War is a Land Use

Panel contribution to the Population-Environment Research Network Cyberseminar,
"People and Pixels Revisited"
(20-27 February 2018)
https://populationenvironmentresearch.org/cyberseminars/10516

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Since the publication of *People and Pixels* in 1998, 33 civil wars started across four continents, collectively killing and displacing millions of people, crippling national economies, and, in some cases, transforming landscapes due to resource exploitation, cropland abandonment, and urban destruction. Civil wars are the most prevalent type of war (Fearon & Laitin, 2003), as one in five countries have experienced more than ten years of civil war since 1960 (Blattman & Miguel, 2010). At the time of *People and Pixels*' publication, there were 17 ongoing civil wars yet neither 'war' nor 'conflict' of the violent social kind are mentioned within its pages. The lack of inclusion can hardly be a surprise given the still niche position of large-scale violent conflict study in social science research, let alone remote sensing or broader geospatial science. The general interest in remote sensing for social science research raised by *People and Pixels* came even before the opening of the USGS Landsat archive in 2008, which led to an increase in Landsat image downloads by three orders of magnitude in the decade since. Having access to such high quality, free, repeat moderate resolution satellite imagery has been foundational for the continued development of techniques for intra-annual agricultural monitoring and forest disturbance detection and characterize phenology and vegetation-climate linkages using moderate resolution imagery like Landsat.

Now, twenty years after a key inspiration in *People and Pixels* and a decade after opening of the Landsat archive that have together catalyzed the application of remote sensing data for social science issues, we have interdisciplinary awareness; access to imagery with utmost radiometric, spectral, and temporal resolution; and ever more sensitive spectral metrics and informed algorithms, but remote sensing-driven research on civil war effects remains a rarity. Here, I identify the need for greater inclusion of the satellite's view for understanding civil war processes; I outline a conceptual approach--*war is a land use*--in support of satellite image time series analysis for characterizing civil war effects on the landscape; and briefly discuss future directions to overcome persistent interdisciplinary challenges.

Let's first discuss the social side of the matter. A civil war is a large-scale armed conflict between the government and at least one internal non-state group that results in at least one thousand deaths within state boundaries (Fearon, 2004; adapted from Sambanis, 2004). Much existing literature on civil war focuses on macro and structural triggers of civil war onset (Dixon, 2009; Collier & Hoeffler, 2004) or civil war duration (de Rouen & Sobek, 2004), research that tends to focus on decision-making processes and actions of belligerents that result in the continuation or eventual termination of a civil war. In contrast, there is little systematic research on the means of survival and sustenance of the potentially millions of non-combatant civilians whose lives may have been upended by the war.

The consequences of large-scale violent conflicts are notoriously difficult to map. Traditional field-based reporting is often highly localized, meaning that conflict events in geographically isolated communities are overlooked. Indeed, in Syria over the course of the Civil War that has become an internationalized Conflict, the state and other belligerent groups restrict freedom of the press and physical access to key regions, restrictions that vary with shifting territorial control. The absence of detailed information on how individuals, households, and communities experience violent conflict means that researchers often rely on proxies of conflict (e.g., whether dwellings have been destroyed, the number of deaths in a household, and whether a household has ever been displaced). Remote sensing-based approaches, on the other hand, open up otherwise enclosed spaces and can gauge landscape-level proxies of conflict such as intra-settlement damage, agricultural abandonment due to population displacement, and establishment of informal settlements.

However, remote sensing approaches are challenged by civil war processes and landscape relationships that are non-linear and spatially non-stationary as different regions of a country experience the conflict differently. The effects of civil war on a region's cities, farms, and forests are also often multi-directional, stabilizing some processes such as forest cover change in a *war as conservation* scenario, and inducing agricultural abandonment in a *development in reverse* scenario. As such, there is no generalizable relationship between war and landscape processes. Potential land cover change trajectories during a war depend upon the initial local-level conditions at the onset of the war, and the spatially differentiated pattern of landscape changes during war reflects the aggregate influence territorial control, human mobility, and the means of supporting livelihoods and basic human sustenance and survival. Examination of the various place-based relationships linking wartime livelihoods, human mobility, and the mechanics of the war itself is perhaps the most pressing direction for civil war research (Blattman & Miguel, 2010), and one that remote sensing is best positioned to address.

