Chapter 12
Lidar at El Pilar: Understanding Vegetation Above and Discovering the Ground Features Below in the Maya Forest

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Abstract Lidar data from El Pilar shows great potential for understanding the ancient and contemporary Maya forest landscape. Exploring these rich three-dimensional data with ground visualization strategies using Geographic Information Systems (GIS), our field validation strategy integrates the twenty-first-century tools Lidar, Global Positioning Systems (GPS), and GIS with time-tested methods of field observation and assessment of surface features and vegetation. While there is no doubt Lidar is a stimulating addition to the geographical and archaeological tool kit, we recognize it is essential to understand the sources of features our visualizations reveal. Our survey protocol evaluates human impacts on the forest environment by identifying and mapping ancient cultural features, recording basic characteristics of vegetation, and deriving information to extrapolate to the expanding database of Lidar coverage in the Maya Lowlands. Based on emerging results supporting the viability of the milpa-forest garden land-use cycle at the regional and local scales, we hypothesize the Maya created land-use strategies that can be modeled and tested at the site scale at El Pilar.

Keywords Lidar · Maya settlement · Maya forest

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N. Torrescano-Valle et al. (eds.), *The Holocene and Anthropocene Environmental History of Mexico*, https://doi.org/10.1007/978-3-030-31719-5_12

Introduction

The Maya Forest Landscape

Interpretations of preindustrial land use depend on archaeological survey to locate and document settlements. Yet in the case of the Maya area, where the landscape itself was domesticated (Ford and Nigh 2015; Ford in press), land-use studies must also include the forest to capture human impacts on the environment through time. Archaeologists view the tropical forest as a challenge to understanding the ancient Maya, impeding progress toward mapping and identifying ancient settlement remains, when it should be seen as an historical archive of human adaptation and ingenuity. Most major Maya sites have been identified (Fig. 12.1), yet El Pilar, the largest site in the Belize River area, was not recorded until 1983. Today, the El Pilar Archaeological Reserve for Maya Flora and Fauna is defined by contiguous boundaries incorporating 20 km^2 in Belize and Guatemala (Fig. 12.2; http://marc-ucsb.opendata.arcgis.com/). With new Lidar technology expanding our views of the Maya forest (e.g., Canuto et al. 2018; Chase et al. 2011; Ford et al. 2013; Ford 2014; Magnoni et al. 2016; Reese-Taylor et al. 2016), we have the opportunity to see above and below the canopy and perceive the Maya forest, along with archaeological remains, as part of the cultural landscape.

Explorers began to report lost cities hidden beneath the Maya forest canopy in the mid-nineteenth century (Stephens 1969), and these reports gained considerable traction in the Western imagination when Sylvanus[1] Morley led the Carnegie Institute of Washington's expeditions to the Maya Lowlands in the early twentieth century (Adams 1969). This work set the stage for scientific efforts to understand Maya settlement, such as Bullard's Northeastern Petén surveys (Bullard 1960) and Puleston's Tikal surveys (Puleston 1973, 1983), which created standards for subsequent settlement pattern research (e.g., Rice 1976, 1978; Ford 1981, 1986, 1990, 1991; Ford and Fedick 1992; Ford and Horn 2017). An understanding of settlement patterns from these pioneering studies provides insight into ancient Maya land use, but the importance of forest cover has largely been ignored.

Technological developments in the decades since these first studies have enhanced survey tools and allowed an unprecedented expansion of settlement pattern studies in the Maya Lowlands, but the need for field survey under the forest canopy persists. Today, Lidar has brought a new perspective on the Maya forest (Canuto et al. 2018; Chase et al. 2011, 2014, 2017; Ebert et al. 2016; Ford and Horn 2018; Hutson et al. 2016; Prufer et al. 2015; Reese-Taylor et al. 2016; Rosenswig et al. 2013; Yaeger et al. 2016, among others in the region), and coverage has expanded to include more than 3000 km^2 across the Maya heartland of the greater Petén (Fig. 12.3; Ford et al. 2018). We now have substantial geospatial datasets, stretching from the ground surface to the top of the canopy, embedded in Lidar point clouds that await continuing efforts in remote visualization and field validation for reliable extrapolations. Diverse projects are working with this regional coverage,

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[1] Interestingly the Roman god of forests

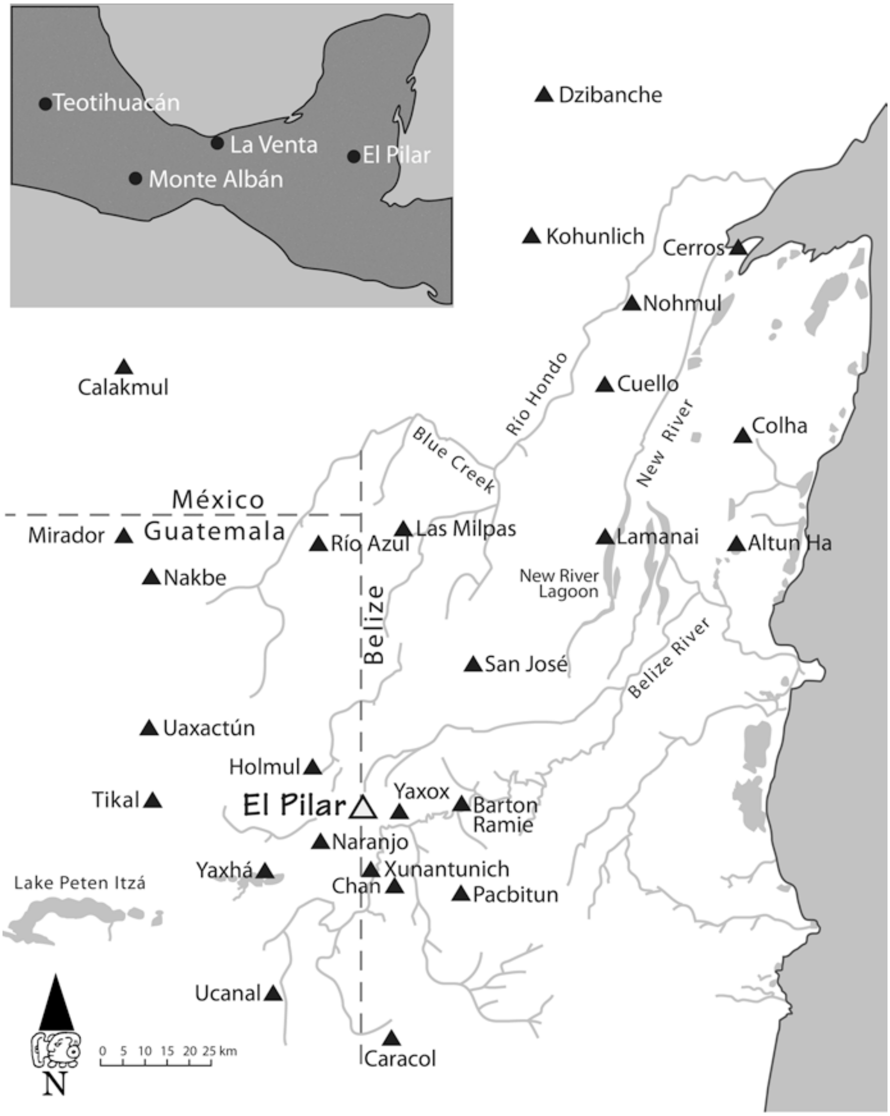

Fig. 12.1 Regional Maya area with El Pilar and major sites noted

and we see real value in this phenomenal resource being shared among all investigators of ancient settlement and land use. Recognition of features in visualizations and assessment of these features on the ground has remarkable potential to expand interpretation to the regional scale (Stular et al. 2012). Increasing data validation efforts (Ford and Horn 2018) point to an intricate landscape that is best understood by including studies of vegetation and investigating impacts, past and present, on the forested areas (Ford 2008; Prufer et al. 2015).

