Winter 2021

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## Repository Citation

Hutson, Scott R.; Dunning, Nicholas P.; Cook, Bruce; Ruhl, Thomas; Barth, Nicolas C.; and Conley, Daniel, "Ancient Maya Rural Settlement Patterns, Household Cooperation, and Regional Subsistence Interdependency in the Río Bec Area: Contributions from G-LiHT" (2021). *Anthropology Faculty Publications*. 29.
https://uknowledge.uky.edu/anthro_facpub/29

# Ancient Maya Rural Settlement Patterns, Household Cooperation, and Regional Subsistence Interdependency in the Río Bec Area: Contributions from G-LiHT

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Research on intensive agricultural features contributes to the social relations of farming, including the means by which farmers mobilize labor and the possible destination of surplus. Lidar provides high-resolution data on ancient houses and agricultural features at a regional scale. This paper uses lidar data from NASA's G-LiHT airborne imager to derive insights about rural demography, interhousehold cooperation, and subsistence interdependency among the ancient Maya. We assess the differences in intensity of agricultural investment in rural and urban areas of the Río Bec region of southern Campeche and Quintana Roo, Mexico, leading to inferences about regional food exchange and complex economies. The scale of interconnected ridges and terraces clearly implies interhousehold cooperation, yet this cooperation was not centralized. Rather, we envision a landscape of smallholders who jointly planned the layout and articulation of agricultural features but pooled most of their labor at the level of the household.

**Key words:** economic anthropology, agricultural intensification, smallholders, Maya Lowlands, lidar, landesque capital

Dating at least back to Wittfogel's discussion of hydraulic civilizations, anthropologists have had a long-running interest in agricultural innovations that leave durable signatures on the land. Many of these labor-intensive innovations have come to be known as landesque capital (Brookfield 1984). Referring to landscape features from ancient, pre-capitalist contexts as a form of capital invites challenges, but the term "capital" has the salubrious

Submitted February 11, 2021; accepted April 21, 2021; published online November 1, 2021.

*Journal of Anthropological Research*, volume 77, number 4, December 2021.
 https://doi.org/10.1086/716750

effect of highlighting relational aspects of agricultural intensification (Widgren and Håkansson 2014). Two important questions about the social relations of agricultural production include how people mobilized labor to construct such features and what happened to surplus yields from these features. In the Maya area, writers often presume suprahousehold labor mobilization for terraced and ridged fields, with ancient authorities extracting surplus as part of political economies.

Fifty years ago, geographers and archaeologists began to identify ancient remains of intensive agriculture, in the form of terraces and wetland fields, in the Maya area. Many of these initial discoveries came from the Río Bec region of Mexico (Figure 1), where researchers such as Turner (1974, 1983; Turner and Harrison 1981) and Thomas (1981) helped revolutionize our understanding of Maya farming and established this region as one of the centers of terracing in the Maya world. Additional mapping projects in the Río Bec region at Becan, Chicanna, Río Bec, and the Chactún area (Carrasco Vargas et al. 1986; Lemonnier and Vannièrre 2013; Šprajc et al. 2021) revealed extensive terracing and other agricultural features. This work led to regional-scale estimates of the scope of intensive farming. The current paper uses publicly available lidar (Light Detection and Ranging) data from NASA Goddard's Lidar, Hyperspectral, and Thermal imager (G-LiHT; Cook et al. 2013) to test these estimates and expand our knowledge of rural settlement patterns and demography in the Río Bec region of Mexico. Placing this knowledge in broader geographical context allows us to explore the social relations of production surrounding landesque capital, including insights about interhousehold cooperation and subsistence interdependency.

Lidar has permitted remarkable advances in the study of intensive agriculture (e.g., Beach et al. 2019; Canuto et al. 2018), and terracing is no exception (Chase and Weishampel 2016; Chase et al. 2017; Macrae and Iannone 2016). Lidar data emphasize the scale of Maya landesque capital and, combined with paleoenvironmental data, provide strong evidence for feedbacks on various environmental processes, such as climatic change (e.g., Turner and Sabloff 2012). Three developments enable the current paper to build on this prior body of research. First, the G-LiHT lidar data as well as lidar acquisitions from other nearby areas (Beach et al. 2019; Estrada-Belli and Balanzario 2019; Guderjan 2018; Reese-Taylor et al. 2016; Šprajc et al. 2017; Tsukamoto et al. 2019) expand the scale of high-resolution mapped terrain with agricultural features by orders of magnitude. Prior to lidar, fully reported mapping with quantifiable data on agricultural features from the Río Bec region consisted of scattered parcels that, when combined, do not amount to more than 5 $km^2$ of habitable uplands. Second, GIS software enables rapid measurements, such as length and volume of agricultural features. Third, advances in terracing research and settlement patterns research in neighboring areas provide an exciting broader context for comparison. Yet, we still have to acknowledge that the stair-step carbonate bedrock of the Yucatan produces patterns that can be difficult to differentiate from terraces (Beach et al. 2015).