It's common to highlight the spatial detail of satellite imagery since such resolution captures buildings, infrastructure, and even tents at informal settlements at fine detail, yet the long-term, systematic collection of satellite imagery is necessary for both an historical and up-to-date view on landscape change during a civil war. Though bi-temporal change detection at the onset and conclusion of war with satellite image is both anecdotal and cumulative, repeat monitoring with satellite image time series data can build a conflict chronology of immediate and cascading effects across broad spatial extents. Indeed, on-demand satellite imagery analyses in response to identified, large-scale conflict events provide a critical role in documenting conflict effects on human settlements and transportation infrastructure for humanitarian monitoring and aid delivery, but the broader spatio-temporal conflict patterns and attendant landscape processes remain out of view. Moreover, the duration of civil wars requires a long-term perspective as the war, itself, progresses. With consistent repeat imaging, we can readily characterize changes in urban condition that may result from construction, deterioration, or damage at regular intervals, and document spatially variable trends in agricultural production that may function with population displacement and territorial control.

The recent launches of moderate resolution satellite remote sensing platforms are well positioned to meet the the spatial and temporal requirements of long-term landscape monitoring. The

combination of 10-30 meter resolution imagery collected by Sentinel-2a/2b (launched in 2015 and 2017, respectively) with 30 meter Landsat 8 imagery (launched in 2013) provides 2-4 day repeat coverage over a given location, and the harmonization between these sensors supports fundamentally similar measurements, radiometric and spatial resolutions, characterization of landscape condition, as well as trend, state, and cyclical changes therein. (Future missions like Landsats 9 and 10 (expected launches in 2020 and 2030, respectively) will further the legacy of cross-sensor continuity.) The systematic, long-term perspective afforded by remote sensing time series data supports examination between seasons, years, and war periods spanning pre-, during, and post-war periods. Using longer time series yields more and spatially varied information to establish a reliable baseline of pre-war conditions; detect subtle changes in land cover condition or land use intensity during the war; identify systematic or cyclical changes that reflect the intent of land managers; capture disturbances associated with the absence of land use decision-makers or direct conflict effects (such as destruction or acute degradation). In sum, the development of various spatially explicit facets of wartime conditions and change provides insight into conflict processes of violence, displacement, and destruction, and is foundational for identifying place-based needs for post-conflict peacebuilding and reconstruction efforts

In order to improve the relevance and effectiveness of remote sensing-based study of civil war effects on the landscape, we can conceptualize civil war as a land use with attendant relationships to livelihoods, socioeconomic conditions, and ecological processes. With a land use framing, researchers may leverage available social information on human mobility and socio-economic conditions during the war with satellite image-derived metrics of land cover condition and change related to land use activities. For example, populations internally displaced during a civil war may strategically relocate to regions with less localized conflict, greater stability in control, and higher food security (Le Billon, 2001). Years of such movements may thus reshape the spatial distribution of land-based economic activities, with clear opportunity for detection by remote sensing time series analysis. Such activities fall within a war economy taxonomy put forth by Goodhand (2004) that includes “combat”, “shadow”, and “coping” economies. The combat economy directly supports continued conflict through economic interactions that achieve military objectives, including territorial capture and control over natural resource exploitation (e.g., running oil fields), while the shadow economy involves smuggling of commodities (e.g., coca, opium) and extraction of localized high-value resources (e.g., diamonds) (Collier & Hoeffler, 2002; Fearon & Laitin, 2003; Hegre, 2004; Ross, 2004). Central to the coping economy are labor migration and remittances earned through livelihoods that are commonly based on geographically diffuse, subsistence resource use (e.g., smallholder agriculture) (Auty, 2001). Compared to combat and shadow economies, there has been much less attention given to the role of the coping economy within civil wars (Ballentine & Nitzschke, 2005), yet is well suited for investigation by remote sensing. Thus, a conceptualizing civil war as a land use driven by wartime economies not only capitalizes on the full suite of remote sensing analytical capabilities, it will also put remote sensing scientists in deeper communication with civil war researchers and practitioners to collaboratively assess socio-environmental effects of civil wars in coming decades.

As we move towards ever greater abundance and more frequent acquisition of satellite imagery, assessing war as a land use will bring us closer to understanding fundamental connections between people and pixels in war torn regions, the geographic *pattern* of conflict rather than the

locations of violent events, the conflict chronology driven by place-based *processes* rather than discretized events, and the *meaning* of landscape changes rather than their respective magnitudes. The work required to better couple remote sensing and civil war studies echoes the values of remote sensing data for social science outlined by Rindfuss et al. in 1997--context, complementarity, and gauging social effects from a multi-scalar perspective. While not yet fully realized, the most productive advances will not come through improved atmospheric correction techniques or more robust machine learning approaches but rather by critically and collaboratively working across the already porous boundaries between remote sensing and social sciences. This would mean remote sensing scientists developing competency in existing social science frameworks that attempt to schematize the complexity of violent conflict (e.g., Lederach, 2003); social scientists developing an understanding of the inherent temporal and spatial variability of landscape change regardless of civil war processes; and all involved establishing analyses that prioritize the welfare of the most vulnerable. Developing such complementary literacies will help ensure that the analytical rigor for both the remote sensing and social science aspects of a given investigation are of comparable depth and breadth.

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