Does the Past Influence the Present or the Future? Deep Time, Land Use, and Remote Sensing in Southern Mexico

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Abstract: This paper reports the initial results of a pilot study investigating the relationships among long-term land use, settlements, historic population, and their potential influence for understanding and evaluating current and future land use. Most of our work to date has been focused on evaluating changing patterns of historic settlement and its relationship to what we know about the historic environment and landscape. Here, we instead rely on remotely-sensed big data as a first step to see how patterns of past land use are correlated with what we know about current land use and land cover. The pilot study initiates a broader research agenda that better incorporates what we know about past landscapes into contemporary land use decisions and to offer critical insights into how the future could be shaped by integrating information about the past. As a first step, the analysis is intentionally broad so that our next steps can provide the fidelity and resolution to offer place based information for design and planning. Nevertheless, it offers a unique window of perception into current land use and a platform for operationalizing evolutionary uses of the past for better managing, designing, and planning complex land systems and moving beyond analogic uses.

Keywords: Landscape, LiDAR, GIS, resilient landscapes, long-term landscape change, ancient landscapes, and geodesign

1 Introduction

In 1973, Billie Lee Turner carried out a transformative research program to document terracing, agricultural intensification, and a chronology of ancient land use in the Southern Maya lowlands in Mexico. Based on research in the Rio Bec region of the southeastern Yucatan peninsula, TURNER (1974) concluded that intensive agriculture in the form of agricultural terraces and raised fields must have been widespread throughout the Maya lowlands, linking ideas about agricultural intensification to BOSERUP's (1965) model of agrarian change. Beyond challenging long-held slash-and-burn (swidden) based models for Ancient Maya agricultural practices, TURNER's (1974) work was influential in two key ways: (1) he tightly linked concepts of intensification with population pressure and ideas about Maya settlement densities, and (2) he chronologically connected these systems to the 'peak' of the Ancient Maya Civilization (250 to 850 CE). Subsequent studies of the Ancient Maya also used this work to consider the collapse of Maya civilization as a consequence of population pressure and the over-exploitation of resources across the region (WEBSTER 2002).

Several decades later, DEARING et al. (2010) asserted the critical value that deep-time perspectives offered for understanding complex land systems and assessing their future. Their transformative work concluded that understanding the interactions between communities and environmental processes within a complexity framework is the critical foundation for antic-

Journal of Digital Landscape Architecture, 8-2023, pp. 75-83. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-740-3, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537740009.

ipating the future of land systems and planning. Two uses of the past to inform land systems are described in their paper, *analog* and *evolutionary*.

Analog perspectives are commonly promoted as narratives for learning about the past. They offer snapshots in time about the past. They do not directly link the past to the present and can be limited in their direct application for assessing current conditions and planning future complex systems. For example, numerous studies of the past have been used to describe processes of collapse due to land stress or challenges of sustained landscape management (MURTHA 2009, TAINTER 2006, WEBSTER 2002). While much of our work has been focused on developing those narratives, here we take a first step towards a different approach.

In contrast, DEARING et al. (2010) suggest that an evolutionary view of the past across long timescales offers an essential perspective for assessing current and future land systems because the present is tightly coupled to the past. Theoretically, this connection allows scientists, designers, and planners to address long timescale processes, like challenges of sustained fertility or large-scale climate patterns (e. g., El Niño) that are repeated regularly. According to their paper, evolutionary views provide a better understanding of the relationships between fast and slow processes. Furthermore, studying past legacies may also provide a more complete understanding of the cultural and environmental elements influencing contemporary land use and settlement system dynamics (DEARING et al. 2010). But there are no clear methods for operationalizing the past for design and planning in this way.

