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# War and Deforestation in Sierra Leone

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**Abstract:** The impact of armed conflict on the environment is of major public policy importance. We use a geographically disaggregated dataset of civil war violence together with satellite imagery of land cover to test whether war facilitated or prevented forest loss in Sierra Leone. The conflict data set allows us to establish where rebel groups were stationed and where battles and attacks occurred. The satellite data enables us to monitor the change in forest cover (total, primary, and secondary) in all of Sierra Leone's 151 chiefdoms, between 1990 (prior to the war) and 2000 (just prior to its end). The results suggest that conflict in Sierra Leone acted as a brake on local deforestation: conflict-ridden areas experienced significantly less forest loss relative to their more conflict-free counterparts.

## Introduction

Tropical forests constitute important stocks of natural capital for many developing countries by generating benefits, including timber, fuel wood, natural erosion regulation, and biodiversity<sup>1,2</sup>. Forests are also necessary agents in global efforts to combat climate change because they sequester significant amounts of carbon<sup>3</sup>. Africa's deforestation rate is twice the average in the rest of the world<sup>4</sup>, making it a focal point in current discussions to halt deforestation through mechanisms such as the U.N. Collaborative Program on Reducing Emissions from Deforestation and Forest Degradation<sup>5</sup>. Meanwhile, nearly half of all African countries are currently or have recently been embroiled in civil war<sup>6</sup>. While war's adverse effects on human and physical capital have been documented<sup>7</sup>, evidence of its impact on the environment is sparse.

Studies on the link between war and the environment have mainly focused on how either too much or too little natural capital may cause civil unrest. Proponents of the "resource curse" contend that in weakly governed states with abundant natural wealth, political factions vie to control the sizeable revenues from resources such as timber that are fueling the conflict and a cycle of exploitation in which forests are both driver and casualty<sup>8,9</sup>. Other scholars claim environmental scarcities can engender violent conflict through a variety of channels<sup>10,11,12</sup>, while still others argue that there is unlikely to be a strong relationship between resources and conflict<sup>13,14</sup>.

There is a growing literature studying the link running the other way, from war to environmental impacts, and the studies that have focused on understanding fighting's consequences for forest loss find mixed results, suggesting that further research will be useful<sup>15,16</sup>. In analyzing the implications of Colombia's civil war, Álvarez shows that insecurity promoted deforestation in locations where the *Ejército de Liberación Nacional* rebel group cleared land for coca production, while in other areas they preserved forests that aided their cover from government surveillance<sup>17</sup>. Dávalos' investigation into the consequences of Colombia's war on forest patterns is similarly inconclusive<sup>18</sup>. In more recent work, Stevens et al. (2011) find that there was substantial reforestation during the early period of the Nicaragua civil war of the late 1970s and 1980s, while deforestation increased later in the conflict<sup>19</sup>. In contrast, Nackoney et al. (2014) find that there was more rapid primary forest loss in the Democratic Republic of Congo during the 1990-2000 period relative to 2000-2010, and argue that this is consistent with an adverse effect of civil war

on forests, although the presence of widespread armed conflict during both time periods complicates the interpretation of this pattern as a war impact<sup>20</sup>. In one of the most comprehensive of recent analyses (and one that uses an approach closely related to the current paper), Fergusson et al. (2014) examine Colombian municipalities over time and show that violent activity by paramilitary groups is associated with significantly more local deforestation<sup>21</sup>.

Theoretical predictions from economics and political science on whether war is likely to facilitate or prevent forest loss is also ambiguous. One set of hypotheses posits that the instability engendered by war encourages forest extraction because people face shorter time horizons and higher discount rates, leading to increased resource extraction. Weakened property rights enforcement in the chaos of war may further embolden armed groups to extract valuable forest (or other natural) resources to fund their activities, in a variant of the well-known “tragedy of the commons”<sup>22</sup>. Wartime bombing or chemical spraying, such that employed by the U.S. military in the Vietnam War, may also directly destroy forest. Accordingly, forest cover might be expected to decrease in conflict areas.

A second set of plausible hypotheses point in the opposite direction, namely that war will protect forests by raising the costs of extraction and sale while simultaneously lowering the expected economic returns to farming. In wartime, the infrastructure (e.g., roads, ports) needed transport timber may simply not be functional. Trade sanctions may limit access to overseas markets. Farmers may also be discouraged from converting forests into agricultural land because they fear expropriation of their crop by bandits or soldiers. More mechanically, farmers may also leave more existing land fallow in wartime either because they are literally driven off their land or because they themselves become fighters in the conflict<sup>23</sup>, leading some fields to gradually return to a forested state. Alix-Garcia et al (2013) show that the opposite set of economic conditions, namely, rapidly rising income due to a large-scale government social program in Mexico, led to rapid deforestation, especially in areas characterized by limited local transportation infrastructure<sup>24</sup>.

A key constraint in making research progress in this important area has been the relative lack of sub-national data on both war violence and forest loss. Early studies relied on personal observations and historical accounts of forest degradation and fighting<sup>25,26</sup>. Recent work

(discussed above) has incorporated spatially explicit forest measurements, thanks in part to the rapid evolution of land-change science and satellite technology<sup>16,27,28,29</sup>. Nonetheless, sub-national conflict data are often hard to acquire, not least because of the chaotic circumstances under which they are produced. Without this data one cannot credibly assess how variation in the intensity of conflict within a country affects local environmental degradation.

In this study, we use a chiefdom-level dataset of conflict incidents in Sierra Leone, which we pair with remotely-sensed satellite imagery of land cover to examine evidence of war's impact on forest cover. The conflict data set allows us to establish where the leading rebel group, the Revolutionary United Front (RUF), was stationed as well as where battles and attacks occurred. The satellite data enables us to monitor the change in forest cover (total, primary, secondary), in all of Sierra Leone's 151 chiefdoms, between roughly 1990 (prior to the civil war) and 2000 (just prior to the end of the civil war). By combining micro-conflict and satellite data in this way we are able to directly test whether war facilitated or prevented local forest loss in Sierra Leone.

