1 **Agronomic or Contentious Land Change? A Longitudinal Analysis from the Eastern**

2 **Brazilian Amazon**

3 **Corresponding Author:**
4 Stephen Aldrich, PhD
5 steve.aldrich@indstate.edu
6 812-237-2258
7 Department of Earth and Environmental Systems
8 Indiana State University
9 159 Science Building
10 Terre Haute, IN 47809
11
12 Cynthia S Simmons, PhD
13 cssimmons@ufl.edu
14 Department of Geography
15 University of Florida
16
17 Eugenio Arima, PhD
18 arima@austin.utexas.edu
19 Department of Geography and The Environment
20 University of Texas-Austin
21
22 Robert T Walker
23 roberttwalker@ufl.edu
24 Center for Latin American Studies and Department of Geography
25 University of Florida
26
27 Fernando Michelotti
28 fmichelotti@ufpa.br
29 Institute for Agrarian and Regional Development Studies
30 Federal University of the South and Southeast of Pará
31 Marabá, Pará, Brazil 68507590
32
33 Edna Castro, PhD
34 edna.mrcastro@gmail.com
35 Center for Amazon Studies
36 Federal University of Pará
37 Belém, Pará, Brazil
38

1   **Abstract**

2   Since 1984, nearly 1,000 people have been killed in the Brazilian Amazon due to land conflicts

3   stemming from unequal distribution of land, land tenure insecurity, and lawlessness. During this

4   same period, the region experienced almost complete deforestation (< 8% forest cover by 2010).

5   Land conflict exacts a human toll, but it also affects agents' decisions about land use, the subject

6   of this article. Using a property-level panel dataset covering the period of redemocratization in

7   Brazil (1984) until the privatization of long-term leases in the eastern Amazon (2010), we show

8   that deforestation is affected by land conflict, particularly in cases of expropriation of property

9   for agrarian reform settlement formation. Deforestation on these settlements is much greater

10   when soils are poor for agriculture and when the land has been the object of past conflict.

11   Deforestation and conflict are episodic, and both agronomic drivers and contentious drivers of

12   land change are active in the region. Ultimately, the outcome of these processes of contentious

13   and agronomic land change is substantial deforestation, regardless of who was in possession and

14   control of the land.

15

1 **1)   Introduction**

2 Conflicts over access to natural resources and land have emerged as important drivers of land

3 change [1-4]. Land is the most important economic asset and sole source of income or

4 subsistence for millions of families [5-7]. In many parts of the world where socio-economic

5 exclusion and marginalization lead to unequal access to land, conflicts emerge resulting in

6 environmental degradation in many cases [8-11]. The nexus between land conflict and threats to

7 natural resources is a widespread phenomenon. Transnational social movements like *La Via*

8 *Campesina* have recently stimulated the rural poor to question access to land, often limited for

9 institutional and historical reasons at odds with social equity. These movements have motivated a

10 rural constituency that aggressively seeks more dignified, farm-based livelihoods. As a

11 consequence, contention over land has seized headlines throughout the Global South, with

12 notable movements in South America including ongoing conflict and land reform in Bolivia [12,

13 13], Paraguay [14], and Brazil [2, 15-18]. Further afield, notable land reform movements also

14 have transformed land tenure discussions in Southeast Asia in the Philippines [19, 20] and

15 Indonesia [1, 21], and in Africa [22], including Liberia [23, 24], Zimbabwe [25-27], and South

16 Africa [28-30]. We speculate that when such social phenomena manifest in forest-rich nations,

17 deforestation occurs for reasons of social conflict in addition to more traditional agronomic

18 pressure, and therefore these nations require policy interventions tuned to the distal factors that

19 are sustaining social inequalities.

20

21 The Brazilian Amazon is no exception to this narrative. Over the past three decades conflict over

22 land in the Amazon has claimed the lives of 995 people [31], with well over half of Amazonian

23 municipalities experiencing at least one land conflict since 1985. Previous research has identified

24 many factors driving Amazonian deforestation including fiscal incentives, transportation costs,

1   migration, and household processes. The link between land conflict and deforestation has also

2   been investigated recently [36, 37-39], including in other regions [32, 33]. Between 1964 and

3   1997 land reform pursuant to such conflict may have accounted for 30 percent of Amazonian

4   deforestation overall [34]. Despite Brazil's prohibition for new land reform settlements in

5   forested areas, this is where the vast majority are formed [34-37]. As Brown et al. [38]

6   demonstrate, deforestation is greater in on settlements formed by means of direct action land

7   reform (DALR) occupations, and in municipalities adjacent to conflict areas. Other recent work

8   has also shown that agricultural markets and speculation also significantly enhance deforestation

9   rates [e.g., 39], raising the question whether both processes are at work in the Amazonian

10   landscape. The study presented here shows a direct, and more nuanced, link between

11   deforestation at the property-level over a 27 year period and contentious interactions between

12   large landholders and the landless in their struggle to claim properties. Specifically, we analyze

13   the effects of back and forth changes in the control of land between those two groups on land use

14   decisions and long-term effects on deforestation.

15

16   The objective of the article is therefore to expand the explanatory repertoire of Land Change

17   Science (LCS) by assessing the impact of land conflict on deforestation, referred to here as

18   Contentious Land Change (CLC). To achieve this objective, the article focuses on the destruction

19   of the Brazil-Nut forest (~20,000 Km^2) in Southeastern Para State, which accounts for nearly 17

20   percent of all Amazonian deforestation (Figure 1; INPE 2011). Until recently the Brazil Nut

21   Polygon (BNP) formed unusually dense concentrations of Brazil Nut trees (*Bertholletia excelsa,*

22   *Lecythidaceae*) that sustained a profitable extractive economy in the first half of the 20th century.

23   But the BNP lay in the development pathway of Brazil's Military Government (1964-1985), for

it was here that road-building crews opened the Amazonian forest to occupation with the construction of BR-230, the so-called Transamazon Highway. Government incentives attracted capital from the south and landless farmers from the northeast, disrupting land claims of the Brazil nut oligarchs and setting in motion an interwoven process of social conflict and environmental destruction that continues to this day [34, 36, 40-43]. The region is now almost completely deforested (<8 % forest cover remains), and fights for land there continue to claim lives [36, 44, 45].