These developments permit several findings. First, there are differences in intensity of agricultural investment in rural and urban areas within the Río Bec region, leading to

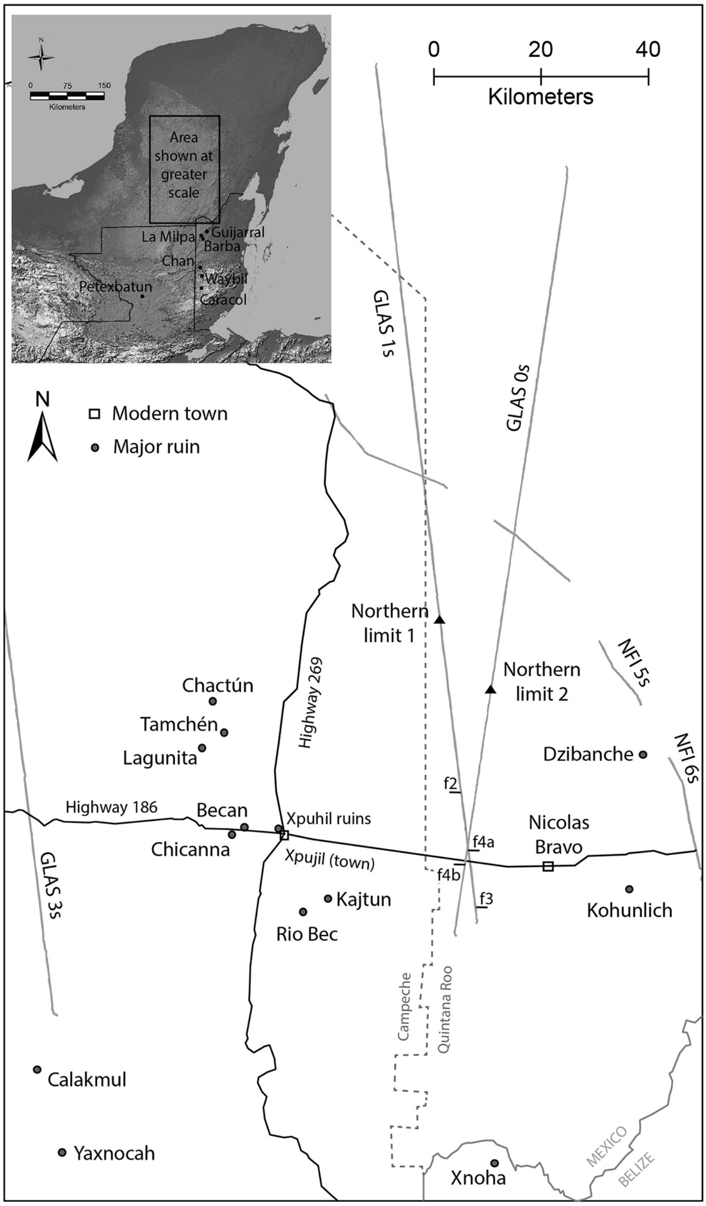


Figure 1. Map with locations mentioned in the text. Labels that begin with "f" represent locations of features shown in subsequent figures. For example, the features in Figure 2 are located at "f2."

inferences about regional food interdependency and complex economies. Second, we find that several rural locations in the Río Bec region contain more upland agricultural features than some parts of the Maya world (Petexbatun, northern Belize) with such terraces, but fewer than at intensively terraced sites in the Belize River valley (Chan) and the Vaca Plateau (Waybil, Caracol). Third, in the Río Bec area, ridges and terraces interconnect with each other and often form domestic enclosures, thus allowing for the identification of houselots or farmsteads. Finally, the scale of interconnected ridges and terraces clearly implies interhousehold cooperation. Yet we argue that this cooperation implies neither centralized control nor village-level work gangs. Rather, we envision a landscape of smallholders who jointly planned the layout and articulation of agricultural features but pooled most of their labor and returns at the level of the household.

