# 4 RAPID LIDAR ASSESSMENT AND VALIDATION IN THE BLADEN NATURE RESERVE

*Mark Robinson, Sara Eshleman, and Keith Prufer*

*Over a decade of Lidar data acquisition in Belize has informed how past humans interacted with Belize's diverse environments. However, diverse environments can pose challenges for Lidar data collection and analysis. In the Bladen Nature Reserve, Toledo District, the dynamic terrain and rainforest vegetation lend to greater noise and less distinct anthropogenic features in the Lidar dataset, making feature identification via a traditional interpreter-led approach untenable. Instead, we developed an iterative approach that utilizes a common model input, a local relief model, and the mounded characteristics of Maya structures to guide an area-based survey around the site of Ek Xux. This rapid assessment informs settlement distribution patterns while simultaneously elucidating limitations in the Lidar dataset that can be accounted for in future models. The method detailed here, or a variant of it, can be applied across Lidar datasets to situate model training data in its environmental context and create more robust feature maps through the comprehensive consideration of error.*

## Introduction

This paper discusses the survey methodology employed by the Bladen Legacy project during its inaugural field season in 2024, detailing Lidar data processing and the results of targeted and systematic ground truthing in the Bladen Nature Reserve, southern Belize. The research expands on the initial traditional survey efforts from the 1990s by the Maya Mountains Archaeological Project (MMAP) (Dunham et al. 1998). This research is in parallel with archaeological research of the Belize Palaeoindian and Archaic Archaeology Project (BPAAP) (Kennett et al. 2020; Prufer et al. 2019, 2020) that has been conducting research in the region since 2014.

Airborne Lidar data greatly enhances the ability to survey extensive landscapes, especially in regions that are logistically challenging due to difficult access, rugged terrain, and dense vegetation. Additionally, Lidar point clouds lend opportunities for the exploration of spatial questions, beyond traditional cartographic approaches. Users can quantify environmental characteristics and isolate specific topographic features, revealing aspects of the landscape and human elements not previously available. However, Lidar data analyses pose their own challenges, with landscape features, vegetation characteristics, and data quality impacting the utility of the data, especially for the identification and visualisation of anthropogenic features (e.g. architecture, water management systems, etc). Question driven processing of Lidar datasets,

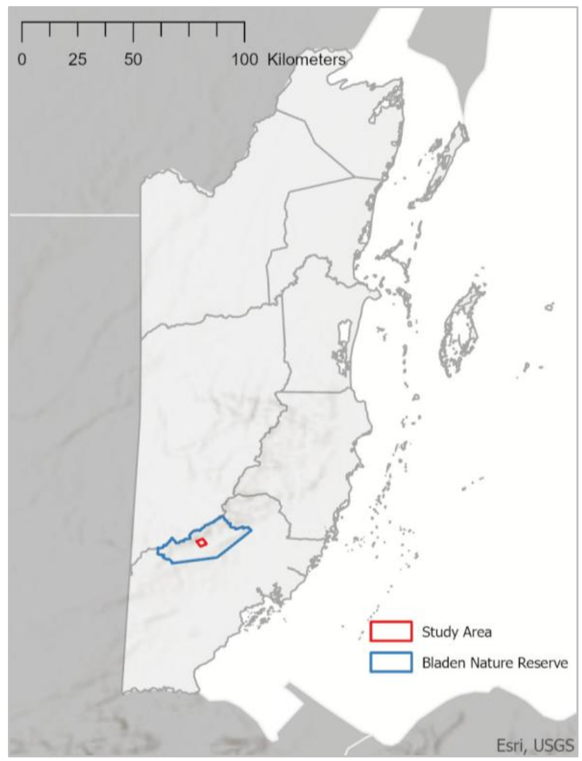


**Figure 1.** Map of the study location within the Bladen Nature Reserve.

with particular attention to the limitations and potential of the particular data, provides an effective utilisation of the dataset and the ability to assist ground-based fieldwork.

We highlight these challenges and limitations for the Bladen Nature Reserve while documenting a rapid data assessment and field survey towards an iterative feedback process that creates robust models of anthropogenic impact. The following method assists in the recovery of

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basic settlement distribution, as well as testing the veracity of remote target identification.