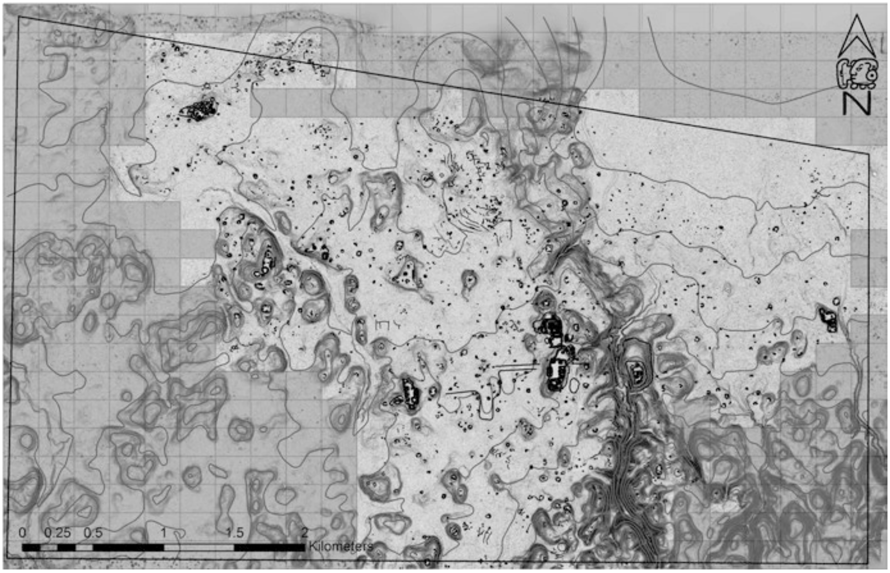

Fig. 12.2 Lidar coverage of the El Pilar Archaeological Reserve for Maya Flora and Fauna

Fig. 12.3 Lidar coverage of the central Maya Lowlands of Guatemala and Belize

In this chapter, we consider Lidar data from El Pilar (Ford et al. 2013, 2015; Ford 2014; Ford and Horn 2018; Horn and Ford in press; Fedick et al. 2016), including the visualization strategy (Pingel et al. 2015) and survey protocol (Horn et al. 2019) we developed based on past field research. Our field validation strategy integrates the twenty-first-century tools Lidar, Global Positioning Systems (GPS), and Geographic Information Systems (GIS), with time-tested methods of field observation and assessment of surface features and vegetation. We find Lidar an exciting addition to the geographical and archaeological tool kit while recognizing the need to understand the source of features observed in visualizations. In the field, we identify and map cultural features and itemize vegetation characteristics that relate to human impacts on the forest environment. We hypothesize that the Maya created viable land-use strategies testable at the regional and local scales (Canuto et al. 2018; Ford and Clarke 2019), and our aim is to test a model of the milpa-forest garden cycle at the site scale at El Pilar. This begins with Lidar data and culminates with field validations.

Lidar Potentials and Pitfalls

The National Oceanic and Atmospheric Administration (NOAA) describes Lidar (Light Detection and Ranging) as a remote sensing method using aircraft fitted with a laser scanner and specialized, survey-grade GPS receivers. The scanners acquire pulsed laser returns that measure ranges or variable distances and pinpoint them in three-dimensional space (NOAA 2019). Originally developed with US government funding for NASA in the 1960s and brought to world attention when Apollo 15 transmitted images of the moon in 1971, this technology has continued to improve over five decades, with first efforts primarily concerned with aerospace development and research applications from the private sector and academy following. Dependent on the quality and capability of the laser scanners, by the 1990s, applied geospatial applications were developing results that promised feature extraction and forest characterizations. Resolution is the next frontier of development, and terrestrial and areal coverages have improved in the last decades (Britannica 2019). Lidar applications now provide dense 3D point clouds reflecting tops of trees, foliage and branches, trunks and roots, and ground surfaces with precision and resolution over large areas, and costs have decreased with more widespread use of the technology (Gaurav 2018).

In the last decade, Lidar has made a splash on the archaeological scene. Broad Lidar coverage in Europe at the beginning of the twenty-first century has been used to great advantage by archaeologists (e.g., Devereux et al. 2005). A little more than a decade later, the technology was applied in the Maya world (Chase et al. 2011), and it has been adopted for research in forested areas across the globe (e.g., Evans et al. 2013; Johnson and Ouimet 2014; Parton et al. 2018). Returning laser pulses that ultimately reach the land surface produce visualizations with astonishing topographic detail when processed with GIS software, as can be seen in the work of

Canuto et al. (2018). These applications demonstrate the importance of Lidar for archaeological prospection, yet more information is encoded in the point cloud than simply the ground surface. Vegetation density, height, and the shape of trees can be detected. Attention to the vegetation can provide clues to ancient as well as modern influences on the forest (Hightower et al. 2014).

Broad swaths of Lidar coverage in Guatemala and Belize (Fig. 12.3) provide a view of the landscape essential to understanding regional settlement and environmental patterns. Analyses of these coverages produce reasonable estimates of 80–120 people/km^2, which extrapolate to population estimates of 7–11 million people across the 95,000 km^2 of the central Maya Lowlands (Canuto et al. 2018). Regional population estimates based on Lidar visualizations are developed remotely without on-the-ground validation or the incorporation of the topographic character and vegetation influence recognized by traditional ground surveys (Bullard 1960; Ford 1986). At this point in the application of Lidar, we are still in the experimental stage, and field validation is essential for landscape interpretations. Detection of small features and vegetation character, environmental impact analyses of settlement, and geographic variables such as slope, soil, drainage, and vegetation must be included in settlement studies to understand land-use and human-environment interactions. Local areas provide insight into variability by combining spatial variables for deciphering environmental influences (cf. Ford et al. 2009), but understanding these influences at the detailed site scale is most challenging.

Our examination of settlement patterns has demonstrated that the Maya, from the regional and local perspectives, managed a landscape with the logic of living in well-drained areas with access to lands amenable to hand cultivation (Ford et al. 2009; Ford and Nigh 2015; Ford and Clarke 2019). The local-scale model for land use with the milpa-forest garden proposes a cyclical procession from forest to field and back again, which creates a diverse landscape over time, consisting of short-term annuals and long-term perennials that meet the daily requirements of the populace. Trees and plants selected for the long term persist as the forest we see today (Campbell et al. 2006; Ross 2011; Ross and Rangel 2011; see Dove 1983). Data on topography, settlement, vegetation, and soil at the site-specific scale are needed to test our model of cyclical field-to-forest cultivation strategies by the ancient Maya, and we are working to accumulate these data on the El Pilar project.