Figure 1 Dominant vegetation pre-1970 in Southeastern Pará, Brazil. The Brazil-Nut Polygon is in the upper right (Northeast) corner of the region. Southeastern Pará straddles the ecotone between closed-canopy forests of the Amazon and the Savanah environments of Brazil's Cerrado.

We pursue our objectives as follows. In the next section, we provide a background discussion of the study region, its development and integration with the Brazilian economy, and history of conflict. Next, we articulate a theoretical model of CLC that distinguishes land cover change resulting from agronomic decision-making and change driven by land conflict, from which we derive the primary research hypotheses that land conflict increases deforestation. Regression analyses, using panel data enabled by a unique set of geographic and historical data covering the period of redemocratization (1984-1985) through formal land regularization in 2010 [46], are employed in order to explicate CLC and empirically assess the significance of land conflict on deforestation. These include (1) a multi-decadal satellite image series covering 27 years (1984-2010); (2) cadastral maps for large holdings (4,886 ha average) and agrarian reform settlements;

1   and (3) a newspaper archive detailing land conflicts unfolding at property scale for the same

2   period as the satellite imagery (more than 8,000 individual pages). This information enables the

3   systematic evaluation of deforestation associated with the social inequalities driving land conflict

4   in the Amazon Basin. Thus, the article provides evidence for an important driver of land change,

5   typically overlooked in deforestation studies but of likely significance given climate change,

6   rural poverty, and land grabs occurring world-wide.

7   **2)   Background**

8   Our analysis of CLC addresses southeastern Pará, a 212,375 km^2 geographic expanse below the

9   Transamazon Highway and east of the Xingu River in the state of Pará, where land ownership

10 has long been in contention (Figure 1). Most of the region's land cover in the mid-1970s was

11 dominated by closed canopy tropical forest, comprising a variety of valuable hardwoods

12 including mahogany (*swietenia macrophylla*), rubber trees (*hevea brasiliensis*), and Brazil nut

13 (*bertholletia excelsa*). Early in the opening of this region to development and natural integration

14 (1964-1975) cerrado grasslands (open herbaceous land cover interspersed with shrub forest)

15 covered an estimated 11 percent of this region, whereas agriculture occupied most of the

16 remainder (8 percent), primarily in the vicinity of the region's principal city, Marabá, and along

17 roads in the South. The remaining 81 percent of the region was covered with primary forest.

18

19 Although much of the region experienced land conflict through the later part of the 20th century,

20 our analytical modeling resides in the its northern reaches in the BNP, an area of more than

21 6,800 km^2 located roughly between the Tocantins River and the Carajás mines (Figure 1). The

22 BNP, much of it once covered by dense stands of Brazil-Nut trees and dominated by non-timber

23 forest extraction, reveals a notorious history of violent land conflict [2, 36]. The question this

research aims to address is the extent to which conflict was a factor in the forest's demise, which

today amounts to a very limited fraction of its original extent.

Like most of Pará, the BNP remained isolated until the later part of the 20th century, although

Brazil-Nut extraction from concentrations of the trees referred to as *castanhais* stimulated an

early boom. The *castanhais* first functioned as common properties accessible to all, but the state

government of Pará enclosed most of them with long-term leases, or *aforamentos*, granted to

wealthy locals. The enclosure process unfolded during the first half of the 20th century, creating

an impoverished rural population whose ranks grew with the implementation of Brazil's

ambitious development plans. The construction of a highway network (i.e., the Belem-Brasilia in

1956, PA-150 in 1964, running north-south through the BNP, and the Transamazon in 1970,

running east-west through the BNP) triggered the in-migration of peasant farmers eager to

escape drought and poverty in northeastern Brazil and joblessness in the South. Gold discoveries

also sparked waves of wildcat miners. Significant numbers of the new rural poor sought to

alleviate poverty by occupying small parcels on lands that large-holders had enclosed as their

privatized *castanhais*, an action justified by squatter rights (*usocapião*) as afforded in the 1964

Land Statute [47, see especially Article 13], and subsequently permitted in the 1988 Constitution

of Brazil [48, see articles 184-191]. The vast forested land of the BNP was the ideal target of the

landless since forests were deemed unproductive and the properties too large to surveil for

squatters.

Initial conflicts in the Brazil-Nut region of Southeastern Pará intensified with the arrival of

armed Maoist guerrillas in the late 1960s, whose range of operation extended from São Felix do

Xingu in Pará, east to Estreito in Tocantins State, and from Marabá to just south of Redenção, Pará [49]. Brazil's military government declared the region a national security zone and eradicated the insurgents between 1972 and 1974 in a controversial campaign that left many casualties, and few prisoners [50, 51] and solidified the federal governments militaristic stance toward the region's landless poor. During, and immediately after (1975 onwards), this period the sons and daughters of the Brazil Nut oligarchy came home to the region after attending national and international Universities, bringing new ideas about forms of business and production to the region. Land uses in the region quickly began to shift from extensive-Brazil Nut extraction, relying on the matrix of closed-canopy forest to maintain production, to cattle ranching, which required the removal of forests. Going hand-in-hand with this shift (which took the better part of a decade) were economic subsidies meant to encourage and "improved" and more technical cattle economy [52-54], totaling more than USD$2.3 billion in 2019 dollars. Competition for land between rich and poor continued, leading to the so-called Brazil Nut War (1984-1989), a bloody engagement pitting long-term lease (*aforamento*) holders, the Brazil Nut oligarchs and their new ranching progeny, against a peasantry in want of land [55]. The legal designation of the Brazil-Nut Polygon (BNP) in the heart of the conflict zone took place at this time, as the oligarchs sought state intervention to secure their land claims, to no avail.

With the opening of popular politics following redemocratization in 1984-1985, land conflict dynamics throughout Brazil shifted from uncoordinated squatting by landless farmers to an organized landless movement led by social movement organizations (SMOs) dedicated to agrarian reform, specifically targeting the BNP. In Brazil, landless movements (e.g. Movement of the Landless Rural Workers -MST) employ DALR, the most common confrontational tactic

being the surprise occupation of large-holdings by 100s to 1000s of landless families. These

occupations happen on properties SMOs deem vulnerable to expropriation for agrarian reform

[56], as permitted by the 1988 constitution [48]. Between 1988 and 2014, more than 1.275

million families participated in DALR, and more than 40% of participating families and 70% of

land occupied was in Amazonia [57]. Pará State, which contains the study area, accounts for 6.6

percent of families and nearly one-fourth of all land impacted by DALR nationwide [58, 59].