*Location*

The study focuses on the Ek Xux site in the Bladen Nature Reserve (BNR) (Figure 1). The BNR encompasses the watershed of the Bladen Branch of Monkey River, which runs from the volcanic slopes of the Maya Mountains in the northwest, through rugged limestone karst and alluvial valleys, to the coastal plain in the east. Elevation ranges from over 1,000 m in the mountains to the northwest to 350 m in the main river valley (Prufer 2005). Soils in the alluvial valleys incorporate carbonate and volcanic materials, making them a rich agricultural landscape hosting diverse biotic communities and economic resources (Dunham and Prufer 1998). The climate is classified as tropical wet seasonal, receiving 3,500-4,000 mm of rainfall annually, with a dry season from February to May (Walsh et al. 2014).

The lack of recent human disturbance and relative shelter from hurricanes has resulted in the establishment of old growth tropical forest, albeit with a range of distinct habitats related to biotic and abiotic processes that produce variations in species composition and forest structure. Broadly, evergreen forests in the alluvial valleys transition to semi-evergreen forest (25–50% deciduous taxa) on the upper slopes, and semi-deciduous forest (50–75% deciduous taxa) on the ridges (Brewer et al. 2003; Iremonger et al. 1994, 1995). Canopy species diversity is highest on the alluvial soils in the valleys. The subcanopy is dominated by palms (Arecaceae), including *Astrocaryum mexicanum, Attalea cohune, Bactris mexicana,* and *Chamaedorea* spp. Botanical survey begun by the project in 2024 (conducted by botanist Steven Brewer - Wild Earth Allies), is generating detailed vegetation data that will inform future Lidar processing, help elucidate anthropogenic legacies on environments, and contribute to conservation monitoring and policy decisions for the reserve co-managers, Ya'axché Conservation Trust.

*Archaeology*

The alluvial Ek Xux valley, ringed by vertical limestone mountains, hosts the Maya site of Ek Xux. Ek Xux is one of the few sites in Southern Belize to evidence a Maya presence in the Early Classic (and earlier), persisting through the Classic period (Braswell and Prufer 2009; Prufer 2005; Prufer et al. 2020). The area was abandoned ca. 1,000 cal BP. The inaccessibility of the remote location has meant minimal human disturbance over the last millennium.

Research at Saki Tzul and Mayahak Cab Pek rock shelters, both located in the Ek Xux drainage, document occupation of the region since the Late Pleistocene (Kennett et al. 2020, 2022; Prufer et al. 2019, 2020, 2021). Isotopic evidence from human burials in the rock shelters evidence the timing of the transition to agriculture, with maize becoming the dominant staple by 4000 years BP (Kennett et al. 2020), over a millenia before the construction of the urban core. Previous cave research documented the utilisation of subterranean spaces from the Early Formative to the Historic periods (Prufer 2002).

Surveys by Andrew Kindon (Kindon 2002) and Marc Abramiuk (2005) in the 1990s under the Maya Mountains Archaeology Project (directed by Peter Dunham) identified 189 nucleated multi household plazas at the site. Survey was conducted using transit, mapping the location, size and shape of encountered structures. Survey was limited to the northern end of the Ek Xux valley, centred around the size core, with the southern portion of the valley left unmapped due to time constraints and the logistical challenges of remote research.

The Bladen Legacy project endeavours to assess long-term anthropogenic impacts on tropical forests through interdisciplinary, high-resolution spatial and temporal analysis. An initial objective is to determine the extent and intensity of past human use of the landscape, which can be partially achieved through directed Lidar modelling.

## Methods

Research in 2024 focused on assessing the wider settlement distribution of Ek Xux. This entailed:

1. processing Lidar for the identification of archaeological structures and
2. pedestrian survey to validate Lidar-derived identifications while collecting data to refine

identification processes.

While the two-pronged approach, guiding field work with remote sensing, has become common practice, the methods applied and choices made in processing and validating geospatial data are highly varied. Here, we used an automated approach for developing target locations and then embarked on an area-based pedestrian survey, due to the limitations of our dataset and in order to yield data to improve additional iterations of our settlement model.