## Materials and Methods

**Background.** Sierra Leone is located between the 7<sup>th</sup> and 10<sup>th</sup> parallels north of the equator on the west coast of Africa<sup>30</sup>. Its rainfall is concentrated annually between May and November and averages 2000 mm in the north to more than 5000 mm on the coast<sup>31</sup>. This ample supply of water and moisture sustains a substantial area of primary and secondary forest that covered two thirds of the country prior to the war (Table 1). Primary forests are either moist evergreen or semi-deciduous trees, mainly over 30 m high<sup>32</sup>. Typical species in these stands are: *Lophira alata*, *Heritiera utilis*, *Uapaoa guineensis*, *Erythrophleum ivoransis*, *Brachystegia leonensis*, *Piptadeniastrum africanum*, *Daniellia thurifera*, *Terminalia ivorensis*, *Parkia bicolor* and *Anthonotha flagrans*<sup>32</sup>. Secondary growth, which develops when agricultural land (which had earlier been cleared of primary forest) is left fallow, consists of younger trees and thickets. Common tree species are *Musanga cecropioides*, *Carapa procera*, *Macaranga barteri*, *Bridelia micrantha*, *Myrianthus arboreus*, *Phyllanthus discoideus* and *Sterculia tragacantha*, as well as the following thicket species: *Lantana camara*, *Manniophytum fulvum*, *Abrus precatorius*, *Discorea bulbifera*, *Clematis grandiflora*, *Adenia lobata* and *Scleria bovinii*<sup>32</sup>. Apart from the tiny fraction of forest held under

government conservation, all forested areas are communally owned and governed by a customary land tenure system.

**Data.** We studied the consequences of Sierra Leone’s civil war on forests using chiefdom-level data matched with a remotely sensed time series of land-cover change.

The conflict dataset was collected by Sierra Leone’s No Peace Without Justice (NPWJ) conflict mapping project that kept a comprehensive record of the location and intensity of all reported armed violence during the war<sup>33</sup>. We constructed chiefdom and district-level measures from the descriptions of incidents in this report. We use two main conflict measures. The first captures whether or not an RUF rebel base was present in a chiefdom during the 1990 to 2000 period. The second measures the number of battles and attacks that occurred in each chiefdom or district.

Measuring conflict by observing whether or not an RUF base was present is relevant because, while many armed actors were involved in the war, over 95% of the 975 recorded attacks, and over 75% of the 1368 recorded battles and attacks, involved the RUF as the primary fighting force<sup>33</sup>; data construction details are discussed in the Supplemental Appendix and in Bellows and Miguel<sup>34</sup>. Since the RUF perpetrated most of the violence, it is plausible that land cover could be affected where RUF bases were stationed. To capture this effect, we define a binary (0/1) variable  $RUF_{id}$  that indicates the absence or presence of an RUF base in chiefdom  $i$  and district  $d$ . There were on average 0.748 (s.d. 1.266) RUF bases per chiefdom (Table 1), and nearly half of all chiefdoms had an RUF base.

Battles and attacks are also a relevant determinant of land-cover change because they often involve larger-scale military campaigns of more than 150 soldiers that could exert formidable pressure on the landscape and local population. More than 60% of the 1,995 violent incidents included in the NPWJ report were classified as battles or attacks<sup>34</sup>. Events were coded as attacks if an armed group came into a village and burned houses, raped or killed residents. Battles consisted of armed encounters between two groups<sup>34</sup>. The data confirm that battles and attacks occurred throughout the country with substantial variation across neighboring chiefdoms (Figure 1, Panel C). On average there were 9.06 (s.d. 9.67) such incidents per chiefdom (Table 1). While it is conceptually

possible that these two measures capture quite different phenomena – for instance, if the presence of an RUF base and thus greater RUF control of an area leads to fewer clashes and less violence – these two measures are in fact strongly positively correlated (correlation coefficient +0.33), and a considerable portion of civil war violence occurred in areas with RUF bases; to illustrate, chiefdoms with RUF bases experience more than twice as many battles and attacks on average compared to other chiefdoms, and this difference is significant at 99% confidence.

To map forest-cover change, we collaborated with University of California, Berkeley's Geospatial Innovation Facility and acquired Landsat satellite data for Sierra Leone for the period *c.* 1990 - 2000. For *c.* 1990, Landsat Thematic Mapper (28.5m) data was obtained, predominantly 1986; and for *c.* 2000, Landsat Enhanced Thematic Mapper Plus (28.5m) from 1999-2002 was obtained, predominantly 2001.

Previous studies have shown that digitally processed high-resolution satellite images provide the most accurate estimates of the area and distribution of land cover<sup>35,36</sup>. Digital analysis was performed on seven images corresponding with Sierra Leone's dry season, which runs from November to March, when the distinction between forest and non-forest land-cover classes is most pronounced. For each time period, the outputs were projected into an equal-area coordinate system, edge-matched and merged into a seamless dataset for Sierra Leone's 151 chiefdoms. We produced direct measures of land-cover change by classifying the *c.* 1990 and *c.* 2000 data together in a multi-date image. Deriving change estimates in this way rather than single-date images reduces false-change inaccuracies caused by the inevitable classification errors in each image.

We selected a simple set of forest classes: total forest, primary forest and secondary forest. Total forest covers both primary and secondary forest cover. Primary forest areas cover older, established forest; secondary forest areas cover younger forest and scrub areas that often consist of a mixture of trees at different stages of regeneration as well as high shrubs. Our outcome measures are the percentage point difference in forest classes for each chiefdom over the two-date time period.

**Methods.** We investigate the relationship between conflict incidence and forest-cover change with linear models. We let  $F$  index percentage point changes in the three outcome measures: total forest, primary forest, and secondary forest. We let  $i$  and  $d$  index the chiefdom and district-level observations, respectively. We first estimate an OLS regression of the form:

$$(1) \quad F_{id} = \alpha + \beta_1 RUF_{id} + \beta_2 I(BA_{id}) + X_{id}'\gamma + \varepsilon_{id}$$

We first consider the effect of a rebel Revolutionary United Front (RUF) base being present in a chiefdom on forest cover, where  $RUF_{id}$  indicates the presence of a base in chiefdom  $i$  in district  $d$ . We then turn to examine the impact of battle and attacks and code  $I(BA_{id})$  as a binary (0/1) variable that indicates the absence of a battle or attack in chiefdom  $i$  and district  $d$ , in other words, the extensive margin of such incidents in a chiefdom. Our estimates capture the mean shift in forest cover change due to conflict exposure measured in these two ways. We assume the error term  $\varepsilon$  may be correlated between neighboring chiefdoms but is independent across districts, and include robust standard errors clustered by district in each model.