Site-scale Lidar coverage at El Pilar (Fig. 12.2) can contribute to considerations of ancient land use, vegetation cover, and sustainability in the tropics, where contemporary land use is expanding at the expense of the forest. The standard narrative views deforestation as the only outcome of living in the Maya forest (e.g., Turner and Sabloff 2012). This is difficult to contemplate when considering certain facts. For instance, how could the Maya forest be among the most diverse on Earth (Mittermeier et al. 2000) and be composed of dominant plants that are economically useful (Campbell et al. 2006; Dussol et al. 2017a, b; Ford 2008; Thompson et al. 2015) if the area were denuded of forest cover in the past? The seed bank harbored in the soil reflects millennia of directed human impact, and forest gardens flourish today among traditional Maya farmers as they did in the past, providing a source of seeds that sprout and recommend themselves in their appropriate habitat throughout the region (Ford and Nigh 2015). The archaeological sites and forest vegetation are both part of ancient Maya heritage.

Breaking Down the Point Cloud

Examining Lidar point clouds for vegetation cover and terrain features is essential to assessing ancient and contemporary land use and land cover in the Maya forest and beyond. The fidelity between what can be identified remotely at large scales, such as the regional scale of 1:250,000 offered by Canuto's team (2018) and even the local scale of 1:50:000 presented by Ford et al. (2009), may not be as easily matched in the Maya area at the site scale of 1:10,000 or less. Large features are readily identified, yet the complexity of small features, natural and archaeological, can be bewildering. With the data coverage at hand, we are in a position to appreciate the concordance of features identified remotely and targeted for field validation. As concordance studies increase in number and sophistication, we will be able to extrapolate on a firmer basis from field validations to remotely identified features at the local and regional scales. We also advocate the examination of topographic variability and vegetation qualities, which are clearly an influence on feature identification in Lidar imagery (see Prufer et al. 2015).

Appreciating vegetation influences, past and present, involves unpacking the point cloud and understanding the field conditions. The point cloud is usually divided into zones dependent upon the first laser return, reflecting the height of the biomass or forest canopy, the last laser return representing the land surface (frequently visualized as a "bare-earth" hillshade image), and intermediate zones corresponding to different levels of the understory. Canopy and understory density constrain how many pulses make it to the ground surface and thus the resolution provided by Lidar imagery (Fernandez et al. 2014; Fig. 12.4).

Ground Truth

Understanding the settlement patterns of ancient societies is among the highest priorities for archaeologists, and Lidar visualizations provide a direct means of deriving an image of these patterns. At the regional and local scales, general patterns of

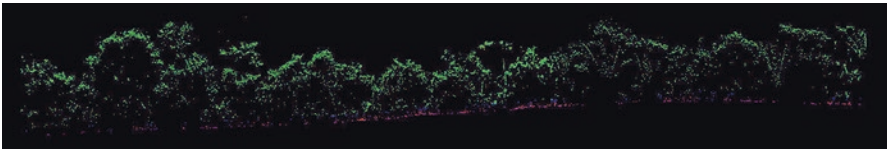

Fig. 12.4 Cross section of terraces at El Pilar

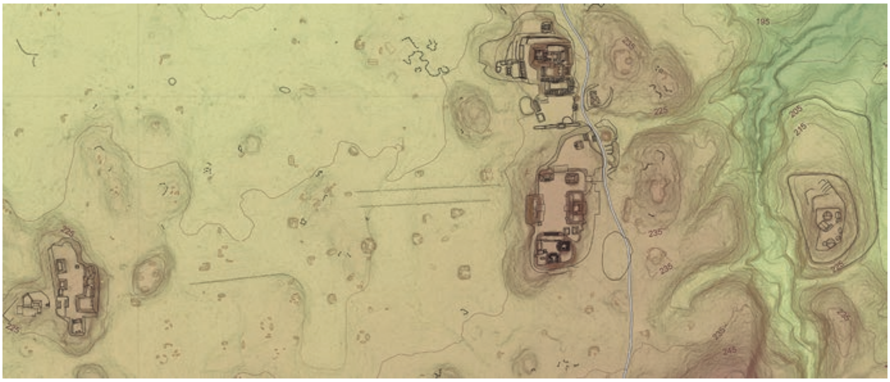

Fig. 12.5 El Pilar core area features with Lidar visualization

Maya settlement located in well-drained uplands have been recognized since Bullard's work 60 years ago (1960, 1964). These general settlement and environmental relationships continue to prove valid (Fedick and Ford 1990), as can be seen in the identified features of Canuto and colleagues (2018; Fig. 12.6) and in our work at El Pilar (Fig. 12.5). Yet there are many more useful data harbored in the Lidar point cloud. It is common that 1%–5% of the total returns penetrate to the surface. Thus 95–99% of the point cloud relates to the vegetation biomass.

At the El Pilar Archaeological Reserve for Maya Flora and Fauna, we have mapped 1647 unique locations in an area of 12 km^2 of which 1360, or 83%, were field-validated as cultural features and 287, or 17%, were rejected. Confirmed features include structural remains, depressions and aguadas, chultuns (underground storage pits), quarries, terraces, and linear features or berms. Rejected elements identified in Lidar imagery fall into several categories of natural features (tree falls, palm debris, ant mounds, or slumped earth) and errors generated in the Lidar visualization process.

Mapped features in our survey include those targeted (763, 56%) and those discovered (597, 44%) in our current coverage of 12 km^2. Features identified in the field, and not a priori detected on the visualizations, provide insight into the inherent challenges of interpreting Lidar visualizations. Considering the domestic architecture, we have mapped 529 residential units, comprising solitary or grouped small structures. Such domestic architecture constitutes the cultural remains most likely to impact our interpretation of population and land use. We discovered 54 of these residential units, or 10%, in the field. Other features, such as chultuns, quarries, depressions and aguadas, and berms and terraces, combine for a total of 831 recorded features, of which 543, or 65%, were discovered in the field. On the positive side, since the majority of residential units (90%) were features identified in Lidar imagery and targeted for validation, these features can contribute to land-use discussions. Residential units, however, make up only 39% of all mapped features, with the remaining 61% comprising the features mentioned above. These features make a significant impact on the landscape and will be missed in the absence field

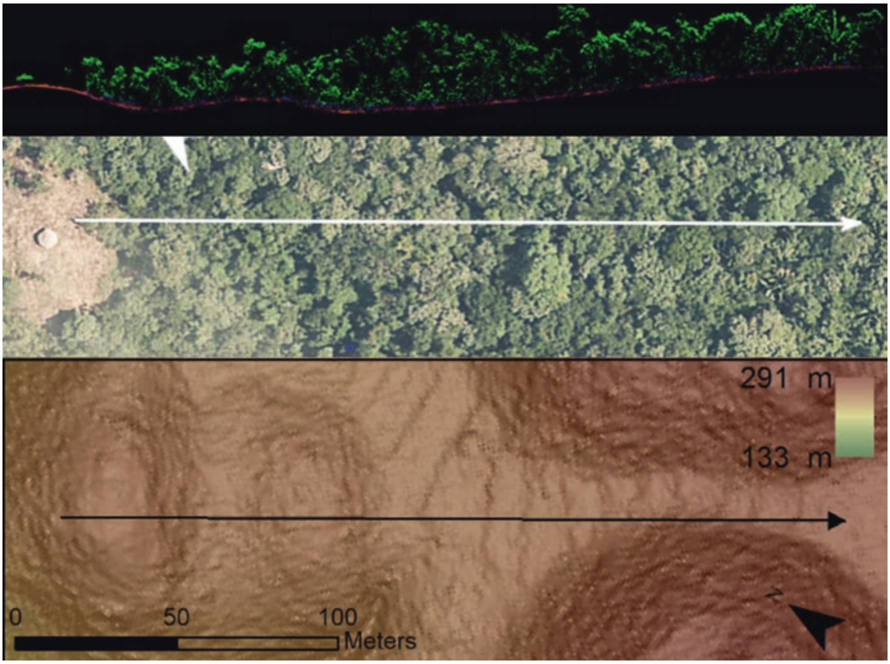

Fig. 12.6 Linear features confirmed as terraces at El Pilar

survey. Landscape features represent much variety, and all features are not residential. This must be considered when inferring human interactions with the landscape, considering settlement density, and developing population estimates.