*Lidar data collection and preprocessing*

In 2019, NCALM collected a 24 km$^2$ swath of airborne Lidar data encompassing Ek Xux and the nearby upland site of Muklebal Tzul. Data collection occurred from a plane-mounted Teledyne OpTech Titan MW multispectral Lidar sensor (Fernandez-Diaz et al. 2016). NCALM technicians aligned, cleaned and classified the resulting point cloud and interpolated the ground points into a 0.5 m digital terrain model (DTM) with a kriging algorithm in Surfer by Golden Software. See Fernandez-Diaz et al. (2014) for additional detail on NCALM's Lidar data processing workflows.

The high resolution DTM served as the source for visualizations that make anthropogenic features apparent (Figure 2). Specifically, to elucidate human features, we created hillshade, local relief, gradient relief, archaeological-optimized, and elevation-tinted multidirectional hillshade visualizations in ArcGIS Pro version 3.1.2 and the Relief Visualization Toolbox (RVT) version 0.9.6 plugin for QGIS version 3.30.3 (Kokalj and Somrak 2019; Zakšek et al. 2011). An initial visual assessment discerned that significant limitations to this dataset exist - features appear less clear than in datasets elsewhere and there is considerable noise throughout the DTM. Thus, a traditional manual identification and digitization of anthropogenic features is not possible here and in order to determine the settlement pattern of Ek Xux Valley, a pedestrian survey is necessary.

*Target location identification*

Traditional survey approaches use manually identified structures as targets for validation. In lieu of manual identification, targets for survey were identified using an automatic approach that relies on the mounded characteristics of Maya structures in relation to convexity and size. Accordingly, a local relief model was used to determine the location of convex features in the dataset, and these features were refined based on size class. The local relief model was created using the Simple Local Relief Model function with a 20 pixel (10 m) analysis window in the RVT plugin for QGIS 3.30.3 (Kokalj and Somrak 2019; Zakšek et al. 2011). Positive values (representing convex surfaces) were extracted from the dataset and converted into polygons. Polygons with an area between 30 and 400 m$^2$ were extracted as possible structures (Figure 3). These potential structures were used as target locations for ground survey. Although we expect structures to exist smaller than the 30 m$^2$ lower threshold, the high noise of the DTM results in a high degree of error; more specifically, targets where a structure is not present (False Positive errors; see Discussion section for elaboration). Recognizing this bias, an area-based field survey was employed.

The validation of local relief model products lends training data to future models, in addition to providing an automatic, rapid dataset based on characteristics of mounded features. Ebert et al. (2016) used a similar initial approach by identifying possible mounds via small-scale topographic position, which is synonymous with local relief at their scale of analysis. This approach can be extended through the use of an area-based survey and an iterative process of model improvement based on the results. In particular, machine learning models are increasingly used for Maya archaeological datasets and surveys that quantify both the locations where features exist and do not exist for training models. Local relief model validation is especially useful because it was the highest performing visualization in a broad-ranging deep learning model in the Maya region (Character et al. 2024). Accordingly, accurate training data, starting with these target locations, will be valuable for not only modelling settlement patterns, but also modelling where and why inaccuracies exist. Automated target identification was conducted in the Ek Xux and A/C valleys (parallel valleys connected by two main passes through the dividing hill range). The