## BACKGROUND

### *Local Landforms, Climate, Vegetation*

The Río Bec region does not have clear boundaries, but it includes areas of southeastern Campeche and southwestern Quintana Roo known to contain ancient stone buildings that exhibit a series of architectural traits (including paired stone towers too steep to ascend and doors surrounded by zoomorphic stone mosaic figures) seen at sites such as Río Bec, Chicanna, Becan, and Xpuhil (see Figure 1; Andrews 1996; Benavides 1995; Carrasco and Boucher 1990; Potter 1976; Ruppert and Denison 1943). The area is characterized by limestone ridges reaching up to 330 m above sea level, commonly elevated 50 m above the surrounding terrain, with slopes that rarely exceed 20° (Turner 1983:54). As part of the Elevated Interior Region of the Central Maya Lowlands, this area essentially lacks natural year-round water sources (Dunning et al. 2012) though water collects in poorly drained, clay-rich karst depressions (*bajos*). Bajos are karst poljes and range widely in size from 1 or 2 to several hundred km$^2$, with smaller ones typically formed strictly by limestone dissolution and larger ones associated with normal faulting (Dunning et al. 2019:129). Many bajos become inundated during the rainy season, which runs from May to December. Availability of water in the dry season often depended on reservoirs (*aguadas*) that may have begun as natural depressions, often within bajos. In the Río Bec region, berms surrounding reservoirs represent backdirt from excavations done to clean or deepen them, as well as to prevent contamination from inflow of surface water within bajos. Reservoirs found in the G-LiHT strips are all substantially smaller than the extensive ones found at the cores of major sites such as Calakmul, Chactún, and Yaxnocah (Dunning et al. 2019; Šprajc et al. 2021; Thomas 1981:1). Annual precipitation averages 1250 mm, but with considerable interannual variability. Annual rainfall increases to the south and decreases to the north (Foster and Turner 2004). The lidar imagery permits a clear distinction between sloping terrain, which we call uplands, and relatively flat terrain (<2°), much of which is bajo. The margin between uplands and bajo can be agriculturally rich due to aggradation of sediment eroded from the hillsides, sometimes caused by ancient forest clearance and hillslope farming (Dunning et al. 2019). Small patches of uplands—promontories/*islotes*—are occasionally found in the middle of bajos. Upland soils consist largely of shallow (5–45 cm in depth) silty clay loams (Turner 1983:56) derived more from aeolian inputs, including volcanic ash and Saharan dust, than from weathering of the bedrock, which is relatively pure calcium carbonate (Bautista et al. 2011). Vegetation consists of high forests in the well-drained uplands and scrub forests in the poorly drained bajos (Pérez-Salicrup 2004). Bajos are more frequent and increase in size toward the eastern edge of the region.

### *Terraces*

Along with the Vaca Plateau in Belize (Chase and Chase 1998; Chase and Weishampel 2016; Healy et al. 1983; Macrae and Iannone 2016), the upper Belize River valley (Fedick 1994; Wyatt 2012), northwest Belize (Beach et al. 2002; Dunning et al. 1999; Hageman and Lohse 2003; Hughbanks 1998; Kunen 2001), the Petexbatun (Beach and Dunning 1995; Dunning and Beach 1994), and Palenque (Liendo Stuardo 2002), the Río Bec area is well known for intentionally built terraces that preserve soil and water and expand planting surfaces on hillsides. Terraces in the Río Bec region were reported by some of the first researchers to visit the area (Lundell 1933:73; Ruppert and Denison 1943:13, 50) and became a focus of study in the 1970s when Turner (1974) mapped 53 open plots of land, many for grazing, along nearby roads, and Thomas (1981) mapped a continuous 3 $km^2$ swath of land surrounding the Becan monumental core. This region contains each of the three major types of terraces reported elsewhere: dry-slope or contour terraces on hillsides that run parallel to slope contours, cross-channel terraces (also called weir terraces and check dams), and footslope terraces. (Box terraces, a less common form [Beach and Dunning 1995; Dunning and Beach 1994:58], have not been documented.) Dry-slope terraces on hillsides are the most common (Figure 2; Turner 1974:119). In terms of construction, Turner (1983:77) identified three styles of dry-slope terrace in the Río Bec area: broad base, stone slab, and double wall. The broad-base terrace is most common, particularly east of Becan, and consists of a front wall containing dry-laid blocks commonly 30 by 15 by 10 cm with fist-sized stone fill behind the wall and a 20- to 40-cm-thick layer of similar stone fill below the wall. The fill below the wall rests on bedrock (see also Macrae and Iannone 2016:317), indicating that builders initially scraped away the original soil. The heights of walls documented by Turner range from 80 to 140 cm, though at Becan, Thomas reports front walls reaching 2 m high. Fill extends up to 3 m behind/upslope from the front wall in Turner's sample and up to 5 m behind the wall in Thomas's sample. Broad-base terraces in the Río Bec area resemble broad-base terraces in the Petexbatun region and the piled stone terraces at Caracol (Chase and Chase 1998; Dunning and Beach 1994). In both cases, farmers also built walls directly on bedrock but did not place fist-sized stone fill between bedrock and the wall base. Excavated examples from the Petexbatun region contain boulders at the foot of the front wall, rather than smaller stones. In many cases, boulders lay on top of cobbles and gravel, which may reduce water buildup that can lead to terrace collapse (Beach and Dunning 1995).