In our second model, we estimate the forest cover outcome conditional on battles or attacks occurring in chiefdom  $i$  with a log-linear model, as in equation 2:

$$(2) \quad F_{id} = \alpha + \beta_1 RUF_{id} + \beta_2 \log(BA_{id}) + \beta_3 \log(BA_d) + X_{id}'\gamma + \varepsilon_{id}$$

As in equation 1, we include the indicator for an RUF base and robust standard errors clustered by district. Here, we also take the natural logarithm of the total number of battles and attacks per chiefdom in order to facilitate interpretation of coefficient estimates as proportional changes in local conflict exposure, obtaining  $\log(BA_{id})$ . This captures the intensive margin of such incidents, complementing the approach in model 1. Since the natural log of zero is undefined, the small number of chiefdoms (13 chiefdoms, or 8% of the sample) in which no battles or attacks took place are dropped from the sample, an approach that is standard in empirical economics (for instance, in Mincerian estimates of the returns to schooling, those with zero wages are typically dropped from the analysis); the results are unchanged using an alternative approach in which  $\log(x)$  is replaced with  $\log(x + 0.01)$  throughout (not shown). To test for spillover effects from conflict in other nearby chiefdoms in the same district, we include a further variable  $\log(BA_d)$  that captures the effect of conflict in district  $d$  on its forest cover. The same disruptions to economic activity and human settlement that might produce localized conflict effects could also affect neighboring areas.



A key issue for our identification strategy is the possibility that unobserved time-varying factors besides the war may have affected Sierra Leone's forest cover. These trends could be correlated with baseline chiefdom population and geographic characteristics, including the degree of remoteness and accessibility to markets, as well as the presence of other natural resources, including the important diamond mining industry in Sierra Leone. One immediate concern is that RUF bases may have been disproportionately placed by rebels in remote and inaccessible areas with ready access to diamond resources, and that underlying trends in deforestation in such areas were different than in other regions. To partially account for this and other potential confounding factors, we include a rich set of chiefdom level covariates  $X_{id}$  in the preferred empirical specifications, including primary and secondary forest cover in 1990, change in yearly maximum NDVI from 1982 to 1990 (partially capturing pre-war vegetation trends), the number of registered diamond mines and non-diamond mines, density of the road network and of rivers, chiefdom population and population density in 1985, and the distance to Freetown, the capital and main port (for details on the data, refer to the Supplemental Appendix and Bellows and Miguel <sup>34</sup>). We also show that results are robust to excluding these covariates. Regarding the concern that RUF bases were systematically located in more remote areas, note that there is no statistically significant correlation between RUF base location and baseline primary or secondary forest coverage (and point estimates are small and t-statistics less than 1, not shown), suggesting that RUF base location decisions were driven by a broader set of considerations.

Other probable sources of underlying variation are regional trends in environmental and economic conditions that might have affected trends in Sierra Leone as a whole. The statistical models above cannot estimate any aggregate national trends. One way to account for them is to measure outcomes in Sierra Leone before and after the war to a region not directly affected by it but plausibly influenced by similar time-varying regional economic factors. We construct such a comparison region in neighboring Guinea from the portions of sub-prefecture political units located within 50 km of the shared border. Note that Guinea did not suffer from civil conflict or large-scale political instability during the study period, making it a plausible counterfactual for Sierra Leone in the absence of the civil war. We minimize variation between the regions due to seasonal and annual environmental conditions by using the same Landsat dataset analyzed for Sierra Leone. The comparison is more robust to environmental factors correlated with latitude

because we also restrict the Sierra Leone sample to the chiefdoms located within 50 km of the border. Finally, we verify that in 1990 the two countries shared similar aggregate economic trends, particularly with respect to their GDPs, agricultural sectors, imports and exports<sup>37</sup>. The estimation equation for model 3 is:

$$(3) \quad F_i = \alpha + \beta_i SL_i + \varepsilon_i$$

where  $F_i$  again indexes the percentage point changes in forest classes in the restricted sample of chiefdoms and sub-prefectures indexed by  $i$ .  $SL$  is a binary (0/1) variable that takes on a value of 1 for Sierra Leone chiefdoms and 0 for Guinea sub-prefectures. The coefficient on this term represents the difference between Guinea and Sierra Leone before versus after the war, where a leading explanation for any differences is the effect of the Sierra Leone war on forest-cover change. While model 3 is arguably more speculative than the main analysis, since the identifying assumptions are more challenging to test, it provides a useful additional test of the main hypothesis and has the advantage of capturing any aggregate national effects of the Sierra Leone conflict.

## Results

Total forest cover in Sierra Leone chiefdoms declined by an average of 9.6 percentage points, from 67.5 percent covered to 57.9 percent covered, across the period of the war (Table 1; Figure 2). This downward trend in forest cover was accounted for entirely by changes in secondary forest cover, which accounts for most forest cover in Sierra Leone: average secondary forest cover dropped from 47.2 to 37.6 percent between 1990 and 2000. Primary forest cover remained constant at 20.3 percent across the civil war period. Despite these trends, visual inspection of chiefdom-level changes in forest cover reveals remarkable variation (Figure 1, Panel A). Out of a total of 151 chiefdoms, 98 chiefdoms lost cover, 12 chiefdoms showed no change (within  $\pm 1\%$ ), and 41 chiefdoms gained forest cover.

To investigate the impact of conflict on these land-cover changes, we first examine the correlation between the sustained presence of RUF forces in a chiefdom (i.e., locating a base there) and changes in forest cover. The location of RUF bases across chiefdoms is presented in Figure 1, Panel B. Having a RUF base in a chiefdom predicts a significant increase in forest cover (relative to chiefdoms that do not contain a base) of 5.98 percentage points (s.e. 2.72) by model 1 and 6.36

percentage points (s.e. 2.53) by model 2 (Table 2, Panel A) in the preferred specification with additional covariates. Estimated impacts are similar in specifications without additional covariates, and if anything slightly larger in magnitude, at 8.67 percentage points in model 1 and 9.37 percentage points in model 2. Given overall trends, this implies that the presence of a rebel base substantially dampened the decline in forest over time, leading these chiefdoms to experience less deforestation, and these effects are statistically significant at high levels of confidence ( $P < 0.05$ ). This conflict effect is mediated entirely by changes in secondary forest cover, with primary forest cover being unaffected by the RUF base measure (Table 2, Panels B and C). It is worth pointing out that this relationship is not simply the result of the RUF deciding to locate bases in more remote forested areas, since there is no significant relationship between baseline forest cover and RUF base placement (as noted above), and these estimates are conditional on a wide range of baseline chiefdom population, geographic, resource, and transportation characteristics (details in Supplemental Appendix Tables A1-A3).