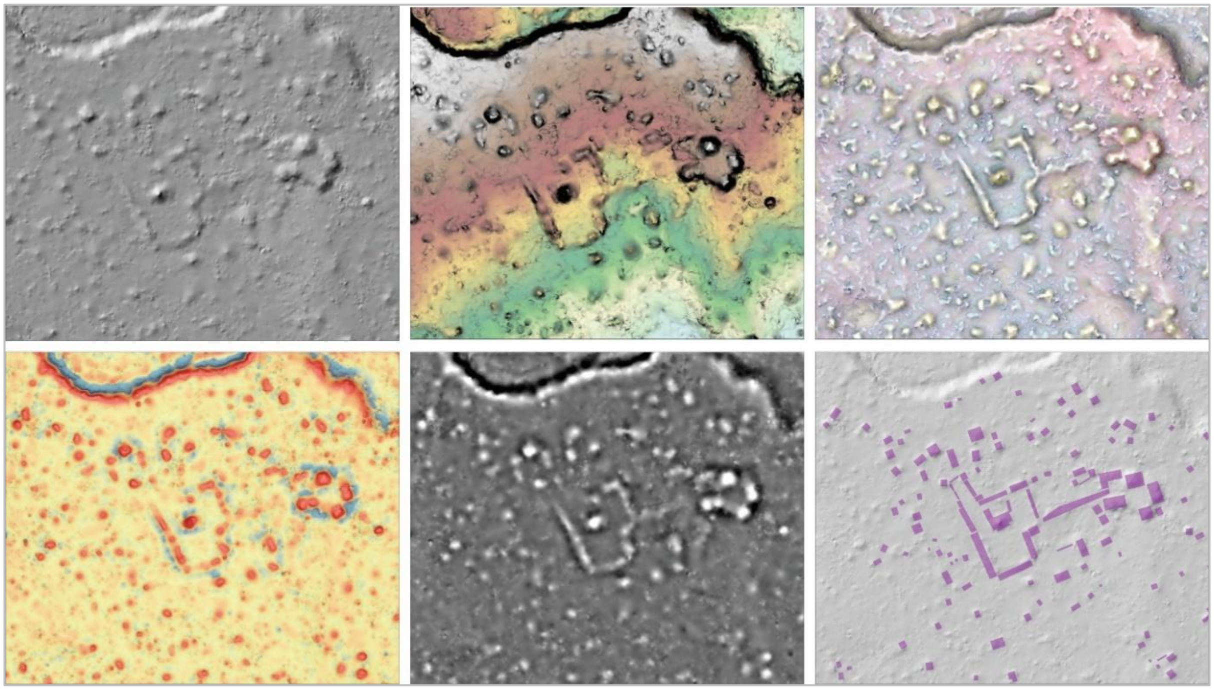

**Figure 2.** Lidar-derived visualizations of the Ek Xux site core. From top-left to bottom-right: hillshade, elevation-tinted multidirectional hillshade, archaeological-optimized, gradient relief model, local relief model, and the hillshade overlaid with previously surveyed structures.