The arrival of SMOs in Amazonia in the 1990s corresponded to a marked increase in SMO-led

DALR that too-often ended with disastrous consequences, as in the murder of 19 landless

activists by military police on April 17, 1996, in Eldorado do Carajás [36]. All told, between

1980 and 2010, there were more than 500 land conflict related deaths throughout Southeastern

Pará [60], nearly half of these (245) in the BNP. Our own data puts the land-conflict fatality

count between 1980 and 2010 at over 1,000 in the BNP, suggesting watchdog groups like the

CPT [31] may be undercounting violence.

Over the thirty plus years of land conflict in this region, rapid and extensive environmental

change was also taking place. The BNP possessed 88% forest cover in 1984, indicating little land

change up to, and including, the period of guerrilla conflict in the 1970s. As Brazil's nascent

civil society allowed for more direct forms of political action, including early DALR actions,

deforestation associated with agricultural expansion and land conflict intensified, and by the end

of 1989 the forests of the BNP had shrunk to a third of their original extent. As DALR

intensified between 1990 and 1996, deforestation continued, and the BNP's forest area decreased

by another 30 percent. By 2000, 75 percent of its original extent was gone, and by 2010 less than

8 percent remained. Thus, within less than 30 years (from 1984 to 2010), the BNP experienced a

nearly complete conversion from primary forest to fields and pastures. Today, the rural poor

reside in agrarian reform settlements that were once BNP *castanhais* (Brazil-Nut groves), and

many engage in calving to supply animals to their former adversaries, the Brazil-nut oligarchs

turned *fazendeiro* (rancher), who fatten the animals and deliver them to ten modern meat-packing

plants which sell chilled beef on domestic and international markets [61].

The history of this region has many global corollaries, and understanding the complex

interactions between CLC and agronomic deforestation is important in the face of ongoing land

conflict and agricultural expansion across the global South. Thus, the landscapes and histories of

the BNP are a model landscape within which to understand how CLC and agronomic pressures

interplay to result in landscape change. This extension of Land Change Science is part of the

ongoing work to address the shortcomings with the concept of unitary decisionmakers, and to

bring social process more explicitly to Land Change Science (LCS) conceptualizations of

landscape change.

3)   Contentious Land Change: Conceptual Framework and Methods

███████*Conceptual Framework*

LCS typically focuses on (1) the proximate decision-making of local land managers, and (2) the

distal and highly aggregated socio-economic environments that comprise a context for the

proximal actors. This study dispenses with the LCS presumption that landholdings are managed

by unitary decision-makers acting in the interest of market production. Often, deforestation

results from contentious interactions between powerful elites and the rural poor, groups with

differing motivations and agricultural practices. Our analysis posits an explanatory framework

that acknowledges the impact of social processes, individual behaviors, and organizational

actions on land change (LC), in addition to the rational economic actor, in this case a farmer or

rancher. Specifically, we address environmental impacts stemming from enclosures of natural

resources [4, 9, 62]. In the study area, land scarcity arose following enclosures of public lands

dedicated to Brazil Nut extraction, the so-called *castanhais*. An important component of land

change in forest frontiers results as land managers deforest in order to engage in agricultural

activities, a process we refer to as agronomic land change, or ALC. Nevertheless, the presence of

land conflict alters this dynamic by introducing new behaviors and social processes that do not

conform to a static, rational actor model.

Changes in land cover in contentious settings, referred to here as contentious land change (CLC),

occur over multiple decades and stem from a variety of actions taken by competing claimants,

including preemptive deforestation in anticipation of seizure by alternative claimants, excessive

land clearance meant to stake a claim, the use of fire as a conflict weapon, and resource mining

(e.g. valuable hardwoods, soils) in advance of expected dispossession [2, 63-65]. DALR may

take years to resolve, and during this time land management changes hands multiple times

between original owner and participants, as DALR actions precipitate a series of land

occupations starting with the initial event until the property is expropriated for the purposes of

agrarian reform. Specifically, property management changes subsequent to a DALR occupation,

but may revert back to the original owner if courts rule for repossession (*reintegração*) and

eviction of the occupiers (*despejo*). However, frequently the property is re-occupied by DALR

participants, and the process repeats, leading to a series of intervals whereby largeholders or

DALR movements effectively control and undertake land change (LC) on the property in

1   question. This process is not unique to the Amazon, and can be observed in other regions

2   experiencing land conflict and rapid environmental transformation.

3

4   For the Amazonian case, we hypothesize that deforestation reflects both ALC and CLC, and that

5   CLC adds to the total amount of deforestation that would otherwise occur under ALC. This is

6   depicted in Figure 2 for two hypothetical properties of 4,000 ha, an average size for a BNP

7   holding (BNP mean = 4,886 ha). One experiences CLC and the other does not. Both follow a

8   linear land clearance pattern at first, a property "life cycle" [66-68]. Divergence sets in at t=2, as

9   DALR participants contest one of the holdings, thereby precipitating CLC. Property control then

10   passes back and forth between DALR participants and the initial land owner, creating a series of

11   management intervals (e.g., t=4 → t=5, t=5 → t=6, etc.). In the other case, the property without

12   contention experiences ALC until 2,000 ha are cleared, or half the holding, in accordance with

13   federal law that mandates a "Legal Reserve" of 50 percent forest [Law 7.511, Law 4.771, Law

14   7.803, and Medida Provisória no 2.166-67, a specification that continue to change; 63, 69].

15

16   **Figure. 2. Deforestation trajectories on landholdings under ALC and CLC.**

17

18   As depicted and hypothesized, the property in contention shows more LC once DALR has

19   initiated (at t=2), and a higher amount of long-run, end-of-period deforestation (at t=10). Figure

20   2 depicts CLC for intervals under DALR control may be "excessive," because of assumed

21   DALR interest in establishing productive-use claims, which usually entail removing

22   "unproductive" forests (e.g., interval t=2 → t=3). Initial owners show more complicated

23   behavior. As with DALR participants, they often wish to demonstrate productive-use and are

known to deforest preemptively to inhibit DALR. Alternatively, when government fails to

defend their claims, there may be no incentive to improve the land and instead they are

motivated to liquidate the value of standing forest as they await adjudication and possible

expropriation. Figure 2 suggests that following expropriation of a landholding to establish a land

reform settlement (t=8), deforestation ticks up, as large numbers of DALR participants divide the

property into individual lots and begin their agricultural activities.