Neither the occurrence of any chiefdom level battles and attacks, nor the number of such battles and attacks at the chiefdom level, are significantly associated with changes in chiefdom forest cover (Table 2, models 1 and 2). Districts are a higher administrative level than chiefdoms, with 14 districts nationwide. A 10 percent (approximately 10 log point) increase in battles and attacks within the district predicts a 0.522 percentage point (s.e. 0.341) increase in chiefdom forest cover, and these effects are marginally statistically significant with a P-value near 0.10 in the preferred specification with additional covariates. We obtain a similar result if we exclude the chiefdom itself when constructing the district average battles and attack variable. Results are again driven by changes in secondary forest (Panels B and C).

Comparing a restricted sample of Sierra Leone chiefdoms with the sample of Guinea sub-prefectures directly on the opposite side of the border reinforces the finding that civil war had a positive effect on local forest growth. Note that the magnitude of the effect size in model 3 is not directly comparable with models 1 and 2 since the explanatory variables differ. Moreover, it represents a lower bound estimate for the reason that, having hosted more than a quarter million war refugees from Sierra Leone, southern Guinea was also not impervious to the conflict <sup>38</sup>. However, if we accept the assumption that the chiefdoms and sub-prefectures on both sides of the

border would have experienced similar trends on average except for the occurrence of direct armed conflict in Sierra Leone, the indicator variable for location on the Sierra Leone side of the border shows that chiefdoms in Sierra Leone experienced a 5.71 percentage point increase (s.e. 0.92,  $P < 0.01$ ) in total forest cover compared to their counterparts in Guinea (Table 3, Panel A), with effects once again driven by secondary forest cover (Panels B and C).

Collectively, these results suggest that conflict in Sierra Leone acted as a brake on local deforestation: conflict-ridden areas with rebel bases experienced significantly less forest loss relative to their more conflict-free counterparts, districts experiencing more attacks and battles had somewhat less forest loss, and chiefdoms in war-torn Sierra Leone experienced significantly less forest loss relative to comparable regions directly across the border in Guinea.

## **Discussion**

While rich in forest and other natural resources, particularly diamonds, Sierra Leone's people are amongst the world's poorest<sup>39,40</sup>. They were made worse by the 1991-2002 civil war, which killed an estimated 50,000 people, forced 2 million others to abandon their homes, and brutalized thousands more with mutilation, rape, and violence<sup>41,42</sup>. Historically, more than two thirds of the economically active population was engaged in subsistence farming<sup>37</sup>, with farmers generally practicing a system of "bush fallowing," otherwise known as slash-and-burn agriculture<sup>43,32</sup>. More often than not, this technique entailed cutting down forest stands for the purpose of cultivating crops in fertile soil<sup>32</sup>.

The presence of a RUF base signals sustained military activity and violence against civilians in a chiefdom. Though soldiers also engaged in longer-range battles and attacks, they returned to their bases and rely on terrorizing local populations both to staff and feed their armies<sup>44</sup>. The positive relationship we observe in Table 2 between the presence of RUF bases and forest growth is thus consistent with the class of political economy theoretical hypotheses that predict that the existence of armed conflict, and its attendant disruption of local economic activity, may in some cases help to slow deforestation. It is also consistent with the finding that rebel groups in certain parts of Liberia predated on civilians, triggering large drops in food production<sup>45</sup>.

One plausible reason why this might be the case is that the militias recruited soldiers and porters from the population surrounding their bases, who either responded voluntarily to the allure of sharing in the spoils of war or were forcibly abducted. The loss of local farming population slows the conversion of forest to agricultural land and also encourages reforestation of existing land. Recent research supports this hypothesis <sup>23,46</sup>. Upon interviewing a group of over 1,000 randomly selected ex-combatants from Sierra Leone, Humphreys and Weinstein learned that the majority of recruits for both the RUF recruits and the main pro-government militia, the Civil Defense Force, originated from rural areas. Moreover, they determined that fighters' top pre-war occupations were farming and schooling, and that the RUF often targeted rural schools for recruitment (e.g., the children of farmers who also sometimes did farm work themselves).

Another possible theoretical mechanism that is consistent with our results is that RUF forces terrorized some farmers into economic inactivity. As part of a strategy of maintaining control of both resources and people in the areas around their bases, RUF soldiers were notorious for their pernicious tactics, particularly physical mutilation <sup>47</sup>. With machetes and axes, they routinely intimidated the civilians they encountered by severing their genitals, limbs, lips, and ears <sup>48</sup> in an attempt to brutalize them into submission. These activities, coupled with local recruitment of fighters, diminished agricultural activity in the chiefdoms containing RUF bases, with attendant increases in the degree of local forest cover. Thus under no circumstances should the slower deforestation in RUF controlled areas be interpreted as the result of enlightened policy decisions on the part of the rebel group. Note that the maintenance of forest in areas with more RUF bases is unlikely to be due to a desire for greater cover against enemy bombing given the limited use of air power in the Sierra Leone civil war <sup>49</sup>.

Our results on the impact of battles and attacks point in a similar direction. Whilst the presence of a RUF base tends to signal sustained violence against civilians, battles and attacks in the Sierra Leone civil war tended to be sporadic and of short duration. This helps explain why our chiefdom battle and attacks measure is less strongly associated with forest change than the chiefdom RUF base presence measure. However, when battles and attacks become prevalent within a broader geographical area, like the district, then there is suggestive evidence that the rate of deforestation falls. This pattern indicates that widespread armed conflict disrupts agricultural activity by

disabling key forms of transportation and marketing infrastructure, much of which only exists at the district level. This disruption in turn blunts incentives for farmers to invest in expanding or even maintaining farmland, thus conferring some protection to adjacent forests.