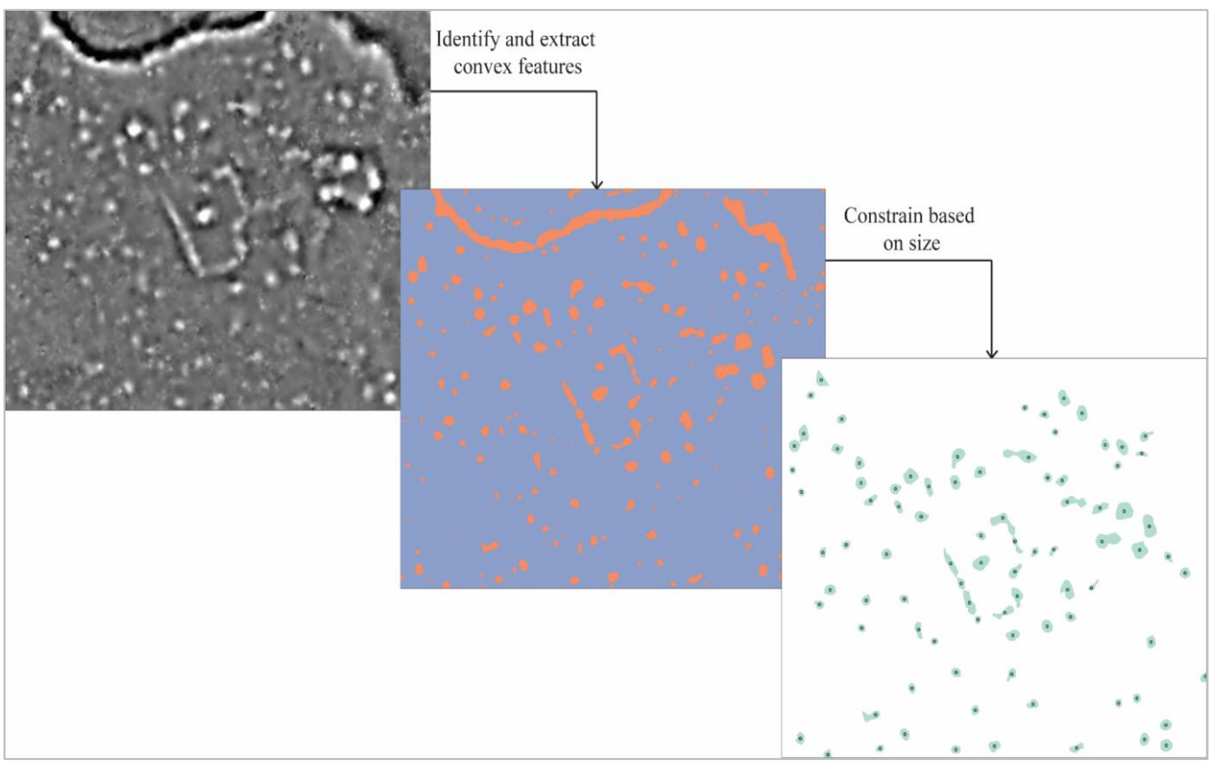


**Figure 3.** Workflow for target location identification. From left-to-right: a local relief model is used to identify convex areas, from the output shapefiles are created and those within the size threshold (30 to 400 m2) have their centroid coordinates extracted.

northern sector of Ek Xux Valley was not included as this area is characterised by abandoned river courses, creating a distinct terrain of sharp topographic change, increased roughness, and extensive boulder and stone deposits, which greatly increase the error of automated identifications. Limited pedestrian survey was conducted in this area to better understand the terrain for future survey strategization.

*Area-Based Survey Approach*

An area-based ground survey approach was necessary due to the limitations of the dataset, but it is also a valuable approach regardless of data quality since it allows for a comprehensive error assessment, identifying False Negatives and confirming True Negatives (Garrison et al. 2023). More specifically, we recognized the lower threshold of 30 $m^2$ for structures would exclude some structures from the dataset, and the locations of these small mounds are necessary for a complete settlement model. Consistent with this area-based approach, the landscape was divided into a 100x100 m grid using the Create Fishnet tool in ArcGIS Pro version 3.1.2, with each grid square assigned an x and y coordinate and row and column numbers. The grid squares were subdivided into 50x50 m quadrants, making a manageable unit for effective ground survey and subsequent analysis.

*Ground survey*

Ground survey was conducted primarily utilising GNSS enabled smart phones. Hand-held GPS units (Garmin GPSMAP 67i) were loaded with preconstructed map layers. The usability of smart phones, especially in regards to the ease and aesthetics of displaying and alternating between visualizations, made them preferable to the dedicated GPS devices. Field testing found the location accuracy to be equivalent. A range of map layers, including a base grid and the target locations (detailed above), were loaded into the *Avenza* app (free version) on our smart phones.

A team of two or three conducted the pedestrian survey. We chose survey locations on a grid basis to provide dispersed results across the landscape, tracking coverage in *Avenza*. Due to the detailed site core survey of MMAP, for efficiency and greatest gains the 2024 survey was focused in areas without prior documentation, with only a small survey in the site core area to test the validity of target identifications against the detailed 1990s survey data.

We aimed for 100% visual coverage for each grid square; however, practicalities with vegetation density, lost or unreliable GPS tracking, fatigue, and the sometimes difficult to discern structures, adds error. Each structure was recorded with a GPS point and a size estimate. At target locations without a structure present, vegetation and terrain were documented, along with other potential reasons for the False Positive.

**Results**

Field survey was conducted between 19 May - 17 June 2024, interspersed with other research activities (excavation, botanical survey, sediment coring, etc.). A total area of 680,000 $m^2$ (39% of the 1,766,016 $m^2$ total area modelled for target identification) was covered by the survey team, assessing 248 targets within the area-based survey (Table 1). 71 of the targets were confirmed as human constructions (Figure 4; True Positives), with 177 targets rejected as False Positives (Figure 4; see Discussion for details on the nature of False Positives). Despite the high proportion of False Positives, a further 69 structures were documented by the ground survey (Figure 4; False Negatives), which had not been picked up as targets from the local relief model approach. A higher frequency of True Positive and False Negatives (both describing structure occurrence) occur near the site core, consistent with greater structure presence (Figure 4). False Positives occur more frequently towards the extreme extents of the valleys.