Figure 2 presents the hypotheses tested in the article graphically, which are that land conflict

augments deforestation magnitudes, such that (*H1*) deforestation is greater during those time

periods with land conflict compared to periods with relative peace. We also hypothesize (*H2*)

that among properties that have had land conflict, those properties that have been expropriated

have greater deforestation. Although our theoretical frame elaborates different motivations for

land managers to deforest during periods of contention, it doesn't attribute responsibility for

deforestation to a specific class of land manager – the original largeholder or the DALR

participants – as both classes are responsible at different times. That said, LCS scholarship thus

far has tended to attribute deforestation to the creation of a settlement project, thus the settlers

are the culprits without much consideration of the role played by the largeholders in the DALR

process. The expectation is that once a settlement is created, the cumulative impact of individual

smallholders is greater than would be the situation under a unitary largeholder. The spatial-

temporal dimensions of our data allow for the direct examination of whether deforestation was

greater during periods of contention or settlement formation (*H1 & H2*). Finally, in keeping with

the notion of CLC as a driver of change, we hypothesize (*H3*) deforestation is greater by the end

of the study period on properties that have had contention compared to those without.

1

2   **Data and Methods**

3   3.b.i) *Analytical Approach*

4   We address our hypotheses (*H1, H2, H3*) using OLS regression, which we then extend using a

5   series of "treatment effects" analyses in a panel environment, and pooled OLS regression. We

6   present several models in the text, but also include other specifications in the supplemental

7   information (SI). The panel approach corrects the limitations of Aldrich [63] and Aldrich *et al*.

8   [44]. The model takes the form

9

10   $$Y_{i,t} = \beta X_{i,t} + \alpha_i + u_{i,t}$$

11

12   Where *Y* is the dependent variable, deforestation rate or total deforestation in hectares

13   (depending on model specification), on property *i* at time *t*, *β* is the coefficient for *X*, a binary

14   variable indicating if conflict occurred, α is the intercept, and *u* is the error term.

15

16   For all hypotheses we included control variables (see Table 1 and SI-1) which captured the effect

17   of time-variant changes in the region, such as rainfall [70], changes to the road network, and

18   economic growth rates, etc. However, many "traditional" land cover change control variables

19   like the quality of the resource base (e.g., soil quality) and distance to market (independent of the

20   evolving road network) are handled automatically by our panel approach [71, 72], as is spatial

21   autocorrelation [73: 27].

22

In order to control for potential bias arising from selective occupation, we adopted a two pronged approach whereby matching estimators were used as a pre-processing step to select a balanced sample of properties that are comparable with respect to certain pre-occupation characteristics. [see: 74]. Panel models were then applied on the matched dataset to estimate the effect of the variables of interest. The matching procedure was implemented as follows. First, we created a cross-sectional dataset of all properties and a treatment binary variable if the property was ever occupied or not. We then calculated the propensity score of being occupied or not through a logit regression using cost-distance to cities, cost-distance to roads, property size, and quality of soils for agriculture. A property in one group (occupied or not) was considered to have a similar property on the other if their propensity scores were within a caliper distance of 0.063, or 0.55 standard deviations of the scores, after Austin [75]. Overall, the original sample was already balanced with the exception of one property (see SI-2).

3.b.ii) *Data*

Given the long-run specification of our hypotheses, a panel dataset including annual observations of forest cover and land contention was required. Annual land cover maps were created by classifying 52 Landsat 5 TM images (path 223, rows 64 and 65) using a hybrid classification method similar to Simmons et al. [36] and Aldrich et al. [44]. Annual contention data was collected for each property from newspaper accounts published in two regional newspapers, *O Correio do Tocantins* and *Opinião!*. These are the two newspapers from the region that reliably published semi-daily or daily newspapers over the entire study period (two other papers published intermittently, but did not provide sufficient coverage to include in the systematic dataset). Both newspapers began consistent publication in 1984. Each newspaper account was

1   read, and salient details of the conflict recorded (e.g., number of deaths, police involvement,

2   names of property owners, character of the conflict, what type of conflict events took place) and

3   summarized (see SI-3 for complete details). Accounts from both newspapers were then

4   compared, and when events were reported in both newspapers, which was frequent, the details

5   were combined into single reports for each property in the statistical dataset. We matched events

6   to properties using the property cadastral described above [76], matching by property name,

7   location (generally indicated by municipality -- this study area covers parts of nine

8   municipalities), and owner name (see SI-3 for details). For this analysis we constrain the time

9   period to correspond with the redemocratization of Brazil after twenty years of a military

10 dictatorship (i.e., 1984) through the date when the State of Pará, Brazil formally transferred the

11 large properties of the study area into private hands in 2010 [46]. The study period we employ

12 has other benefits, including placing a hard limit on the range of archival research in difficult

13 conditions (including a lack of formal records on conflict in the region before approximately

14 1982), and the fact that the majority of properties in the region were totally, , or close to totally

15 (single-digit forest cover proportions) deforested by 2010.

16

17 A variety of control variables were used, all in relative agreement with well-established drivers

18 of land change [e.g., 77]. Road data that show the temporal evolution of the road network are

19 difficult to find in most cases, but data was made available for this project by Walker et al. [78]

20 and updated to 2010 extent using roads data provided by the Brazilian Institute for Geography

21 and Statistics. City locations were acquired from the Brazilian National Institute for Geography

22 and Statistics. Distance to cities was generated using the roads data, represented in kilometers.

23 Inflation Rate was acquired from the World Bank. Annual precipitation, meant to control for

1   climate variation over the study period [one of the early observable effects in the region, see 79],

2   was acquired from NOAA/OAR/ESRL PSD (http://www.esrl.noaa.gov/psd/). In some cases we

3   interact or decompose explanatory variables to better understand potential drivers of change.

4

5   The data sets were integrated at the property level acquired using a cadastral map of 180 large

6   landholdings published by the Superindendency for Amazonian Development [76], a now-

7   defunct government agency. The paper map was digitized at 1:50,000 scale, and attributes from

8   the map, such as property size, name, owner name, and title status (i.e., definitive title, long term

9   lease, unknown, no title) were associated with each property and included with the above

10   described datasets. Agrarian reform settlements and associated expropriation records were

11   acquired from the Brazilian National Institute for Colonization and Agrarian Reform (INCRA)

12   and were matched these to our cadastral map using overlay analysis.