The complex set of factors that drive land cover change make it challenging to isolate the effect of war alone, especially if trends in both agricultural production and armed conflict were sensitive to local climatic and environmental conditions. In this sense, our comparison of Sierra Leone chiefdoms with nearby Guinea prefectures arguably provides a useful test because it removes a significant part of unobservable agro-climatic variation that may affect forest cover regardless of conflict incidence (Table 3). The fact that we find that conflict afflicted chiefdoms in Sierra Leone suffer much less forest loss relative to prefectures across the border in Guinea therefore gives us greater confidence that our RUF base and district battles and attacks results are in fact capturing the causal impact of war on forests. Note that 60 percent of all RUF bases are located in the subsample of Sierra Leone chiefdoms near the Guinea border (Figure 1, Panel B; Figure 3).

Due in part to favorable climate and soil factors, Sierra Leone is a highly forested country, with almost 60 percent of the country under forest after the war, of which roughly two thirds is secondary forest and one third is primary forest. A notable finding in our analysis is that the impact of war is only observed in secondary forest cover. Primary forest is virtually untouched both nationwide and in chiefdoms experiencing more war violence. In fact, during our study period of 1990 to 2000, primary forest conversion was effectively zero in 141 of 151 chiefdoms, and the remaining 10 chiefdoms lost at most 3.0 km<sup>2</sup> of primary forest. The leading explanation is that secondary forest is typically located closer to human habitation and agricultural land, and thus is more directly impacted by local economic and political events. The resilience of primary forest stands in Sierra Leonean chiefdoms also points to the difficulty of pursuing large-scale timber extraction in a country experiencing a major civil war. Roads throughout the country, and especially in the fairly remote areas with primary forest, fell into bad repair and were often too dangerous to travel due to the threat of rebel violence, making it difficult to get machinery in and timber out. Though secondary forests offer considerable amenities – in the form of carbon sequestration, biodiversity preservation, erosion prevention, fuel and food – they are far less

dependent on networked infrastructure for their extraction. This in turn means they are much more affected by the intensity of local armed conflict, as our analysis finds.

## **Conclusion**

Many observers have argued that war will have a devastating impact on the environment and conservation outcomes, as it undoubtedly has on the populations affected by conflict. Our study, which makes innovative use of within-country conflict and remote sensing data, demonstrates that reality may be more nuanced. Indeed, we find that having more intense conflict in a particular part of Sierra Leone actually helped to prevent the local degradation of secondary forests. These findings underscore the usefulness of using spatially explicit micro-data to study how war impacts the environment, and form part of ongoing efforts to make progress in this important area <sup>50</sup>.

To be absolutely clear, it goes without saying that these findings do not imply that civil conflict should be seen as socially desirable in any sense. While precise data on the channels underlying these patterns is unavailable for Sierra Leone (as in many war-torn societies), a plausible explanation is that widespread disruption of economic activity, due in part to forced recruitment into armed groups and physical displacement of a terrorized rural population, contributed to sharply reduced agricultural production in areas directly affected by war violence, with subsequent regrowth of secondary forest in some places.

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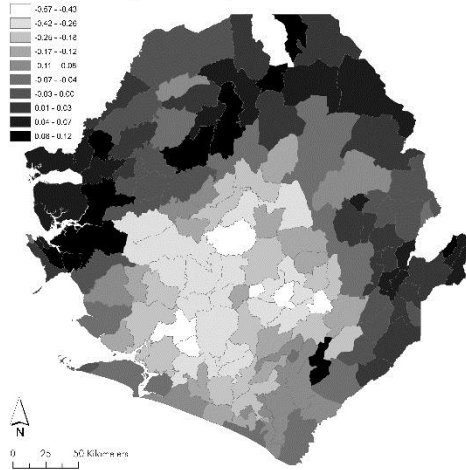
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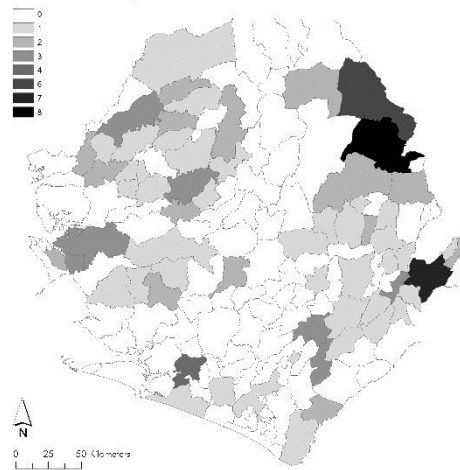
Panel (A)

Percentage Point Change in Total Forest per Chiefdom c. 1990 - 2000



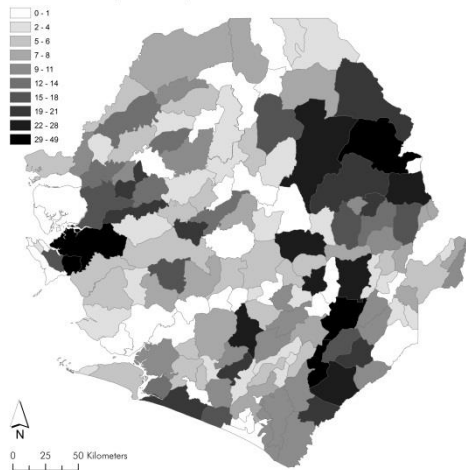
Panel (B)