Terrain features remotely sensed and attributed to terraces and channels need field validation. Confirmation of these features is essential, as not all linear features will be validated (Figs. 12.6 and 12.7). When confirmed, agro-engineering features have been equated with land-use intensification, and while this may be so, it actually implies land *limitations*, where water must be slowed down (terraces) or drained (channels) to increase land productivity. Indications of agricultural intensification not tied to infrastructure, such as increases in labor inputs and changes in crop scheduling, will not be reflected in visual surface features. Infield forest garden management is more intense than that of distant outfields, whether on terraces, in drained fields, or on unmodified terrain. Only field validation will provide the appropriate means to assess the validity of agro-engineering interpretations and the relative importance of agricultural intensification.

The archaeological survey methods developed in the Maya forest over the past 60 years are essential to the Lidar validation process. Putting archaeological "boots on the ground" is the only way to determine if features identified in Lidar images are cultural remains or one of several potential "false positives" listed above. Equally challenging are linear or curvilinear features, which are presumed to be signatures of land modifications but are often artifacts of the Lidar visualization process

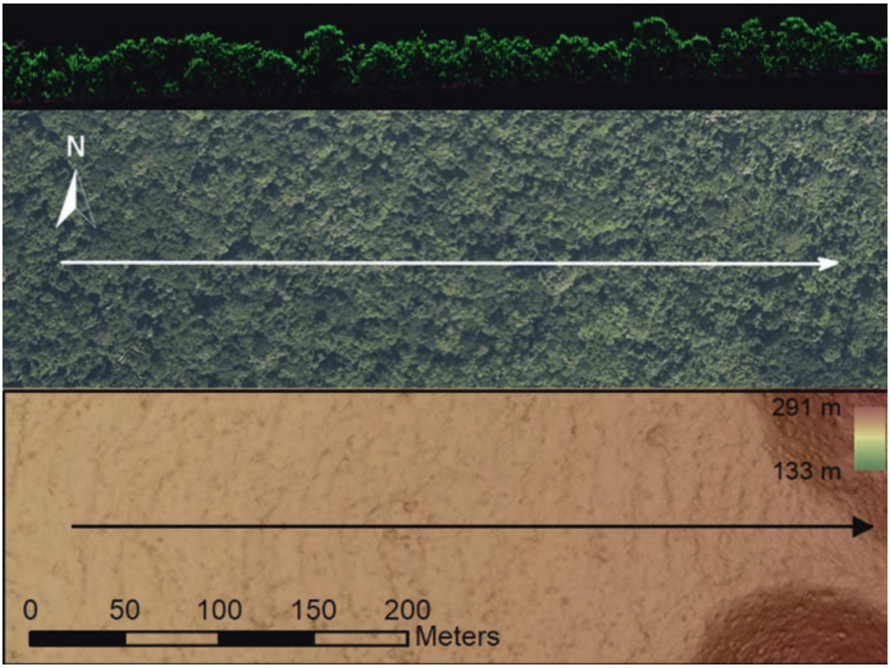

Fig. 12.7 Linear features interpreted in the Lidar visualization

(Fig. 12.7). We are in the early stages of testing the terrestrial patterns revealed by Lidar in the Maya forest, and there is no doubt of its importance in visualizing the topography, drainage, slopes, and vegetation across wide areas. With standard GPS navigation units, we can locate and validate surface features identified remotely within c. 7–14 m (Ford et al. 2013), which is sufficient resolution for mapping at the site scale. Structure counts and locations, and the relationships between these remains and other features, are better understood with field inspection (Ford 2014). As stimulating as the imagery is, we need to understand where small, and presumed domestic, structures may or may not be present and how other features impact human-environment interactions. Strides are being made with Lidar technology and significantly in methods of visualization (Pingel et al. 2015; Canuto et al. 2018), where we think the greatest potential lies.

Vegetation and the Canopy

Relatively unexplored by archaeologists employing Lidar are investigations of vegetation biomass data derived from point clouds (but see Hightower et al. 2014 for an example). Vegetation character, density, and height are part of the three-dimensional data points gathered by Lidar sensors (Fig. 12.8). The Lidar point cloud incorporates the entire forest biomass, from the surface (last laser pulse return) to the top of

Fig. 12.8 Oblique view Lidar

the canopy (first return), and includes shape characteristics of the vegetation that allow identification of particular trees (Fig. 12.4).

We have only begun our exploratory forays into the potential of Lidar and the concordance of visualizations to field identification. How can the Lidar help in the remote assessment of vegetation composition and height? What can the field identification of forest characteristics and documentation of the dominant plants reveal about human impacts on the forest? These are questions we are examining at El Pilar.

Our field protocol calls for the validation of Lidar targets and on-site visual assessment of terrain characteristics, vegetation density, and the identification of the dominant trees by master forest gardeners (Horn and Ford In Press; Horn et al. 2019). Evaluations of the Maya forest have determined that the dominant plants in the region show distinct influences of human selection based on alfa and beta diversity (Campbell et al. 2006; Ross 2011). Our data on the 20 dominant plants of the Maya forest (Table 12.1; based on Campbell et al. 2006) provide a basis for understanding human influence, past and present, on forest composition.

A total of 7395 dominant plants have been identified at 907 mapped sites in 12 km^2 of survey at El Pilar. This makes for an average of 8 dominant trees per site and 638 per km^2. We recorded the number of trees (Fig. 12.9), providing a relative impression of the distribution of the dominant plants across the site. The trees are not uniformly distributed and while some are ubiquitous, others are infrequent. While most mapped sites have the dominant trees present (Fig. 12.10), those that lacked trees were found in disturbed areas primarily covered by the bracken fern, *Pteridium*. Observed distributions of the dominant plants suggest variations that reflect environmental factors across the surveyed areas.

Given our interest in variability, we examined vegetation density and height using the Lidar point cloud. Density and height reflect modern impacts on the landscape. The binational space of 20 km^2 includes a western half surrounded by the Reserva de la Biosfera Maya in northern Guatemala and an eastern half surrounded by private land holdings in Belize. The difference in land use and land tenure is

Table 12.1 Dominant plants of the Maya forest, their pollinators and uses

Common name	Scientific name	Pollinator syndrome	Primary uses
Bay leaf	*Sabal morrisian*∗	Insects	Food, production
Breadnut	*Brosimum alicastrum*∗	Wind	Food, fodder
Cabbage bark	*Lonchocarpus castilloi*	Insects	Construction
Chicle	*Manilkara zapota*∗	Bats	Food, latex
Cohune	*Attalea cohune*∗	Insects	Food, construction
Drunken baymen	*Zuelania guidonia*	Bees	Medicine
Fiddlewood	*Vitex gaumeri*	Bats	Construction
Give-and-take	*Cryosophila stauracantha*	Beetles	Production
Guaya	*Talisia oliviformis*∗	Bees	Food
Gumbo-limbo	*Bursera simaruba*∗	Bees	Medicine
Hog plum	*Spondias radlkoferi*	Insects	Food
John Crow redwood	*Simira salvadorensis*∗	Moths	Construction
Mahogany	*Swietenia macrophylla*	Insects	Construction
Mamee cirila	*Pouteria campechiana*	Insects	Food
Mayflower	*Tabebuia rosea*	Bees	Construction
Monkey apple	*Licania platypus*	Moths	Food
Mylady	*Aspidosperma cruentum*	Insects	Construction
Wild mamey	*Alseis yucatanensis*	Moths	Construction
Wormwood	*Piscidia piscipula*	Bees	Poison
Zapotillo	*Pouteria reticulata*	Insects	Food, latex