Our paper reports the initial results of a study across southern Mexico as an attempt to investigate a connection or a disconnect between past land use intensity and current landscape change. Relying on remote sensing and geospatial modeling, we first summarize the analysis of 458 samples of environmental LiDAR documenting details about deep past land use, primarily relying on evidence of settlement and agricultural intensification. Using these samples, we calculate a built environment index for small watersheds across our sample geography. We then investigate the three decades of land use and land cover between 1992 and 2012 to quantify whether past land use intensity correlates to recent landscape change and how these changes compare spatially. We aim to use these data not only to compare our inventory of the past to the current complex land systems of southern Mexico, but also to speculate how deep time perspectives can be better integrated into geodesign, studies of land systems architecture, and territorial scale design and planning (TURNER et al. 2013).

2 Data and Methods

The primary historic data used in this study were collected by the NASA Goddard Space Flight Center, led by Dr. Bruce Cook, using NASA Goddard's LiDAR, Hyperspectral & Thermal Imager (G-LiHT) system (COOK et al. 2013, GOLDEN et al. 2016, HERNÁNDEZ-STEFANONI et al. 2015). The mission's primary objective was to refine measurements of above-ground forest carbon stocks in Mexico (see GOLDEN et al. 2016). The data were collected in April 2013 as part of a multi-institutional, bi-national study of above-ground biomass (AGB) and species-richness that covered large swaths of Mexico (HERNÁNDEZ-STEFANONI et al. 2015). The research was designed to inform deforestation programs, including the United Nations REDD+ (Reducing Emissions from Deforestation and forest Degradation, plus conservation, sustainable management of forests, and enhancement of forest carbon stocks), and to aid in the design of effective strategies for selecting natural protected areas (see http://www.un-redd.org/aboutredd). When we processed and analysed bare earth models of these data, we were taken aback not by lost ancient megacities but by the complex distributions of ancient households and associated landscape features.

NASA captured and processed 610 LiDAR samples over southern Mexico, ranging in size from 3 ha to 4100 ha (GOLDEN et al. 2016). Importantly, these flight tiles connect well-sampled areas, such as the Central Maya lowlands, with western regions like the Usumacinta basin that have been more sparsely surveyed (see figure 1 in GOLDEN et al. 2016). They also connect coastal sites to landlocked upland sites reliant on rainfed agriculture throughout history. In prior papers, we documented the important structure and variety of these samples and why they are unique and important to studies of the Ancient Maya (GOLDEN et al. 2016, SCHRODER et al. 2020).

We processed 458 samples and documented five (5) distinct, durable feature types as polygons: 1) structures, 2) platforms, 3) plazas, 4) aguadas or borrow pits, and 5) causeways and five distinct (5) feature types as polylines: 1) architectural terraces, 2) agricultural terraces, 3) walls, 4) canals or ditches, and 5) paths (SCHRODER et al. 2020). For this paper, we included agricultural terraces, walls, platforms, plazas, and structures as a currency for our built environment index. We documented 8,763 terraces, 10,287 walls, 3,659 plazas, 3,244 platforms, and 54,488 structures across the geography of the G-LiHT samples (SCHRODER et al. 2020).

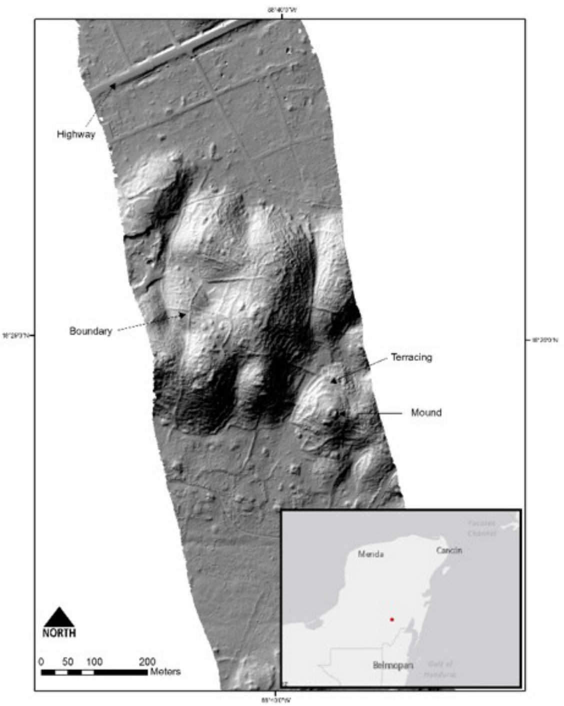

Fig. 1:
Illustration of G-LiHT LiDAR data and features identified through the interpretation of bare earth digital elevation models. Information about ancient household remains, land use, and infrastructure have been systematically annotated for 458 samples.

