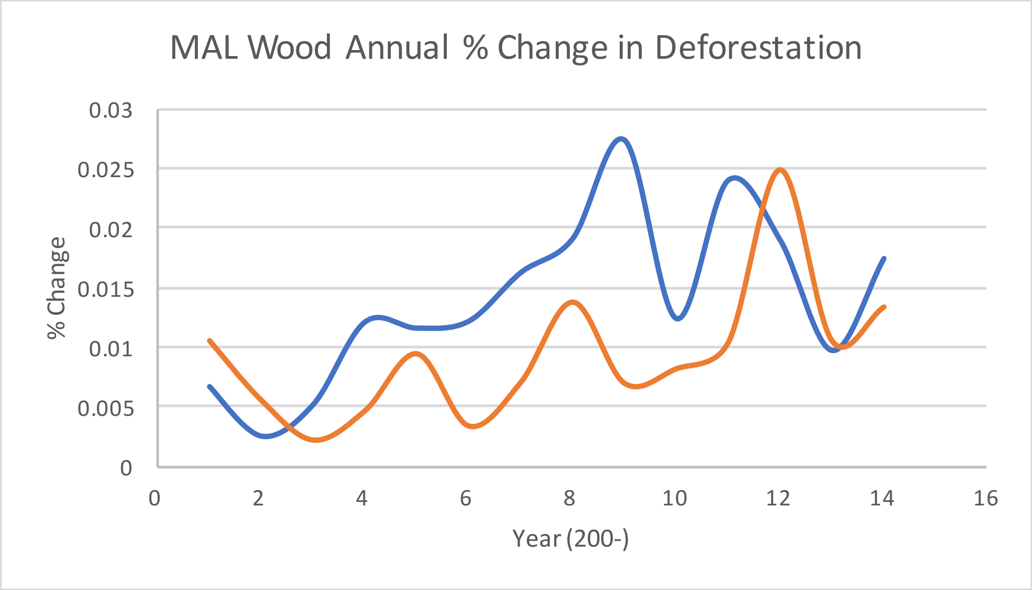

Figure 3: Percentage change in rates of annual deforestation for Cambodian economic land concessions. The orange denotes the rates of investment plots, and the grey denotes the rates of non-investment plots.