Table 1 records the survey statistics as well as the model performance metrics, Recall, Precision, and F1 score. Recall assesses the sensitivity of a model (i.e., its prediction accuracy). Here, it refers to how often the model correctly identified a structure, considering all validated structures. Precision is the likelihood that the model identifies a non-structure feature as a target. The F1 score is the harmonic mean of precision and recall, and a standard way to express model performance. The values for Recall, Precision, and F1 are 0.51, 0.29, and 0.37, respectively.

**Table 1.** Results for the area-based surveys and model quality metrics.

| | |
|---|---|
| Area Surveyed ($m^2$) | 680,000 |
| Targets assessed | 248 |
| True Positives<br>(Targets with Structures) | 71 |
| False Positives<br>(Targets without structures) | 177 |
| False Negatives<br>(Structure not at a target location) | 69 |
| Recall (R): $\frac{True\ Positive}{True\ Positive + False\ Negative}$ | 0.51 |
| Precision (P): $\frac{True\ Positive}{True\ Positive + False\ Positive}$ | 0.29 |
| F1: $2 \times \frac{R \times P}{R + P}$ | 0.37 |

**Discussion**

Landscape and vegetation of the region presents limitations for Lidar data collection and analysis. The dynamic geology at the transition between limestone and volcanic landforms lends to rugged, steep karst uplands and flat expansive valleys. The rapid transitions between landforms presents difficulties for regulating flight patterns and capturing sufficient data points across the terrain, resulting in more variable ground point density. The average point density within survey quadrants varied from 4.24 to 29.15 points per square meter, with a ground point density of 0.04 to 1.53 points per square meter (Figure 5). For the total Ek Xux region, the ground point density averages at 0.22 points per square meter. For comparison, the Uxbenka Lidar dataset at averages 2.72 points per square meter (Prufer et al. 2015), the Belize River Valley at 2.8 (Yaeger et al. 2016), and the Buenavista Valley at 1.74 (Garrison et al. 2023). Lower point density provides less data for DTM interpolation, resulting in lower quality Lidar-derived products. It should be noted that ground point density can be increased via a reclassification of the point cloud, but this will increase quality only if the new ground points legitimately represent the ground. The ground point density of this dataset is likely a source of target location inaccuracy, particularly to the southern extent of the Ek Xux Valley where the point density is especially low (Figure 5). In addition, the number and accuracy of ground points is affected by vegetation. During our survey efforts, many of the False Positives (target locations without structures) had vegetation characteristics that resulted in convex landforms in the local relief model, with the most common being buttresses, dense understory, and tree falls with associated root throws (Figure 6). In these instances, either sufficient ground points were not retrieved beneath the vegetation in order to accurately model the ground or the feature is continuous with the ground surface and a model refinement is necessary to differentiate vegetation from structures. The challenges of accurately identifying structures during ground survey, especially in relation to old tree falls, are further compounded with remote sensing data, which will ultimately always be a limitation of the data.

The occurrence of False Negatives (structures that exist but were not target locations) was largely due to the model's size threshold, as well as elevation considerations of