In terms of ancient settlement and land use, we observed unexpected patterns. Fifty-nine percent of samples analysed and located within 10 km of a recognized 'large' Ancient Maya city exhibited very high or high densities (upper 40%) of ancient structures and platforms. This confirmed much of TURNER's (1974) early interpretations about the relationships between populations and agrarian change. But we also found that 38% of samples more than 10 km from a 'large' Ancient Maya city also exhibited very high or high densities, which implies an inverse relationship between population density and ancient city centers, contrasting observations from most regional LIDAR studies focused on lost cities and monumental architecture (CANUTO et al. 2018).

Furthermore, overall structure densities from our analysis, which are used by archaeologists to reconstruct past population histories are higher than recent LiDAR only surveys in Western Belize and in the Peten, Guatemala, traditionally considered to be the densest area of Maya settlements (CANUTO et al. 2018). These results are especially significant due to the distinct sampling strategies used in each study. All prior studies of LiDAR focus on surveying large political centers, but the NASA G-LiHT samples we inventoried capture a broader regional and territorial settlement and landscape.

Finally, when we compare the distribution of ancient residential architecture to the distribution of ancient agrarian features, like terraces and walls, we noticed important but unexpected patterns. Extending a Boserupian framework, we expected high densities of intensive agricultural features to correlate with high densities of ancient structures, plazas, and platforms. Artifact features and structures are currencies of past population densities, commonly used to reconstruct population histories. Yet, there is not a uniform correlation between past settlement density and agrarian features. For example, many areas with high densities of structures exhibit little or no evidence of agricultural intensification, while we also identified areas with terraces and walls with low densities of residential architecture.

Our work to date has been almost exclusively focused on how these data can be used to understand past distribution of populations and their relationship to regional environmental systems. But another key question has been at the forefront of our research, does the legacy of the past influence the present or the future? Or better, can the legacy of the past inform what we plan and design moving forward?

To start the process of this inquiry, we first summarized the intensity of past land use, focused on the built areas of our samples. For every structure, wall, and terrace, we established continuous polygons representing areas of built features, similar to a layer of modern impervious surface. We compared these areas to the overall sample areas of the LiDAR to calculate a simple *built environment index* (or ratio of built to unbuilt). Simply, the index captures the improved area compared to the unbuilt. We then summarized each sample by intersecting these samples with global L12 small watersheds. We examined the spatial distribution of the built environment across the lowland geography and finally compared it to what we know about modern land cover changes between 1992 and 2012, relying on a macro dataset of Global Land Cover, published by the European Space Agency (ESA 2017).

3 Results

3.1 Distribution of Past Built Environment

The 458 samples we analysed crosscut 385 small watersheds from Chiapas, Mexico north through Campeche, continuing to the coasts and the modern states of Yucatan and Quintana Roo (Fig. 2). Summarized by watershed, some clear patterns of built environment intensity emerge from our analysis. While there are pockets of high density across the samples, there are clear hot spots of ancient settlement and land use, largely focused in the central Yucatan and northwest into the modern state of Campeche.