*Plants found in local contemporary home gardens

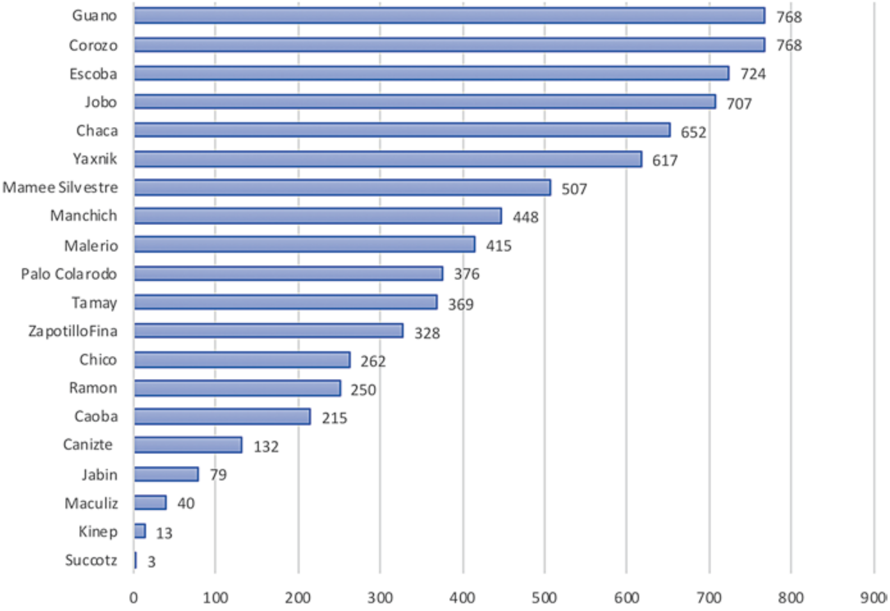

Fig. 12.9 Distribution of dominant plants at El Pilar

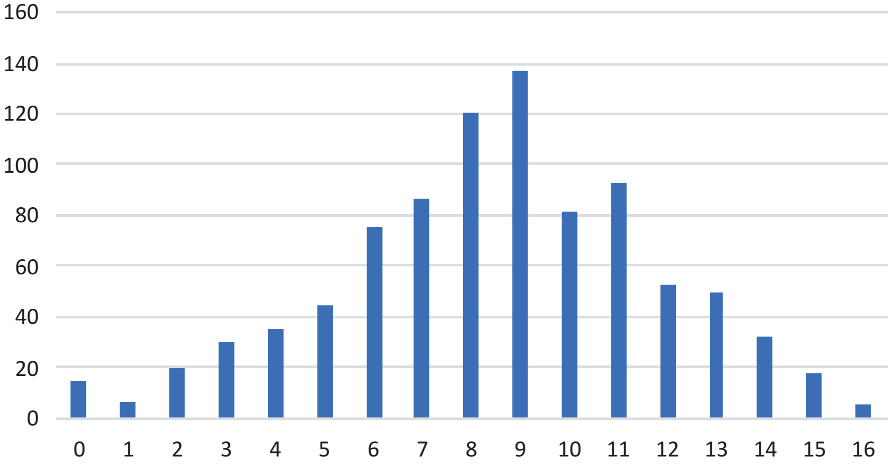

Fig. 12.10 Frequency of dominant plants at mapped sites

evident at the local scale with Landsat imagery (Fig. 12.11) and is apparent at the site scale provided by Lidar visualizations (Fig. 12.12). While the El Pilar Archaeological Reserve for Maya Flora and Fauna was established in 1998, the imprint of recent farming activity is still evident. Today, the expansion of forest clearance and conventional farming north and east of the reserve, and the presence of pastures and traditional farming in the south, continues to impact the local area. There are notable areas where the land cover has been damaged, illegal lumber extraction has reduced the number of large hardwoods, and low canopy areas consist of exclusionary flora such as the bracken fern.

We isolated three areas within the reserve for comparison of land use and land cover indications (Fig. 12.12; note red boxes). We include the transitional wetlands of the NE (Corozal), the monumental core area (El Pilar), and the NW uplands (Amatal). These areas represent examples of topography and slope influencing vegetation (Fig. 12.13) and surrounding land use impacting forest cover. From these three areas, we can see how land use and management have influenced the forest at El Pilar.

The first area to consider is the NE Corozal transitional wetlands. Drainage gradually slopes from the east and south toward the north and west, descending more than 25 meters across 1.5–2 km. Elevations change from above 165 m to below 140 m. Settlement is sparse and concentrated in the slightly higher southern sector, with an average of 51 residential units per km^2. This area is located adjacent to contemporary farms that are experiencing heavy use and impact by fires. Fires in the surrounding area have penetrated the reserve over the past 10 years, impacting canopy height and density (Fig. 12.14). Heavy land clearing is obvious at the NE corner of the reserve, where vegetation has been reduced to just above the surface. Canopy height ranges from 0 to 25 m (Fig. 12.15), with an average around 10 m. This is an