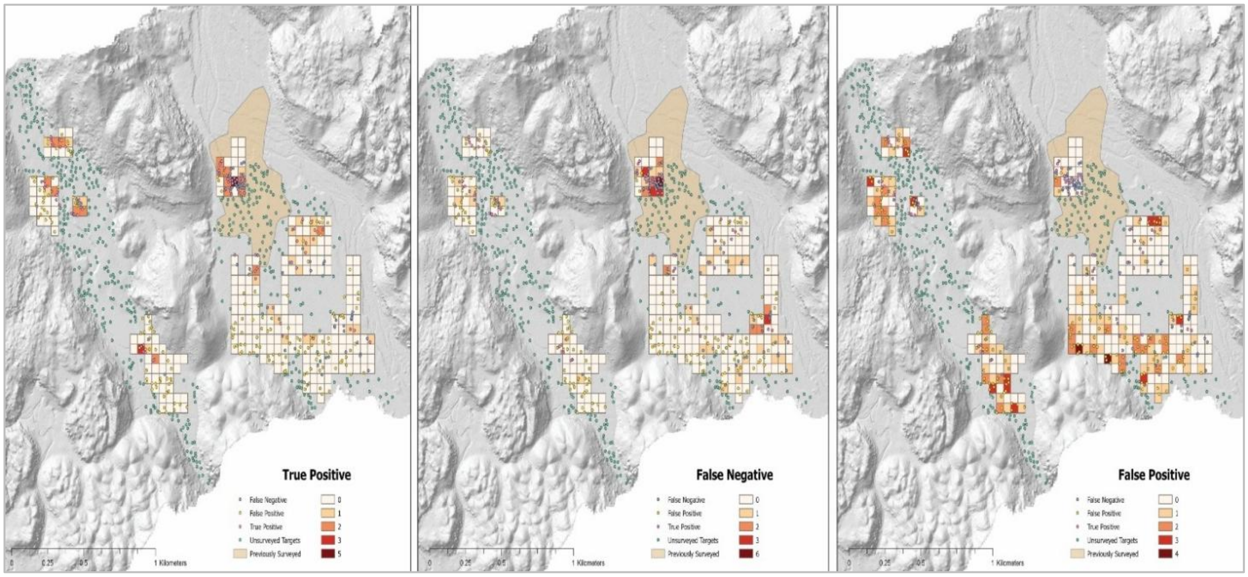


**Figure 4.** Counts for True Positive, False Negative, and False Positive locations within the surveyed quadrats in Ek Xux and A/C valleys of Southern Belize. Unsurveyed targets represent convex locations identified by the local relief approach that were not included in the 2024 field survey.

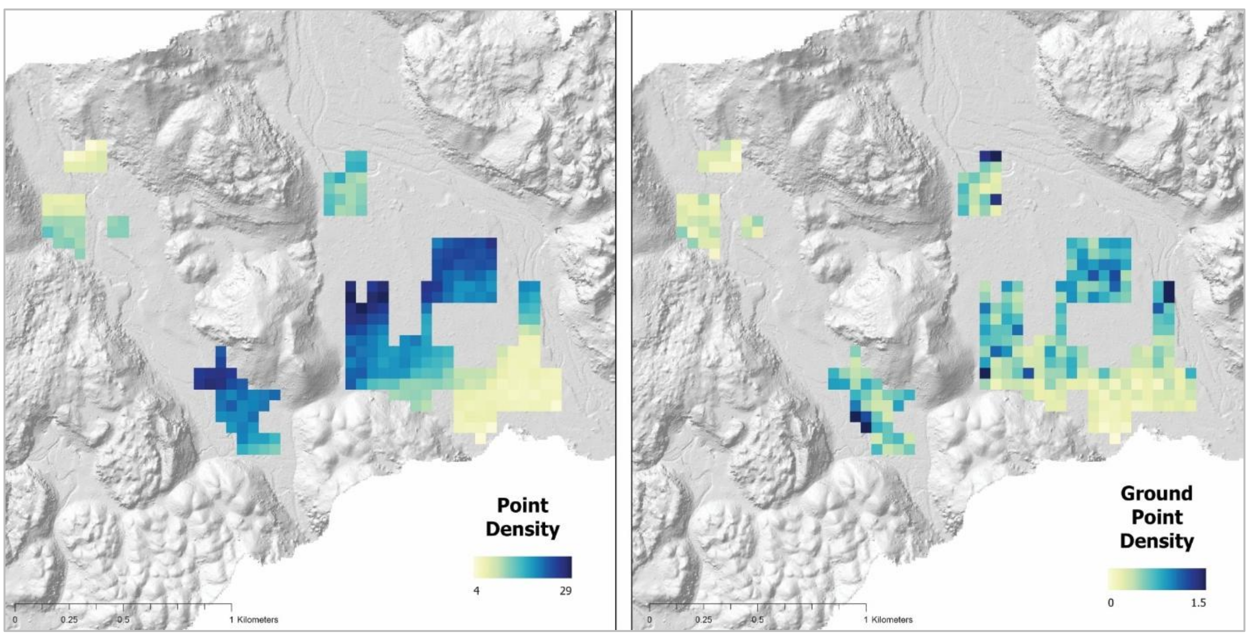


**Figure 5.** The average Lidar point density and ground point density in points per m2 for quadrants included in the present study.