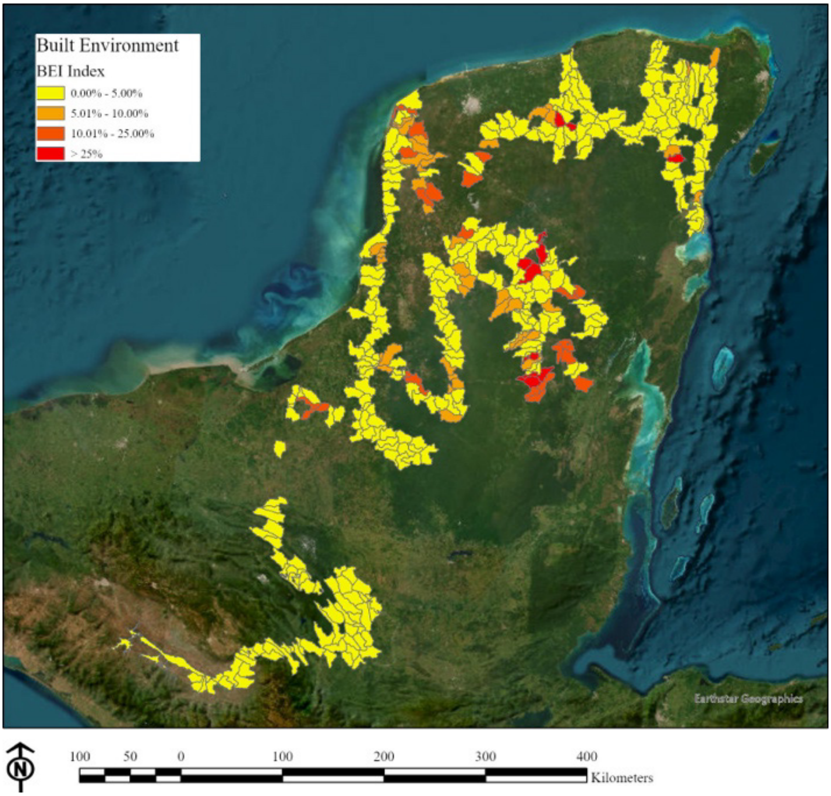

Fig. 2: Map of small watersheds illustrating built environment intensity. <5% impacted is illustrated in yellow, while the most severely impacted watersheds are illustrated in red. The map uses samples of LiDAR to represent overall watershed impact as measured from Ancient Maya settlement and landscape features.

Three hundred and twenty small watersheds were impacted by ancient settlement and land use. The majority of the watersheds exhibit very little development and impact (< 5 %), but seventy-two watersheds exhibit more than 10% developed, while only 5 % of the watersheds are impacted with development covering greater than 25 % of the total sample for each watershed. A handful of watersheds are impacted at levels exceeding 50 %. When compared to what we know about modern watersheds in general, levels of impervious surface with as little as 5 to 10 % can degrade water quality, while greater impairments are expected with levels at 20 to 25% (NOAA 2023). Simply, while there are clustered patterns of expected impairment by ancient settlement and land use, the impacted watersheds are dispersed and almost exclusively located in the central and northwest Yucatan, with almost no coastal impact.

3.2 Comparing Spatial Patterns of the Past with the Present

We then compared the sampled small watersheds to land cover data processed by the European Space Agency (ESA 2017). This global dataset is a critically useful resource to investigate large-scale land use and land cover changes with a standardized global resolution of 300 m per pixel. We used two available land cover datasets from 1992 and 2012. Information about the processing and geospatial data for annual coverages are processed and refined continuously (ESA 2017). We chose the earliest and latest reliable land cover datasets and summarized key land cover categories that best correspond to what we documented as ancient settlement and land use in the G-LiHT LiDAR data. We combined intensive urban land, intensive cropland, and mosaic cropland with less than 50 % tree cover to compare with our built environment ratios calculated for the G-LiHT LiDAR inventories. This includes raster values 10, 11, 12, 20, 30, and 190 for both the 1992 and 2012 datasets. We tabulated the area for each sample period, comparing these areas to the overall area of the watershed (Fig. 3).