13

14   **Table 1. Summary statistics for important characteristics of BNP properties.**

Variable	Average N=180	St. Dev.	Mode	Median	Annual Average 1984-2010
Property Size (ha)	4,886.19	4,666.42	--	3,972.30	
Forest Cover (ha)	2,033.96	2,707.89	0.00	1,007.15	
Annual Deforestation (ha)	157.80	86.28	--	128.50	
Number of Conflicts	0.47	7.86	0.00	0.00	
Number of Deaths	0.05	0.66	0.00	0.00	
Number of Occupations	0.03	0.27	0.00	0.00	
Number of Expropriated Properties	9.74	7.78	1.00	8.00	
Distance to Cities (km)	40.66	17.96	30.91	4.07	
Inflation Rate	416.54	749.59	0.00	8.48	
Average Number of Years since Last Conflict	9.80	7.77	1.00	8.00	
Annual Precipitation (mm)	1789.32	268.15	--	1702.86	

1

2   Table 1 includes summary data for most of the variables employed in this study. Average

3   property size, 4,886.19 hectares, stays constant throughout the study period as the unit of

4   analysis is properties and none are subdivided. Forest cover declined steadily from a substantial

5   proportion of forest cover in 1984 to very little in 2010 (from 11.5% deforested in 1984 to 92.2%

6   deforested in 2010). Conflict events, which we would expect to increase deforestation in most

7   cases given a need by both largeholders and the landless to undertake production and lay claim to

8   the land, varied, with the average of 0.47 conflicts per property per year (but with some very

9   notable spikes in conflict, particularly in the mid-1990s and mid-2000s). Of the 180 properties in

10   the study, 99 of them (55%) experienced some sort of conflict, and in a given year the number of

11   land-related conflicts on contentious properties could range from 0 to 45 distinct conflict events.

12   The number of deaths, which we include to proxy the intensity of conflict, and we expect to

1   increase deforestation, remained low on a per-property basis throughout the study period, with

2   the notable exception of 24 deaths on one property in the mid-1980s. On a property-level, 29.4%

3   experienced violent conflict which resulted in a fatality, with the number of deaths ranging from

4   1 to as many as 24 per year. Occupations, which we expect would significantly increase

5   deforestation, were similarly low on average, but highly variable across the study period, with

6   notable peaks every few years throughout. On a property-level, 35% experienced at least one

7   occupation over the 27 year period, with some properties experiencing as many as 24

8   occupations in a single year (Table 1). Expropriations of properties for agrarian reform, which

9   we also expect would increase deforestation given the need of new smallholders to establish

10   production, start at 0, but increase steadily each year. Distance to cities, which we would expect

11   to be associated with reduced deforestation as distance increases, remains very steady over the

12   two and a half decades of this study, although there is a notable drop in 2003 as the road network

13   is developed (though this drop is an artifact of better data being available in 2003, Table 1). The

14   inflation rate, which we expect would be associated with increased deforestation, as land

15   clearance can be a hedge against high inflation, is high and volatile in the pre-Real period (pre

16   1992), but is more stable and lower in later periods (Table 1). Precipitation, which we expect

17   would have a complicated relationship with deforestation varies year-to-year, with no noticeable

18   increasing or declining trend, despite some indicate that precipitation may be decreasing in this

19   area, probably due to periodic drought associated with climate change [79]. Low amounts of

20   rainfall may be associated with increased deforestation, as agricultural production may decrease

21   during dry periods. We would also expect high rainfall to be associated with decreased

22   deforestation because logging in very wet conditions is difficult or impossible in this region. We

23   also divided our dataset into three equal time periods of nine years (period 1: 1984-1992, period

2: 1993-2001, period 3: 2002-2010) in order to control for semi-decadal trends in OLS and

pooled OLS model specifications.

4)   Results and Discussion

The results of our analysis mostly support each of our hypotheses, with deforestation being

affected by conflict, deforestation being much greater on properties which were expropriated for

agrarian reform settlements, and end-of-period deforestation significantly higher on properties

with conflict and settlement formation. We address each hypothesis in turn, before turning to a

discussion of what these results indicate for CLC and LCS more generally.

   H1: Deforestation is greater during those time periods with land conflict compared to periods
      with relative peace

Deforestation appears to be moderately lower during (and in the year after, see SI-4 for models

with lagged variables) contentious periods, a result that remains consistent throughout all

hypothesis 1 models. In Table 2a we produce a pooled OLS regression model with detrended

(first-difference) deforestation as the dependent variable. This model indicates that land

expropriation and settlement formation is a significant driver of deforestation, increasing

deforestation by more than 47 hectares, and that different times have substantially different

deforestation profiles (with earlier periods having less deforestation – although in later periods

there is less forest to cut). Properties with good soils have less deforestation (12.3 hectares).

Table 2b presents an alternative specification to address Hypothesis 1 which decomposes the

conflict and settlement formation variables into separate categories. In Aldrich et al. [44], whose

analysis extended until only 2003, conflict was a more significant modifier of deforestation than

1   was settlement formation, and the results of Table 2b contradict that analysis to some extent,

2   showing that, while conflict does affect deforestation (especially in cases where settlements have

3   been formed, at 33.5 hectares more deforestation), settlement formation is the variable which

4   increases deforestation more substantially (including in cases where no conflict occurred at all,

5   43.7 hectares). Table 2b also shows that the passage of time after a conflict leads to slightly

6   enhanced deforestation (1.3 hectares), which, combined with the number of conflicts variable in

7   Table 2a, suggests a wait-and-see responds to conflict [44, 63]. Table 2a and Table 2b also

8   indicate that property size is an important control variable, likely because largeholders eventually

9   deforest their entire landholding if afforded the chance. Good soils are associated with less

10   deforestation (14 hectares less). Table 2c presents a fixed-effects panel specification which

11   largely confirms the results shown in Tables 2a and 2b. These results are contradictory to those

12   already reported in the literature in the sense that land conflict appears to be a less substantial

13   and less-significant (in the case of conflict itself, measured by events and deaths, not significant)

14   driver of deforestation than expropriation and settlement formation. Other agronomic variables

15   such as precipitation and soils are also significant (although the coefficient value for

16   precipitation is quite small) and reflect general concepts of how they would modify

17   deforestation, as discussed in the land change literature as a whole.