Number of RUF bases per chiefdom

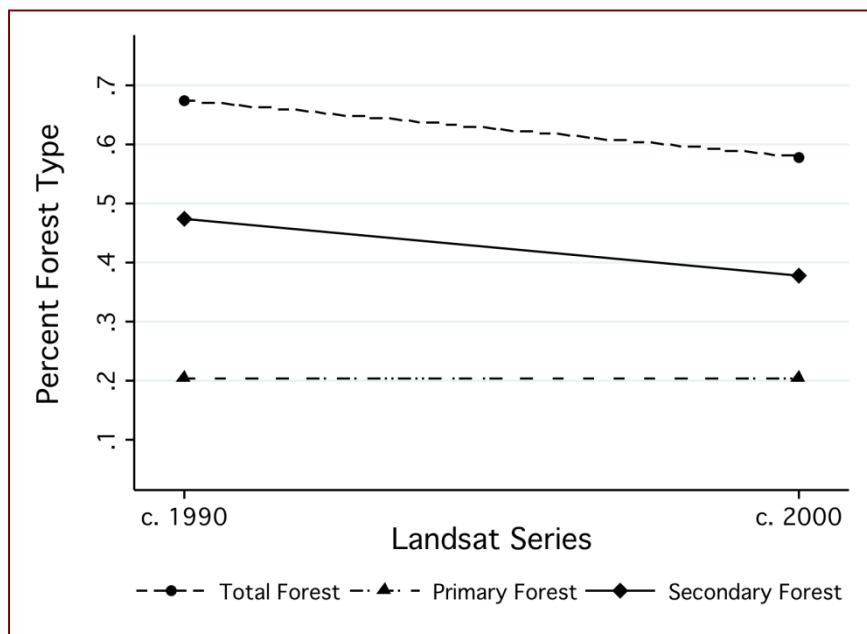


Panel (C)

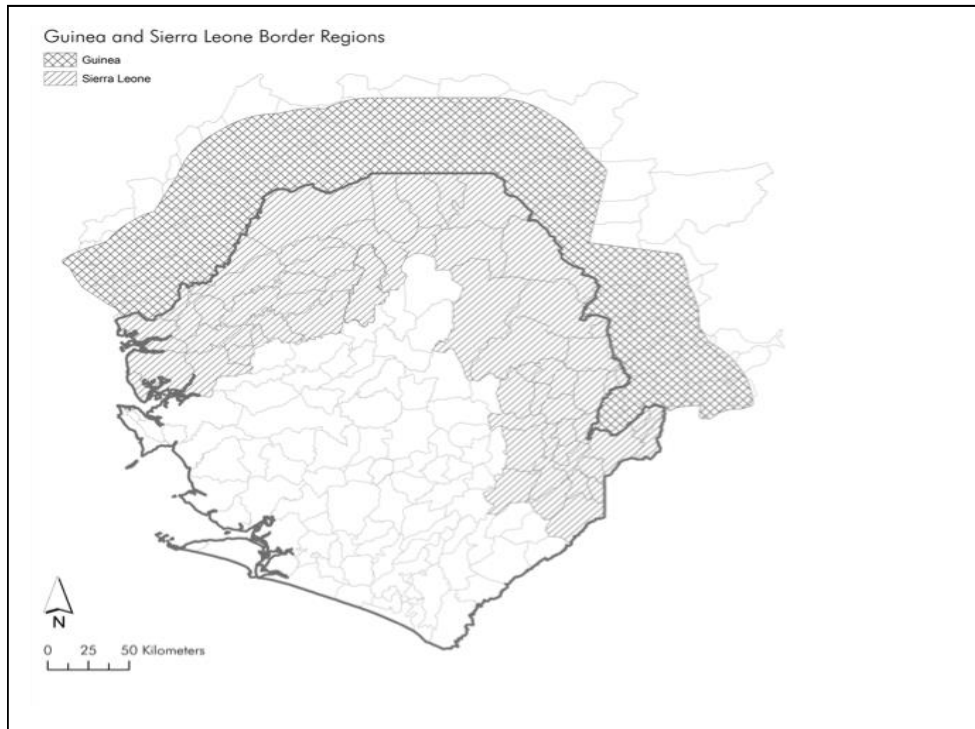
Battles and Attacks per Chiefdom, 1991 - 2002



**Figure 1.** Geographic variation in total forest cover change, in percentage points / 100 (Panel A), location of RUF bases (Panel B), and intensity of battles of attacks (Panel C) by chiefdom.



**Figure 2.** Comparison of pre and post-war forest classes in Sierra Leone, derived from Landsat Thematic Mapper (28.5m) and Landsat Enhanced Thematic Mapper Plus (28.5m) images for the period c. 1990 – 2000. Three classes of forest are represented: primary, secondary, and total forest.



**Figure 3.** Comparison regions in Sierra Leone and Guinea constructed for model 3. Each region encompasses the administrative units located within 50 kilometers of their mutual border. Sierra Leone’s border region includes 62 chiefdoms; Guinea’s border region includes part or all of 54 sub-prefectures.

FOREST COVER DATA	<i>Landsat c. 1990</i>		<i>Landsat c. 2000</i>		<i>Change</i>	
	Mean	(SD)	Mean	(SD)	Mean	(SD)
<i>Sierra Leone</i> (N=151 chiefdoms)						
Total cover forest per chiefdom	0.674	(0.266)	0.579	(0.240)	-0.096	(0.143)
Primary forest cover per chiefdom	0.203	(0.170)	0.203	(0.170)	0.000	(0.005)
Secondary forest cover per chiefdom	0.472	(0.202)	0.376	(0.154)	-0.096	(0.143)
<i>Sierra Leone border region</i> (N=62 chiefdoms)						
Total forest cover per chiefdom	0.535	(0.274)	0.548	(0.272)	0.013	(0.050)
Primary forest cover per chiefdom	0.193	(0.188)	0.193	(0.187)	0.000	(0.000)
Secondary forest cover per chiefdom	0.342	(0.141)	0.355	(0.143)	0.013	(0.050)
<i>Guinea border region</i> (N=54 sub-prefectures)						
Total forest cover per sub prefecture	0.434	(0.195)	0.390	(0.185)	-0.044	(0.049)
Primary forest cover per sub prefecture	0.042	(0.092)	0.042	(0.092)	0.000	(0.000)
Secondary forest cover per sub prefecture	0.392	(0.176)	0.347	(0.166)	-0.044	(0.049)
SIERRA LEONE CONFLICT DATA (1991-2002)						
	Mean	(SD)	Total			
RUF bases per chiefdom	0.75	(1.27)	Number of RUF bases			113
Battles and attacks per chiefdom	9.06	(9.67)	Number of battles and attacks			1,368
Battles and attacks per district	97.71	(63.71)	Number of chiefdoms; districts			151;14

**Table 1. Descriptive statistics for forest cover and conflict measures**

*Forest-cover estimates for Sierra Leone are the percent forest type of total land area per chiefdom. Estimates for Guinea are the percent forest type of the partial or total land area per sub-prefecture located within 50 kilometers of the Sierra Leone border. Changes are the percentage point differences between c. 1990 and c. 2000. Conflict measures present sub-national and national statistics gathered for 1991-2002. RUF indicates the rebel group the Revolutionary United Front. Battles and attacks are events in which two armed groups clash or an armed group attacks a village.*