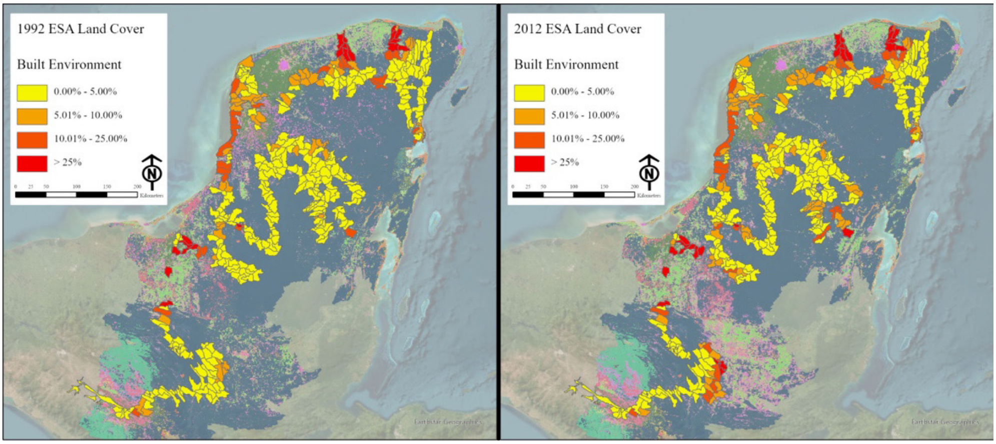

Fig. 3: Map of small watersheds illustrating built environment intensity for 1992 (left) and 2012 (right) land cover from the European Space Agency. <5% impacted is illustrated in yellow, while the most severely impacted watersheds are illustrated in orange and red. The distribution of development is clearly different from past settlement and land use and illustrates some clear recent trends towards coastal development along with intensification of agriculture for cattle in the southern region of Chiapas, Mexico along the Usumacinta.

While not surprising, it is clear that the pace and impact of modern development is substantially more intense, but it is also more widespread across the geography of our study area. Intensive coastal population growth and development are clear along the northwest and northern coasts of the Yucatan in 1992 and 2012.

Additionally, between 1992 and 2012 intensive forest clearings and intensified land use are also evident in southern Chiapas. From long-term field work and research this significant change is not associated with population growth, pressure, and urbanization, but the expansion of cattle production adjacent to the Usumacinta River.

In this paper, we cannot begin to investigate all of the critical shifts in land use and land cover during the recent decades. There are, however, several key observations we can put forward based on this initial and macro analysis. First, while the Ancient Maya utilized coastal resources and there is evidence of coastal settlements, the intensity and density of urban development across southern Mexico in recent decades has been focused almost exclusively on the coastal watersheds adjacent to Campeche, Merida, and Cancun.

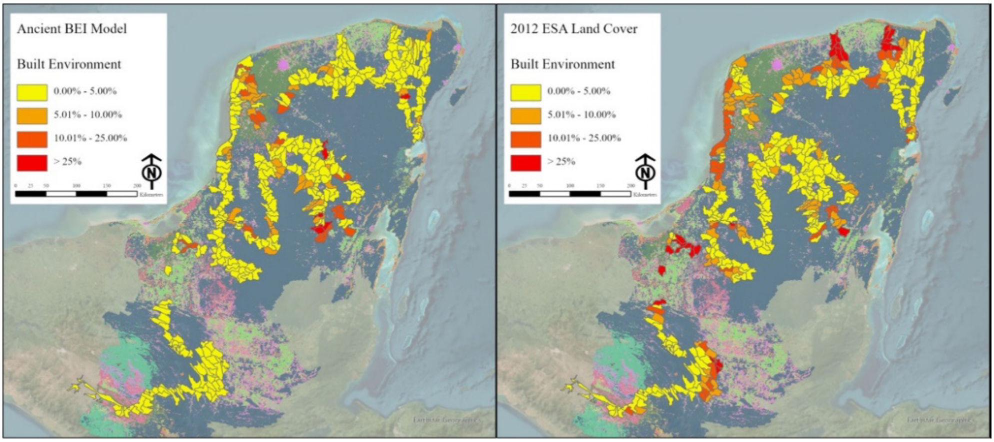

Fig. 4: Map of small watersheds illustrating built environment intensity for ancient Maya settlement and modern land use relying on 2012 land cover from the European Space Agency