18

Table 2. H1 Regression Results.

Dep. Variable:	2a. Pooled OLS, First Difference Deforestation (Hectares), Detrended for Time	2b. Pooled OLS, First Difference Deforestation (Hectares), Detrended for Time	2c. Fixed-Effects, First Difference Deforestation (Hectares)
Regression Characteristics	n = 4619, F [10, 4608]	n = 4619, F [10, 4608]	n = 4619, F [7, 178]
	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000
	R^2 = 0.3286	R^2 = 0.3286	R^2 = 0.0749
Variable Name	**Coefficient (SE)**	**Coefficient (SE)**	**Coefficient (SE)**
Number of Conflict Events	-2.998 (1.78)*		-3.055 (1.92)
Conflict Occurred (Y/N) / **Settlement Formed (Y/N)**			
N / Y		43.771 (6.86)***	
Y / N		-20.227 (9.00)**	
Y / Y		33.520 (10.751)**	
Number of Deaths	4.457 (8.30)	1.898 (8.42)	5.149 (8.17)
Settlement Formed	47.779 (6.82)***		75.899 (29.85)**
Years Since Last Conflict	-0.975 (0.40)**	-1.371 (0.526)**	-2.244 (1.23)*
Annual Precipitation	-0.057 (0.012)***	-0.056 (0.012)***	-0.053 (0.01)***
Property Size (Hectares)	0.029 (0.004)***	0.029 (0.004)***	
Distance to Cities (Km)	0.215 (0.212)		
Soil Binary	-12.350 (5.48)**	-14.198 (5.56)**	
Time Period 1993-2001	-42.609 (9.95)***	-42.489 (9.97)***	-42.243 (13.99)**
Time Period 2002-2010	-155.156 (10.43)***	-152.476 (11.02)***	-152.527 (18.32)***
Constant	172.280 (33.47)***	193.998 (26.98)***	314.961 (19.99)***
Sigma u			139.737
Sigma e			223.045
Rho			0.282

Notes: Statistical significance indicated as follows: * = 0.10, ** = 0.05, *** = 0.000. Robust Standard Error is presented.

H2: Among properties that have had land conflict, those properties that have been expropriated have greater deforestation.

H2 considers just those properties that have had land conflict and aims to elaborate whether expropriation for agrarian reform settlement formation affects forest cover. H2 is supported in all

1 model specifications in Table 3 (and in SI-5). H2 is addressed in in the results of Table 3a

2 through pooled OLS regression, and shows that largeholder control significantly increases

3 deforestation, albeit with a declining marginal effect, as indicated by the interaction of

4 largeholder control with the passage of time. Agronomic drivers are also significant, as is the

5 passage of time. This raises the question about the correlation of deforestation, conflict, and time,

6 with deforestation events and conflict events being episodic on similar timeframes. This is the

7 case, as indicated by SI-6, which makes it difficult to tease apart that deforestation that was

8 undertaken as part of agronomic operations on properties and that deforestation undertaken in

9 response to conflict. This may explain why conflict events are typically not statistically

10 significant in these analysis, but have been found to be significant in others [e.g., 36, 44, 80].

11

Table 3. H2 Regression Results.

Dep. Variable:	3a. Pooled OLS, First Difference Deforestation (Hectares), Detrended for Time, Contentious Properties Only	3b. Fixed-Effects, First Difference Deforestation (Hectares), Contentious Properties Only	3c. Fixed-Effects, First Difference Deforestation (Hectares), Contentious Properties Only
Regression Characteristics	n = 2534, F [11, 2522]	n = 2534, F [9, 99]	n = 2534, F [9, 99]
	Prob > F = 0.0000	Prob > F = 0.0000	Prob > F = 0.0000
	R^2 = 0.3509	R^2 = 0.0747	R^2 = 0.0743
Variable Name	Coefficient (SE)	Coefficient (SE)	Coefficient (SE)
Number of Conflict Events+	-2.054 (1.74)	-2.425 (1.74)	0.196 (2.55)
Number of Deaths+	4.403 (8.47)	3.93 (8.01)	2.78 (4.01)
Largeholder Control+	505.801 (3414.02)	799.863 (4248.08)	6667.603 (3973.95)*
Largeholder Control*Year+	-0.263 (1.70)	-0.416 (2.13)	-3.339 (1.99)*
Settlement Formed+	58.676 (10.78)***	84.814 (42.75)*	88.467 (46.99)*
Years Since Last Conflict		-1.99 (1.23)	-2.168 (1.20)*
Annual Precipitation	-0.067 (0.02)***	0.061 (0.01)***	-0.058 (0.02)***
Property Size (Hectares)	0.028 (0.005)***		
Distance to Cities (Km)	0.228 (0.32)		
Soil Binary	-14.917 (8.63)*		
Time Period 1993-2001	-47.351 (23.15)**	-47.843 (26.45)*	-20.291 (23.29)
Time Period 2002-2010	-178.708 (33.48)***	-181.545 (35.35)***	-135.453 (31.21)***
Constant	203.073 (56.13)***	365.016 (40.36)***	307.174 (42.02)***
Sigma u		170.969	171.097
Sigma e		259.406	259.513
Rho		0.303	0.303

Notes: Statistical significance indicated as follows: * = 0.10, ** = 0.05, *** = 0.000. **+** = in the specification presented in table 3c this variable is lagged. Robust Standard Error is presented.

Tables 3b and 3c address H2 using fixed effects regressions. Table 3c includes some lagged

independent variables. These models indicate that settlement formation is a significant and

substantial increaser of deforestation, and that deforestation is significantly and substantially

higher on rancher/largeholder controlled properties (again, with declining marginal effect). It is

interesting to note that the unlagged Largeholder Control variable is not significant, but the

1 lagged version is; this is likely because a change undertaken in one year is only visible the next

2 given our remote sensing methods.