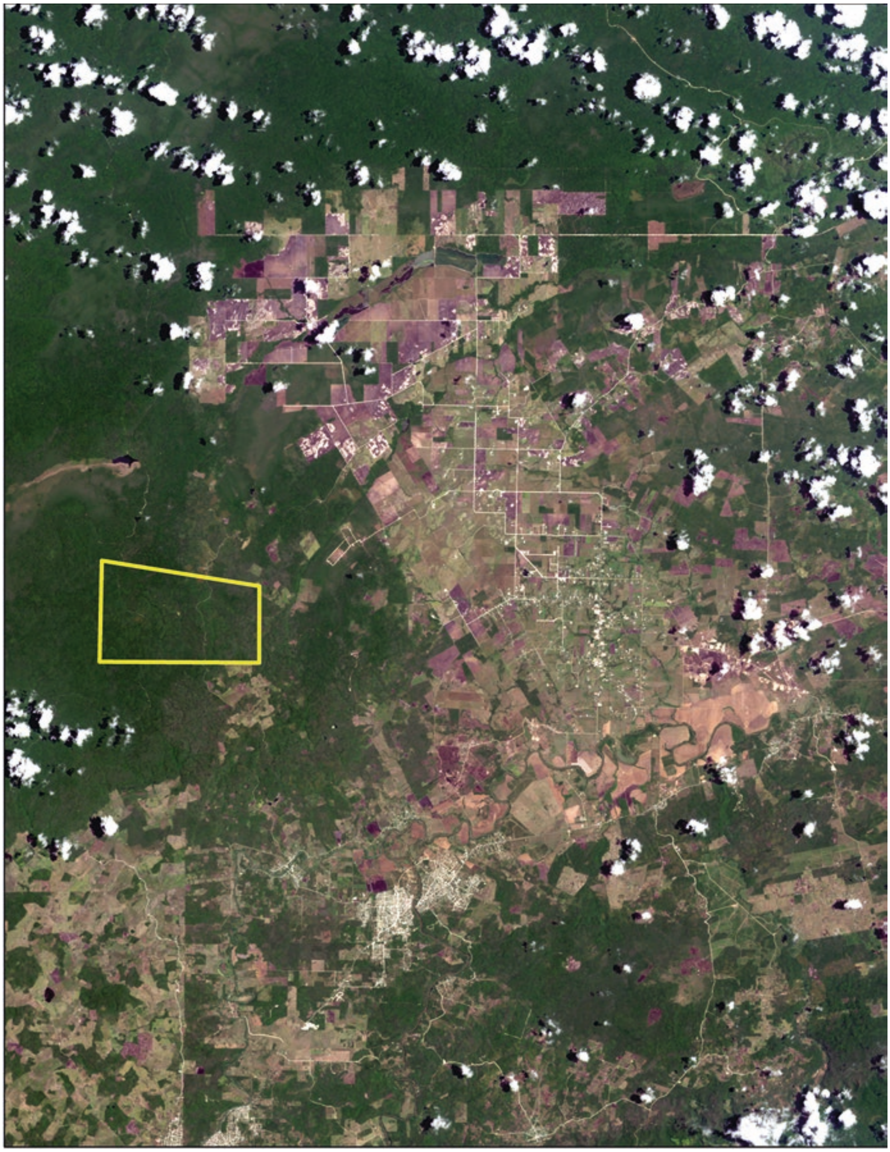

Fig. 12.11 Local El Pilar area as viewed from Landsat 2014

area with few archaeological remains, and where vegetation is dominated by *Attalea cohune;* this the corozo palm from which the area takes its name.

The second area is the core of El Pilar, where the site's impressive monuments are concentrated. This is an area of variable drainage, with a flow gradient running from north to south separating the two ridges supporting monumental complexes. There is considerable relief in the southeastern and southwestern sections, where

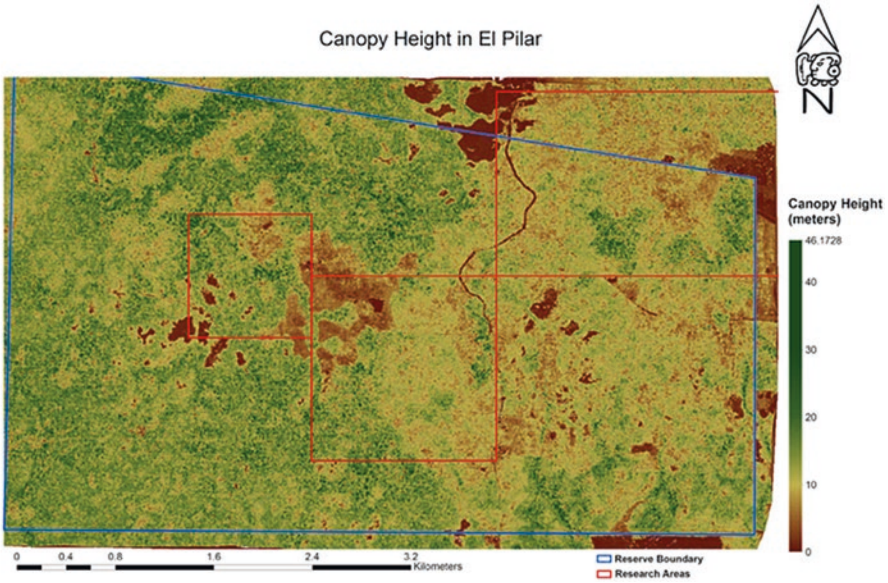

Fig. 12.12 Lidar visualization of the canopy height based on the first laser return