Variable	Model 1		Model 2	
	(1)	(2)	(3)	(4)
<b>Panel A: Total Forest Cover</b>				
Indicator of RUF base in chiefdom	0.0871** (0.0383)	0.0598** (0.0272)	0.0937* (0.0441)	0.0636** (0.0253)
Indicator for chiefdom battles and attacks >0	-0.0363 (0.0503)	0.0151 (0.0391)		
Log (Chiefdom battles and attacks)			-0.0100 (0.0109)	-0.0002 (0.0113)
Log (District battles and attacks)			0.0883 (0.0596)	0.0522 (0.0341)
R-squared	0.085	0.550	0.162	0.564
<b>Panel B: Primary Forest Cover</b>				
Indicator of RUF base in chiefdom	-0.00010 (0.00013)	-0.00011 (0.00014)	-0.000035 (0.000091)	-0.000064 (0.000114)
Indicator for chiefdom battles and attacks >0	-0.000071 (0.000044)	-0.000033 (0.000088)		
Log (Chiefdom battles and attacks)			-0.000103 (0.000064)	-0.000090 (0.000065)
Log (District battles and attacks)			0.000047 (0.000152)	0.000047 (0.000127)
R-squared	0.009	0.083	0.026	0.099
<b>Panel C: Secondary Forest Cover</b>				
Indicator of RUF base in chiefdom	0.0872** (0.0382)	0.0599** (0.0272)	0.0938* (0.0441)	0.0637** (0.0253)
Indicator for chiefdom battles and attacks >0	-0.0363 (0.0504)	0.0150 (0.0391)		
Log (Chiefdom battles and attacks)			-0.00993 (0.0109)	-0.00012 (0.0113)
Log (District battles and attacks)			0.0883 (0.0595)	0.0521 (0.0340)
R-squared	0.085	0.550	0.163	0.564
Additional covariates	No	Yes	No	Yes
Number of chiefdom observations	151	146	138	137
Number of district observations	14	14	14	14

**Table 2. Effect of battles and attacks on percentage point change in forest classes**

*Models with total, primary, and secondary forest as dependent variables, in panels A, B and C, respectively. Standard errors in parentheses. The 13 chiefdoms that did not experience any battles and attacks are dropped from Model 2 since the logarithm is undefined in that case. Columns 2 and 4 include controls for primary forest cover in 1990, secondary forest cover in 1990, change in yearly maximum NDVI from 1982 to 1990, the number of registered diamond mines, the number of other non-diamond mines, density of the road network, density of rivers, chiefdom population and population density in 1985, and log distance to Freetown. Asterisks denote statistical significance levels: \*\*\*  $P < 0.01$ , \*\*  $P < 0.05$ , \*  $P < 0.1$ .*

Variable	Model 3	
	Coefficient	SE
<u>Panel A: Total Forest Cover</u>		
Sierra Leone border region	0.0571***	(0.00921)
R-squared	0.252	
<u>Panel B: Primary Forest Cover</u>		
Sierra Leone border region	-0.000137	(.0000917)
R-squared	0.019	
<u>Panel C: Secondary Forest Cover</u>		
Sierra Leone border region	0.0572***	(0.00918)
R-squared	0.254	
Number of Sierra Leone observations	62	
Number of Guinea observations	54	
Total number of observations	116	

**Table 3. Sierra Leone effect on percentage point change in forest classes**

*Comparison of percentage point changes in forest types (before versus after the war) between Sierra Leone chiefdoms and Guinea sub-prefectures. Asterisks denote statistical significance levels: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.1$ .*



## **SUPPLEMENTAL APPENDIX**

This supplemental online appendix has two components: Section A contains further discussion of the dataset, and Section B contains the complete regression results from Table 2.

### **Appendix A: Data description**

This section contains information on the source of data used as additional covariates (control variables) in the regressions in Table 2, and the measures of Sierra Leone civil war violence.

The primary forest and secondary forest in 1990 measures, as well as the Normalized Difference Vegetation Index (NDVI) measures, are from the same Landsat satellite data that is described in detail in the main text. The chiefdom population measure is from the 1985 Sierra Leone National Census. The number of registered diamond mines, number of registered non-diamond mines, road density, river density, and distance to Freetown (the capital) are from a Geographic Information Systems (GIS) dataset published by the Government of Sierra Leone in 2003, with technical assistance from the United Nations Development Programme (UNDP). The data was produced and distributed by Sierra Leone Information Systems and the Development Assistance Coordination Office (SLIS/DACO) in Freetown. GIS coordinates of all government registered industrial mining sites were combined with firm descriptions from site licenses to determine to location of all registered diamond mining sites. Non-diamond industrial mining plots, including rutile, bauxite, silver, gold, and ‘assorted minerals’, are also observed. The same SLIS/DACO GIS data was also used to construct measures of road density, river density, distance of the chiefdom to Freetown, and the land area of each chiefdom. The land area measure, together with the chiefdom population measure, allow us to create a population density measure.

The civil war violence data comes from the No Peace Without Justice (NPWJ) Report, 2004. A measure of conflict intensity that focuses on troops and soldiers is provided by the number of attacks and battles in each chiefdom. This measure was coded from the NPWJ conflict mapping report. NPWJ is a non-profit organization that works to promote an effective international criminal justice system and to support accountability mechanisms for war crimes. The conflict mapping report seeks to record all violations of humanitarian law that occurred over the entire conflict

period. The ‘factual analysis’ section of the report is organized chronologically by district, and it reports the chiefdom where each incident occurred, allowing for the construction of chiefdom level war violence measures. The report is available online at: <http://www.npwj.org>. One measure used in our analysis is the number of attacks and battles that occurred within each chiefdom. An *attack* is defined to be an incident in which an armed group came into a village briefly, burned houses, raped or killed residents. It is common for attacks to be part of a larger military campaign and thus for human rights violations to be committed on a large scale (e.g. “during these attacks RUF forces burnt down fifty houses, killed nine people, abducted an unknown number of people and amputated a man’s hand with an axe” p. 189). A *battle* is defined to be a confrontation between two armed groups (e.g. “On 25 February, the RUF made a successful counter-attack at the rutile mining site, dislodging the SLA forces based there.” p. 430). Battles need not directly involve violence against civilians, although they sometimes do. There were 1,995 violent incidents recoded in the NPWJ report, and 1,363 of these incidents were classified as either an attack or a battle. The report also contains information which chiefdoms contained RUF bases, another key measure used in the analysis.