3

4 Overall, H2 is supported, and expropriation for settlement formation on them significantly

5 increases deforestation by nearly 90 hectares, a result that aligns with other observations in his

6 region and across the Amazon in general [e.g., 34, 36, 38, 44]. Figure 3 shows this overarching

7 trend visually, where the aggregate outcomes of conflict and deforestation processes can be

8 observed. The trajectory of deforestation is the roughly the same for both (a cumulative growth

9 curve) in later periods, but properties experiencing settlement formation have greater

10 deforestation, particularly after 1996 (a year of many conflicts) and also some more severe

11 upticks in deforestation from year to year.

12

13 **Figure 3. Average Deforested area (hectares) on expropriated for settlement formation and**

14 **properties which were not expropriated for settlement formation.**

15

16 *H3: Deforestation is greater by the end of study period on properties that have had contention*

17 *compared to those without*

18 H3 is supported, and was initially tested through Student's t-test, which shows that properties

19 with conflict have significantly more total deforestation (801 hectares more) than those that do

20 not ($p = 0.0738$, see SI-7). However, such analyses do not consider intervening variables which

21 are also important in the land change process, such as distance to markets, economic conditions,

22 or other aspects of agricultural processes. Therefore, we implement a cross-sectional OLS

1   regression (n=179), similar to that presented in Aldrich et al. [44], albeit for the year 2010

2   instead of 2003.

3

4   Results germane to H3 are evident in Table 4, and show that some aspects of conflict

5   significantly increase deforestation, a result that algins with previous studies [e,g, 38, 44], but

6   also that expropriation and settlement formation appears to be more significant and substantial in

7   end-of-period deforestation in the BNP. It is interesting to note that settlements formed on poor

8   soils have significantly more deforestation (286 hectares, Table 4a) than those formed on good

9   soils (46 hectares of deforestation, Table 4a). Also important is that settlements on properties

10   with a history of conflict do have more deforestation than those that do not have a history of

11   conflict (183 hectares vs 157 hectares, Table 4b). Overall, these results support the idea of

12   contention as a land change driver – though perhaps not as significant as the process of

13   settlement formation – a tendency shown visually in Figure 4.

14

Table 4. H3 Regression Results.

Dep. Variable:	4a. OLS, Deforestation (Hectares)	4b. OLS, Deforestation (Hectares)
Regression Characteristics	n = 179, F [8, 170]	n = 179, F [7, 171]
	Prob > F = 0.0000	Prob > F = 0.0000
	R^2 = 0.9805	R^2 = 0.9806
Variable Name	Coefficient (SE)	Coefficient (SE)
Number of Conflict Events	3.149 (14.45)	
Number of Deaths	-0.487 (3.80)	
Average Precipitation	-3.736 (2.12)*	-3.711 (2.10)*
Property Size (Hectares)	0.951 (0.03)***	0.950 (0.31)***
Distance to Cities (Km)	4.323 (4.32)*	4.181 (2.63)
Soil Binary		-201.318 (118.18)*
No Settlement & Good Soils	-138.247 (129.46)	
Settlement & Good Soils	46.333 (202.80)	
Settlement & Poor Soils	286.405 (100.26)**	
No Settlement & History of Conflict		-139.552 (121.70)
Settlement & No History of Conflict		157.316 (80.48)*
Settlement & History of Conflict		183.311 (102.26)*
Constant	6250.631 (3940.85)	6315.235 (3947.77)

Notes: Statistical significance indicated as follows: * = 0.10, ** = 0.05, *** = 0.000. Robust Standard Error is presented.

Figure 4. Average Deforestation in Hectares for properties with conflict and without conflict.

Overall Discussion

In effect, our analysis appears to demonstrate that some aspects of land conflict increase deforestation on a year-by-year basis, but in the BNP the settlement formation process is what drives deforestation more significantly than conflict itself (Tables 2, 3, and 4). A variety of model specifications place the practical effect of settlement formation on annual deforestation around 47 to 88 hectares per year (Table 2 and Table 3). Furthermore, the quality of the soil and a history of conflict both influence end-period deforestation; poor soils on agrarian reform

1 settlements and a history of conflict on expropriated properties are both significantly associated

2 with higher levels of deforestation (Table 4). Although the results presented here support the idea

3 that contention and the associated process of settlement formation increase deforestation, the

4 result for the landscape of the BNP is near-total deforestation, with the 8,000 km2 of original

5 forest reduced to less than 700 km2 by 2010. In this respect, it appears that contention may

6 hasten the process of deforestation, rather than drive it wholesale, meaning that agronomic

7 drivers are certainly important as well. These insights lead us to revise Figure 2, to reflect the

8 actual stylized trajectory of deforestation in the contentious agrarian landscapes of the BNP,

9 shown in Figure 5. From our analysis it is clear that contention and settlement formation

10 certainly contribute to enhanced deforestation, but they by no means define completely it in the

11 BNP. By 2010 deforestation was greater on contentious and expropriated properties, but

12 uncontentious properties and those that remained unexpropriated still had very little remaining

13 forest cover.

14

15 **Figure 5. Analysis results indicate that the CLC/ALC process looks more like this**

16 **trajectory rather than the one presented in Figure 2.**

17

18 Given what the literature on land conflict and deforestation suggests [e.g., 34, 36, 38, 44], our

19 results are somewhat confirmatory of past suppositions and empirical observations, but our

20 results place more responsibility for deforestation on the process of settlement formation. Our

21 results may differ because we arrived at them through a 27-year panel dataset, providing a much

22 more rigorous test of the effect of conflict on forest change than most studies have previously

23 attempted. Furthermore, land conflicts often involve large properties, for which cadastral

1   information is hard to come by; the analysis presented here is unique for the Amazon basin,

2   given our access to property boundaries for a contiguous set of largeholdings. The results overall

3   uphold the idea that land conflict, and the response of the State to it, has stimulated excessive

4   deforestation in the Brazil-Nut polygon in the arc of deforestation. Data limitations restrict the

5   spatial extent of the analysis; that said, agrarian reform settlements are common throughout the

6   basin, and land conflicts have been endemic in Brazil, as well as throughout South America.

7   When forests stand in regions where adversarial claimants vie for the same piece of land,

8   excessive deforestation is a likely consequence.

9

10 A few of the outcomes from these analyses are interesting given their mixed, or contrary,

11 indications. For example, conflict events seem to decrease deforestation in some models (Table

12 2a), although most model specifications do not indicate this is a statistically significant result.

13 This finding contradicts previous work in the BNP [44], and across the Amazon as a whole [80].

14 However, this seemingly contradictory result probably stems from the level of detail in

15 explanatory variables in this study [i.e., we have more specific independent variables at finer

16 spatial resolution than 80], and employ a 27-year panel dataset [unlike 44].