Second, it is also clear that there has been increased deforestation and intensification of agricultural fields adjacent to these rapidly urbanizing regions. Therefore, there are direct and macro-regional impacts of development that diverge from what we now know about at least 2,000 years of settlement and land use across the southern lowland landscape.

While the current population across our entire study area is likely larger and generally denser today than it was during the peak of Maya civilization between 250 CE and 750 CE, it is clear from these data that Maya settlements were designed, planned, and constructed in very different regional and territorial spatial patterns than we are witnessing in the modern era. Coastal development is dominating these regional systems and the introduction of cattle farming in Chiapas has transformed what has been historically a stable and resilient socio-ecological system adjacent to the Usumacinta River (SCHRODER et al. 2021).

Today, not only are there more urbanized and impacted watersheds than there were 1500 years ago, but there are also areas deep in southern Mexico where the intensification farming has impacted watersheds disconnected from the population growth and pressure adjacent to the coasts.

4 Discussion and Conclusion

Our analysis of these data is simply a step to leverage information about the deep past to evaluate and assess current land use systems with the hope that these data can provide useful information for design, planning, and specifically geodesign. Uniquely, the data we used to document ancient settlements and land use were captured to measure above ground carbon stocks in order to measure and maintain conservation of the tropical forests in southern Mexico. There are, however, many more critical uses of these data and we took this first step to establish some base line data for further investigation of each small watershed in more detail through a combination of remote sensing and fieldwork.

In 1965, BOSERUP (1965) offered a transformative perspective on population growth and agricultural change. Less than a decade later, TURNER (1974) radically changed our perceptions of the ancient Maya by linking his field observations with Boserup's ideas about intensification. Today, almost 50 years after TURNER's (1974) field work in the Yucatan, we may now have the opportunity to better integrate information about the deep past into assessments of current land use and to inform future decisions about settlements and land use.

While Boserup's assessment and investigation of the relationships among population growth, pressure, and agrarian change were transformative, they did not factor in the critical spatial dimensions of how these changes occur (STONE 1996). As more data products become available across the planet, we need to establish ways to quickly capture information about the deep past and compare it to our modern settlements and land use. In the case of the southern lowlands, we know from extensive work, that Maya settlements and communities thrived across this geography for centuries. These data offer clear regional information about where to expand settlements and intensify agriculture. Our future research aims will now investigate whether there are crucial details within these watersheds to inform future land use planning.

Beginning in the 1970s, environmental scientists established the critical value of capturing and processing raw data about our changing environment from remote sensing. Year by year and decade by decade these data document the impact our choices have on the resilience and sustainability of communities. Today, there are new data sources that can provide information from the deep past allowing us to compare our settlement and land use decisions with the legacy of land use written in the landscape (LEWIS 1979).

In this paper, we take a first step, albeit a very speculative first step to investigate the past not simply to reconstruct the socio-ecological dynamics and the cultural history of one of the world's most critical landscape narratives. That work is ongoing and provides an important analog view of the past. But perhaps there is a way to leverage information about the past to evaluate the present and inform future decisions, offering pathways for scientifically informed geodesign and landscape ecological planning. MCHARG (1969) recognized the coupled natural and human systems critical for sustainable and resilient design. For decades since, we have relied on advancements in remote sensing of the environment and GIS to inform the design and planning of future settlements. New data sources, such as LiDAR now offer a more complete picture about these coupled natural and cultural systems. In this paper, we integrate information about how deep time and cultural systems compare to the decisions we make today with the hope that we can integrate these data into regional and territorial scale design.

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