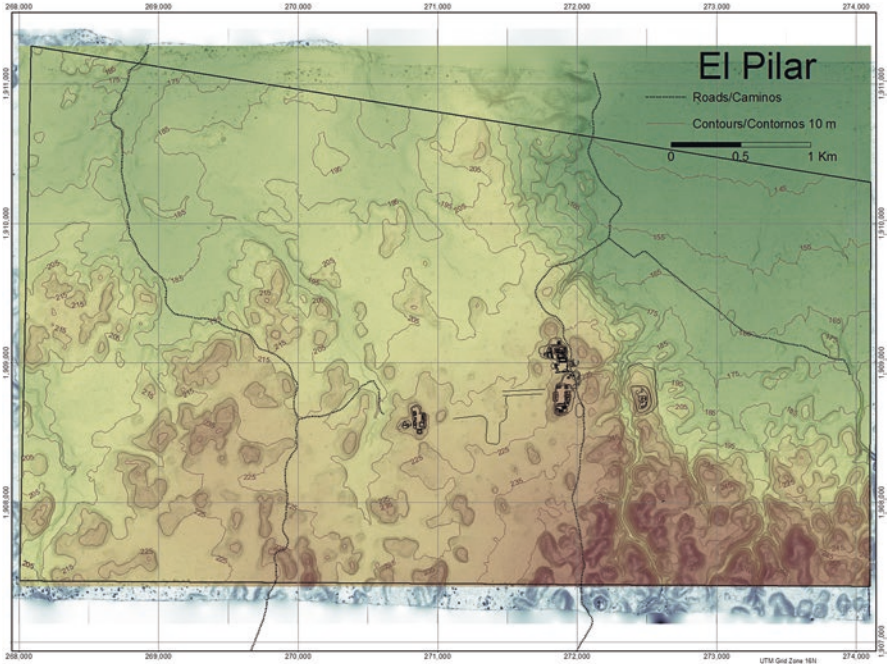

Fig. 12.13 El Pilar Archaeological Reserve for Maya Flora and Fauna topography

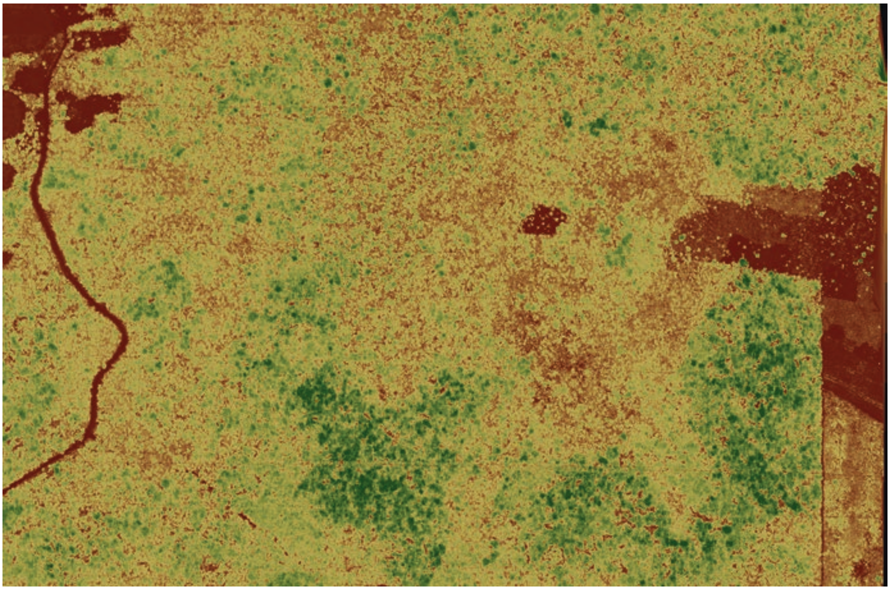

Fig. 12.14 NW Corozal wetland forest canopy cover variation

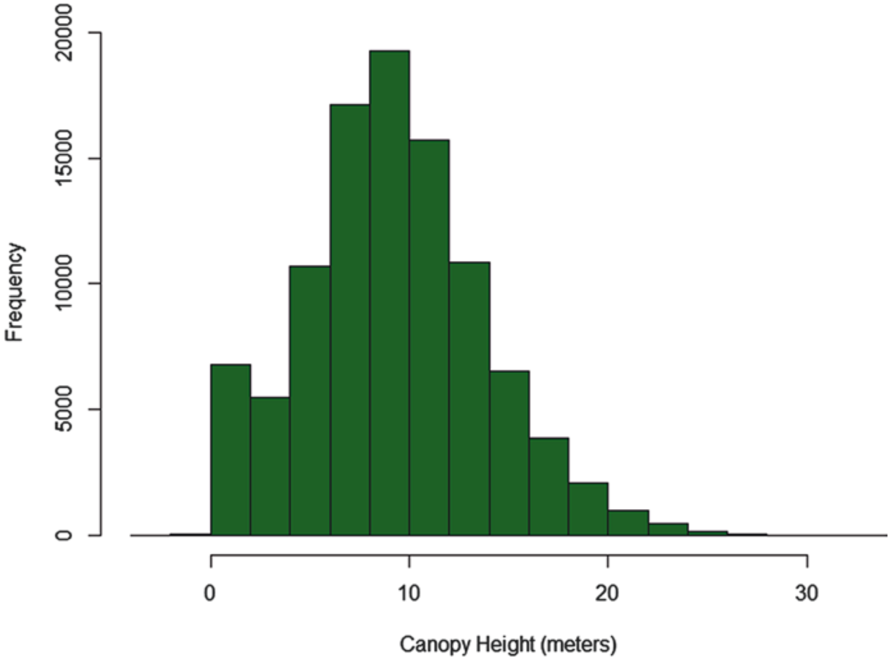

Fig. 12.15 Distribution of canopy height of NW Corozal wetlands

elevations vary from 260 to 270 m on the ridges to less than 210 m in the south-north running drainage. Settlement in this area is dispersed around the monuments, averaging 74 residential units per km^2. A modern road intersects the site core on the east, impacting the monuments on that side. In historic times, this area has been one of significant human activity. The road access is recorded before the 1950s and was mapped by the Central American Geodetic Survey in the early 1960s. There was an established camp for lumber and chicle on the site at that time, and smallholder farming and plantings were noted from the 1970s. Archaeological research began in the 1980s, followed by the delimitation of the archaeological reserve in the 1990s and recognition of government management plans in the 2000s. The road is clearly visible (Fig. 12.16), and the "brizantha" grass of the irregular square in the NW segment is also apparent. Overall the canopy range is similar to the NE Corozal, averaging around 10 m, but the highest trees reach to 30 m (Fig. 12.17). Much of the core area is dominated by corozo palms, but in higher areas the trees are more diverse and include taller hardwoods – at least those that have not fallen to the saws of illegal loggers. Archaeological remains of the major civic center El Pilar span this area and extend into Belize and Guatemala.

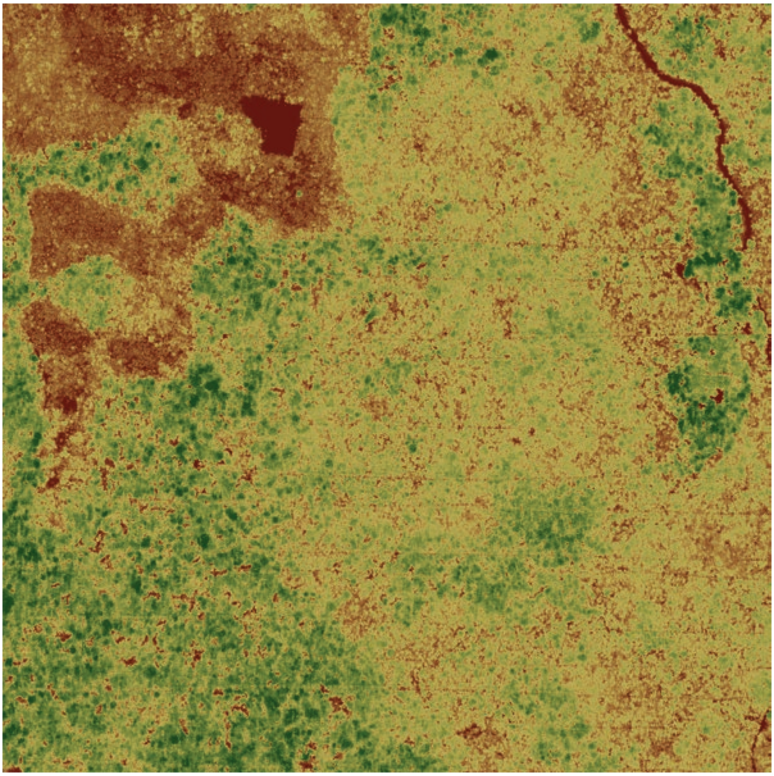

Fig. 12.16 El Pilar core area forest canopy cover variation

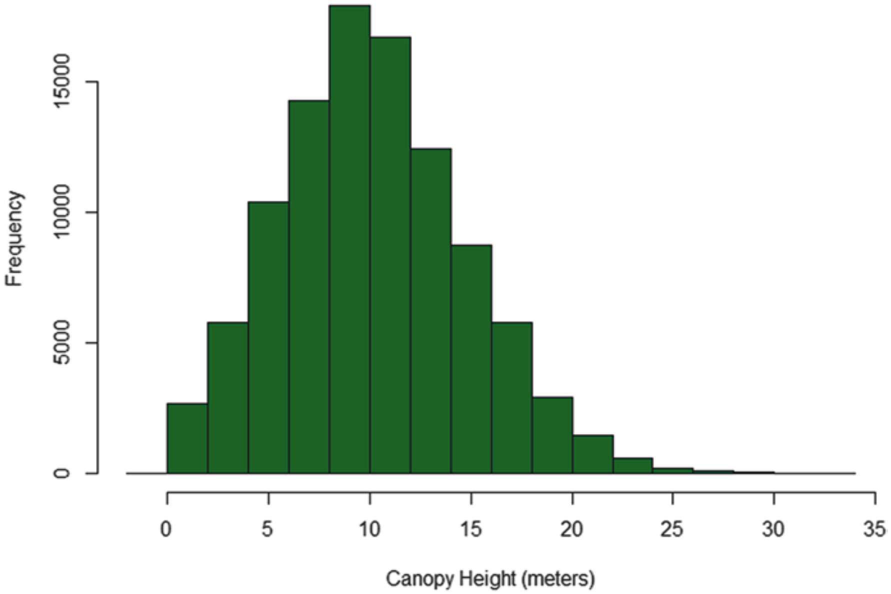

Fig. 12.17 Distribution of canopy height of El Pilar core

The third example comes from the Amatal uplands to the northwest of the El Pilar core area. Water flows from the southwest to the northeast, with the drainage flanked by two major architectural temple complexes built on overlooking ridges. Elevations are lower than those of the core area, beginning around 230 m and descending to about 180 m. Drainage is excellent and the presence of amate trees suggests availability of water. Settlements are large and residential unit density is 78 per km^2 around the monumental complex, equivalent to the site core. While forest cover is generally good, with an average above 15 m and the higher trees reaching above 30 m (Fig. 12.18), the variability demonstrates the impact of poor farming strategies in the area. The irregular blotches in at least seven areas represent the bracken fern that arrests succession where it takes hold. Large hardwoods are present across the area, and several large amate trees give the complex its name (Fig. 12.19).