17

18 One highlight of this analysis is the insight that rancher/largeholder control of a property greatly

19 increases deforestation, although this increase has a decreasing marginal effect (which eventually

20 becomes negative in later time periods, see Table 3). Another outcome that has not been

21 investigated in detail before is the relationship between deforestation and the quality of soil for

22 agricultural uses, particularly in cases of agrarian reform settlement formation. Our results

23 indicate that settlements on poor soils have much higher amounts of deforestation (240 hectares

more deforestation), suggesting that agrarian reform agencies may be able to help avoid

deforestation through preferentially establishing settlements in areas with better soils (Table 4a).

Finally, though settlement formation seems to have a more stable, significant, and substantial

influence on deforestation across the 27 years of this analysis, a history of conflict on a

settlement (in the time before the settlement was created) significantly increases overall

deforestation by the end of the period (table 4b).

Another interesting mixed outcome is the influence of distance to city across the various model

specifications. In all cases distance from cities has a positive coefficient (although it is generally

not significant in our models). This means that increasing distance from city increases

deforestation (by varying amounts, from 0.22 to 4.3 hectares per kilometer). This may be due to

a combination of lower accessibility driving deforestation down, and the effect of environmental

enforcement which is typically greater closer to cities over the time period covered by this

analysis.

Even though some aspects of contention drive deforestation according to our results, the Eastern

Amazonian study area reveals nearly total clearance (with most remaining forest in indigenous

reserves and conservation units). Although some properties in the Brazil-Nut polygon still retain

remnants of their cover, by far most of it has been converted to fields and pastures. This is

consistent with our results, given that land conflict has long afflicted the region, now home to a

large concentration of agrarian reform settlements. As the statistical findings show, land conflict

together with expropriation and settlement formation lead to additional magnitudes of

deforestation beyond what occurs under ALC alone. Nevertheless, these magnitudes, although

significant in a statistical sense in most cases, are less important in empirical terms when

considering the size of holdings in question, nearly all of them covering thousands of hectares

(13 of the 179 properties are under 2000 hectares in area). This is to say that in the aggregate,

ALC probably accounts for a significant amount of deforestation, with CLC exacerbating it in

times, and locales, of conflict. Moreover, the magnitude of forest loss is far in excess of what

would be expected had the largeholders kept forest reserves of 50 percent, as prescribed by

Brazil's forestry code. Thus, the results indicate that deforestation has been excessive, and that it

stems from the region's land managers acting both independently and in competition with SMOs.

This is an important finding given that many land change studies assume a unitary decision-

maker who (rationally) maximized profit. Instead, agricultural decisions may be made by

multiple decision-makers, and when conflict is present the multiple decision-makers generally

chose to remove more of the Amazon's forests.

These results also indicate that expropriation for agrarian reform settlement formation is a

significant increaser of deforestation, in both the statistical and practical sense (see Table 2,

Table 3, and Table 4). In many respects, land reform in this region has put forests at even higher

risk, placing some substantial part of the blame for deforestation in the BNP on the project of

agrarian reform. While this finding should not be discounted, all land change decisions should be

evaluated in some context, and the context of already-cleared areas on expropriated large

properties in the BNP is one of agricultural decimation. Indeed, newly formed agrarian

settlements may have had only one option for fertile and productive household agriculture;

deforestation to avoid long-ranched soils and pastures choked with invasive weeds. This is not to

say that the small agriculturalists who succeeded the large ranchers on those expropriated

1   properties have no part in the blame for the near-total deforestation of the BNP, but their part

2   should be understood in the context of the struggle of the social movements they may have been

3   part of. Indeed, we take criticisms of the solely statistical treatments of conflict to heart [e.g., 81],

4   and suggest that the complex social mechanisms and history of this region, described elsewhere

5   [e.g., 36, 41, 45, 53, 82, 83], provides ample context for these mixed results.

6

7   **5)   Conclusions**

8   Our analysis shows that land change in Brazil, and deforestation in particular, results from both

9   complex social processes and individual behaviors. Overall deforestation in the BNP may not be

10   completely dominated by CLC, but CLC contributes significantly, both in statistical and practical

11   terms, to the overall evolution of land change in the region. Deforestation is greater on the

12   properties of the BNP due to CLC and settlement formation in the time before its ultimate

13   privatization in 2010, and settlement areas are among the most deforested. Overall, as other

14   studies have indicated in more general terms, land conflict and its historical solution (i.e.,

15   settlement formation) increase deforestation as they also increases strife and violence.

16

17   The results presented here also make a compelling case for the consideration of so-called social

18   process drivers of deforestation; as elaborated in our pooled OLS and fixed effects panel

19   specifications, CLC is a significant cause of deforestation in this region. We suggest that similar

20   situations arise in other parts of the world, in which case efforts to mitigate global warming by

21   the carbon sequestration of standing forests must consider the circumstances that put the poor at

22   risk to social mobilization. We also suggest that land change science must pay attention to cases

23   where the assumption of unitary decision-makers and the primacy of economic drivers of land

1 change may fall apart, and consider carefully how social interaction may generate unexplored

2 drivers of change, such as CLC.

3

11

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1 **8)   Supporting Information Captions:**

2 - SI-1. Variable Definition Table

3 - SI-2. Deforestation trajectory on property that was excluded from our analyses after the balancing
4   procedure.

5 - SI-3. Procedures for Newspaper Data

6 - SI-4. Lagged models for Hypothesis 1. Note that lagging does not change the sign of the
7   coefficient for conflict and agrarian reform settlement variables.

8 - SI-5. t-test on deforestation totals (1984-2010, measured in hectares) on contentious properties
9   between those which were expropriated for settlement formation and those that were not. Among
10   properties with conflict those which are expropriated have significantly greater deforestation than
11   those that were not. Note that 99 of the 180 properties had land conflict over the study period.

12 - SI-6. Conflict and the passage of time are correlated (meaning that conflict is episodic, but
13   concentrated in certain time periods). Related to this, deforestation and time are correlated, too.

14 - SI-7. t-test on deforestation totals (1984-2010, measured in hectares) between properties with
15   conflict and those without. Properties without contention have significantly less deforestation
16   than those that do, an outcome that supports H1.