the local relief approach. Many of the structures that were not captured have dimensions below 30 $m^2$, and were subsequently not extracted by the model. A future iteration could decrease the lower threshold, but this will undoubtedly increase False Positive targets. Many of the False Negative features were either relatively low to the ground, and subsequently not differentiated as convex in the local relief model, or they are adjacent to areas with greater elevation differentials, which the local relief model is not robust against. The local relief model is based on elevation variation from the mean elevation of the surrounding area. When steep elevation gradients exist, small differences near the large differences are often not differentiated. For the

**Figure 6.** Sources of false classifications in the present model. Top-left: a large root from a tree throw (False Positive); top-right: ant mound (False Positive); bottom-left: two adjacent buttress roots (False Positive); and bottom-right: a structure covered in lianas (False Negative).

broader topographic position version of this algorithm, using the deviation from mean elevation instead of the difference from mean elevation lessens this bias, but the utility of this correction for the local model is not clear (De Reu et al. 2013). Frequently, the purpose of a local relief model is to identify large differences in elevation, so a deviation approach might not yield a practical advantage like it does for regional topographic position, but merits further assessment.

The use of Lidar products for automatic selection of target locations yields a rapid dataset that is free from observer bias, but also requires iterative modifications for an accurate assessment of human infrastructure. Machine learning models for Maya structures in northern Central America have F1 scores that range from 0.62 to 0.87 with precisions from 0.72 to 0.99 and recalls from 0.60 to 0.89 (Character et al. 2024). These are higher than our values of 0.37, 0.29, and 0.51, respectively. Although employing a different approach, refinement of the model utilising gained knowledge from ground survey should increase model accuracy in line with the machine learning studies. The higher recall score when compared to the precision score indicates that the local relief approach is decent at identifying structures that do exist, but has considerable inaccuracies in identifying non-structures as target locations. This is not surprising given that we took a liberal approach to including targets in the model - there were target areas that are easily discerned as river banks and rocky slopes, but were still included as targets to keep the model unbiased. The comprehensive inclusion of features without observer intervention was instructive as it allows for the documentation of the range of convex features that appear in the Lidar dataset, which allows for the future classification of similar features.

*Next Steps*

The ground-truthed data will be integrated into the next stage of spatial processing, retraining the structure identification classification. Retraining will adjust the sensitivity of analytical parameters to both identify structures that were not identified (False Negatives) and isolate architectural forms from non-architectural signals (tree falls, buttress roots, etc).

Chronology remains a significant knowledge gap for settlement distribution across the region. The intensive radiocarbon dating program from the Saki Tzul and Mayahak Cab Pek rockshelters provides a long-term occupation history, however, this cannot resolve the development and expansion of settlement. Targeted excavation of structures will provide chronological detail to the Ex Xux settlement. The refined model along with this targeted excavation will further elucidate whether structure time period impacts structure shape and Lidar identifiability as is the case elsewhere in the Maya lowlands (Garrison et al. 2023; Yaeger et al. 2016).

The use of local relief for an automatic classification is practical for relatively flat landforms, like those of the Ek Xux and A/C valleys, but additional model adaptations are likely necessary for broad applicability. Notably, local relief was the best performing visualization for a machine learning model trained on diverse landscapes in both Guatemala and Mexico (Character et al. 2024). As a result, the approach presented here may be fruitful in a greater diversity of landscapes, but at the same time the local relief model for karstic landforms near Ek Xux resulted in large numbers of topographic convex surfaces. Thus, it may be necessary to integrate additional landform characteristics in the derivation of the initial model in regions with varying landform types.

The methodology employed here presents a potential route to validate Lidar data for use in analytical models regardless of dataset quality. Although the local relief method is likely specific to flat landforms, the approach can be adapted for broader use. More specifically, area-based surveys based on datasets, such as local relief, that will subsequently be integrated into models, yield valuable information about the dataset and its sources of error. These initial steps allow for more accurate model development and a better understanding of settlement in Lidar datasets amidst Belize's diverse environments.

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