Overview

The impact of human use in the past is evident with the density of residential units and the variety of other features recorded across El Pilar. Large and small structures are found throughout the area. Limestone quarries are found on most hillsides, and probable agricultural features (berms and terraces) are concentrated in specific zones toward the northeast. These are landscape modification features that relate to land use and land cover in the past.

In the example of vegetation at El Pilar, we see that the combination of Lidar classification and field assessment provides the means to understand the nature of past

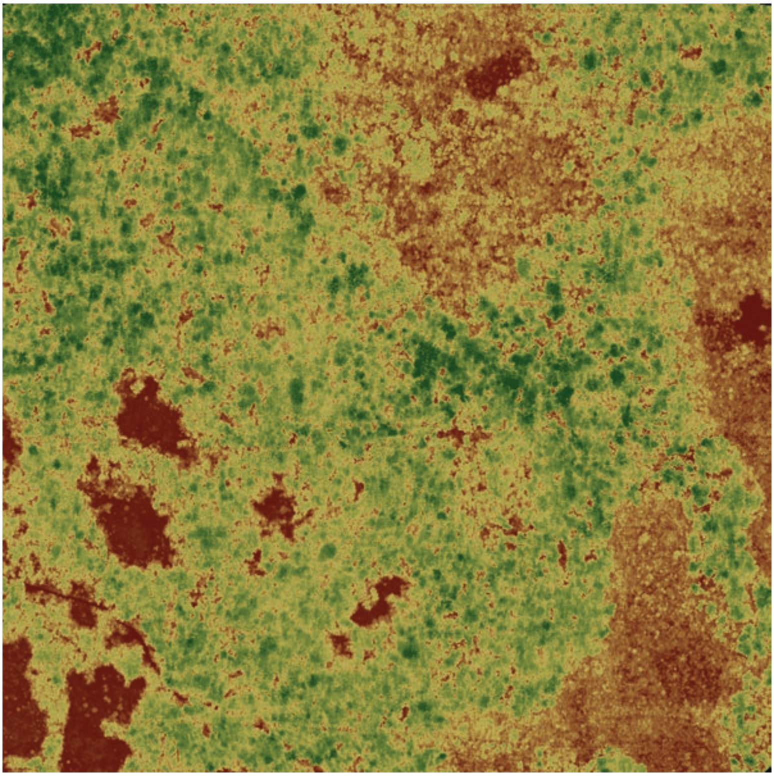

Fig. 12.18 Amatal forest canopy cover variation

influences on the forest species composition as well as historical and contemporary impacts of land use. The presence of the dominant plants of the Maya forest, all of diverse and relevant uses, indicates ancient Maya selection emphasizing important forest products. The establishment of the reserve in 1998 has led to the development and improvement of the forest cover within its boundaries while at the same time revealing agricultural pressures where private land use continues to expand.

Contemporary land use is evident in the vegetation characteristics and the state of the canopy (see Weishampel et al. 2012). Impacts of the agricultural frontier are evident in the east and have affected the vegetation more so here than in areas to the west. Yet throughout the reserve, the areas in the central monumental area and northeast Corozal exhibit the greatest impact. The presence of bracken fern, *Pteridium*, as a cosmopolitan plant that arrests succession where it is established, has inhibited forest recovery inside the reserve. Bracken is adapted to fire and grows fast on the well-drained hills and ridges, typically areas where the ancient Maya settled. Without substantial investment to recover these areas, we can expect the bracken fern will maintain or expand its coverage. Despite the prominent patches of bracken, the presence and persistence of the dominant plants of the Maya forest are evidence that the Maya influenced the landscape, directing biodiversity toward useful plants.

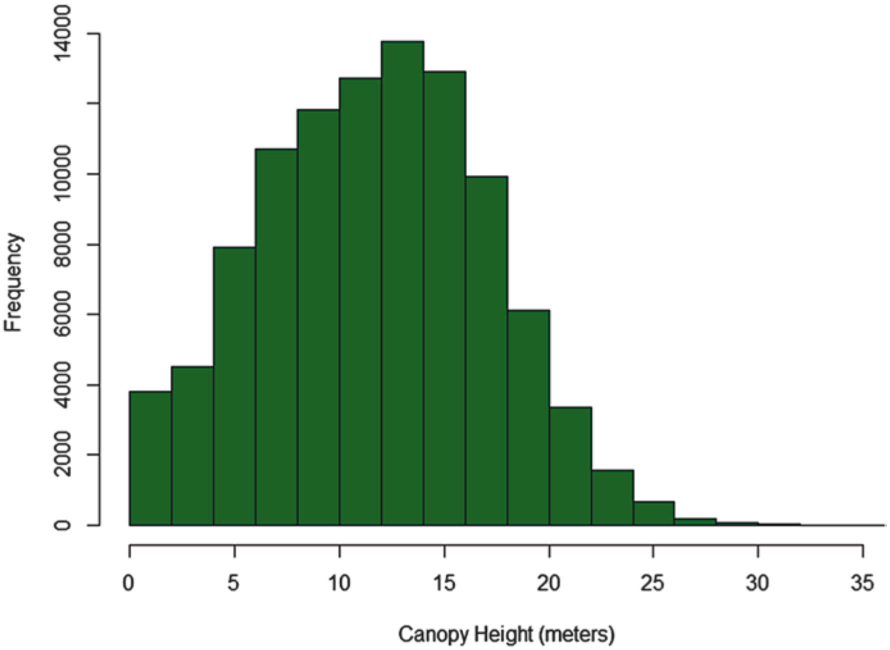

Fig. 12.19 Distribution of canopy height of Amatal

In review, the complexity of the Maya forest as exemplified by research at El Pilar provides a rich foundation upon which to build. To understand the past landscape, we need an appreciation of settlement patterns and how those patterns structured the environment. The study of surface visualizations indicates the promise of Lidar to reveal the secrets of ancient Maya land use. Residential units and many related features (chultuns, quarries, depressions and aguadas, terraces and berms) all point to manipulations that underwrote the successful adaptations of the Maya, past and present.

Conclusion

Fieldwork is the way forward for understanding visualizations created from Lidar data. The more field validation samples for archaeological features and vegetation character, the better the basis of extrapolation to the greater Lidar coverages for Belize, Guatemala, and Mexico. There is little doubt that Lidar is destined to become indispensable for ancient Maya settlement research, improving our understanding of the forested Maya Lowlands. Even as Lidar will have a role to play in the analyses of ancient settlement and the character, height, and density of the biomass captured in point clouds, there will *always* be a need for field reconnaissance and validation.

At the large scale of coverage that exists now, regionally defined topography and landforms alone have great potential for appreciating the nature of vegetation cover. This is the foundation for recognizing the role and influence of environmental factors on the distribution of ancient settlement and contemporary forest cover, which provides a call to action for scholars of land use and land cover to scrutinize sampling strategies and bring the value of Lidar to the detailed site scale.

Acknowledgments Our Lidar project owes much to Anfield Nickel and its associated company Mayaniquel. They have generously donated air photo and Lidar coverage for the El Pilar Archaeological Reserve. Our fieldwork was possible with the support of Exploring Solutions Past and numerous contributors through Experiment.com. Our field activities were accomplished with the support of Lic. Paulino Morales and Master Forest Gardener Narciso Torres. We gratefully thank the Institute of Archaeology Belize and the Instituto de Antropología e Historia Guatemala for their continued support of research and development at the El Pilar Archaeological Reserve for Maya Flora and Fauna.

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