## Appendix B: Complete regression results from Table 2

	Model 1 (2)	Model 2 (4)
Indicator of RUF base in chiefdom	0.0598** (0.0272)	0.0636** (0.0253)
Indicator for chiefdom battles and attacks>0	0.0151 (0.0391)	
Log(Chiefdom battles and attacks)		-0.000208 (0.0113)
Log(District battles and attacks)		0.0522 (0.0341)
Primary forest in 1990 (percentage of total area)	0.0363 (0.0831)	0.0376 (0.0867)
Secondary forest in 1990 (percentage of total area)	-0.448*** (0.0827)	-0.438*** (0.0702)
Change in yearly-maximum NDVI from 1982 to 1990	-0.361* (0.201)	-0.229 (0.188)
Total Registered Diamond Mines (GIS)	0.00291 (0.00196)	0.00226 (0.00187)
Total Registered Non-Diamond Mines (GIS)	-0.00706 (0.00421)	-0.00564 (0.00414)
Road Density (GIS)	0.166 (0.185)	0.122 (0.229)
River Density (GIS)	-0.101 (0.115)	-0.0714 (0.120)
Chiefdom population in 1985 (1985 Census)	-0.0000011 (-0.00000087)	0.0000011 (0.00000074)
Population Density in 1985 (1985 census)	0.000132 (0.000244)	0.000097 (0.000232)
Log Distance to Freetown (GIS)	-0.0332 (0.0275)	-0.0229 (0.0279)
Constant	0.479 (0.339)	0.257 (0.313)
R-squared	0.550	0.564
Number of chiefdom observations	146	137
Number of district observations	14	14

### Table A1. Effect of battles and attacks on percentage point change in total forest

Complete results from Table 2, Panel A: Total Forest Cover (dependent variable). Asterisks denote statistical significance levels: \*\*\*  $P < 0.01$ , \*\*  $P < 0.05$ , \*  $P < 0.1$ . See Table 2 for complete notes.

	Model 1 (2)	Model 2 (4)
Indicator of RUF base in chiefdom	-0.000110 (0.000141)	-0.000064 (0.000114)
Indicator for chiefdom battles and attacks>0	0.000033 (0.000088)	
Log(Chiefdom battles and attacks)		-0.00009 (0.000065)
Log(District battles and attacks)		0.000047 (0.000127)
Primary forest in 1990 (percentage of total area)	-0.000486 (0.000312)	-0.000550* (0.000303)
Secondary forest in 1990 (percentage of total area)	-0.000367 (0.000285)	-0.000409 (0.000289)
Change in yearly-maximum NDVI from 1982 to 1990	-0.000237 (0.000375)	-0.000203 (0.000327)
Total Registered Diamond Mines (GIS)	0.0000089 (0.0000096)	0.000012 (0.000011)
Total Registered Non-Diamond Mines (GIS)	-0.0000022 (0.0000088)	-0.000004 (0.000009)
Road Density (GIS)	-0.000155 (0.000561)	0.000015 (0.000598)
River Density (GIS)	0.000327 (0.000755)	0.000272 (0.000901)
Chiefdom population in 1985 (1985 Census)	-0.0000001 (0.0000001)	-0.0000001 (0.0000001)
Population Density in 1985 (1985 census)	0.0000011* (0.00000051)	0.00000091 (0.00000056)
Log Distance to Freetown (GIS)	-0.0000714 (0.000089)	-0.000059 (0.000078)
Constant	0.00113 (0.00117)	0.000963 (0.00105)
R-squared	0.083	0.099
Number of chiefdom observations	146	137
Number of district observations	14	14

**Table A2. Effect of battles and attacks on percentage point change in primary forest**  
*Complete results from Table 2, Panel B: Primary Forest Cover (dependent variable). Asterisks denote statistical significance levels: \*\*\*  $P < 0.01$ , \*\*  $P < 0.05$ , \*  $P < 0.1$ . See Table 2 for complete notes.*

	Model 1 (2)	Model 2 (4)
Indicator of RUF base in chiefdom	0.0599** (0.0272)	0.0637** (0.0253)
Indicator for chiefdom battles and attacks>0	0.0150 (0.0391)	
Log(Chiefdom battles and attacks)		-0.000118 (0.0113)
Log(District battles and attacks)		0.0521 (0.0340)
Primary forest in 1990 (percentage of total area)	0.0367 (0.0831)	0.0381 (0.0866)
Secondary forest in 1990 (percentage of total area)	-0.448*** (0.0826)	-0.438*** (0.0701)
Change in yearly-maximum NDVI from 1982 to 1990	-0.360* (0.201)	-0.229 (0.188)
Total Registered Diamond Mines (GIS)	0.00290 (0.00196)	0.00225 (0.00187)
Total Registered Non-Diamond Mines (GIS)	-0.00706 (0.00422)	-0.00563 (0.00414)
Road Density (GIS)	0.166 (0.185)	0.122 (0.229)
River Density (GIS)	-0.101 (0.115)	-0.0717 (0.120)
Chiefdom population in 1985 (1985 Census)	-0.0000011 (0.00000087)	-0.0000011 (0.00000074)
Population Density in 1985 (1985 census)	0.000131 (0.000244)	0.0001 (0.000231)
Log Distance to Freetown (GIS)	-0.0331 (0.0275)	-0.0228 (0.0279)
Constant	0.478 (0.339)	0.257 (0.313)
R-squared	0.550	0.564
Number of chiefdom observations	146	137
Number of district observations	14	14

**Table A3. Effect of battles and attacks on percentage point change in secondary forest**  
*Complete results from Table 2, Panel C: Secondary Forest Cover (dependent variable). Asterisks denote statistical significance levels: \*\*\*  $P < 0.01$ , \*\*  $P < 0.05$ , \*  $P < 0.1$ . See Table 2 for complete notes.*