The stone slab form of terrace is generally found west of Chicanna and consists of upright blocks, normally no higher than 40 cm, sunk 20 cm into the soil (Turner

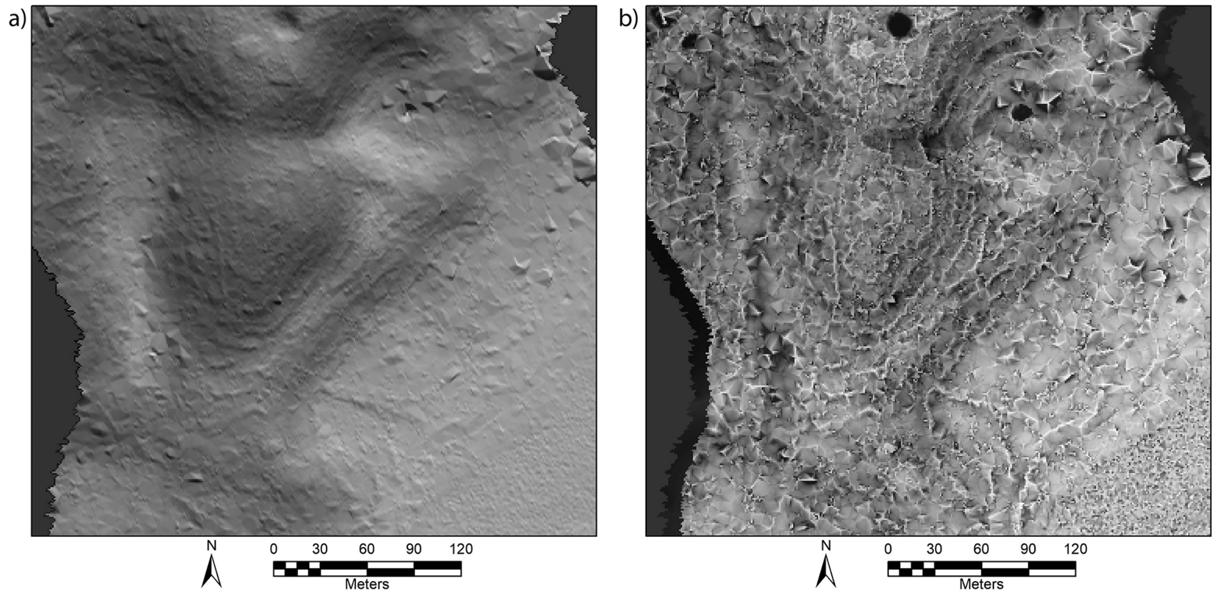


Figure 2. Terraces from GLAS 1s tile 458: (a) rendered in hillshades from 16 angles and (b) rendered with the positive openness technique (see Kokalj and Somrak 2019).

1974:120). Turner (1983) mentions double-wall terraces in passing, as he noticed them in 1980, well after his 1973–1974 field seasons. Lemonnier and Vannière (2013) report double-wall terraces as the dominant form at the Río Bec site. Here, the back wall is situated on bedrock that is significantly higher than the front wall, such that the stone fill between the two walls slopes downward from the back wall to the front wall. As at Caracol, the back walls have larger stones than the front walls. At Caracol, double-wall terraces are normally found in flatter areas and consist of a second wall about a meter behind the front wall with rock fill between the two walls (Chase and Chase 1998). Double wall construction is also often found in footslope terraces positioned at the base of steep slopes to catch down-washing sediments (Beach and Dunning 1995; Dunning et al. 2019).

Though targeted attempts to recover charred seeds and phytoliths pertaining to crops farmed on terraces have often failed (Lemonnier and Vannière 2013:409; Wyatt 2008: 281), excavations behind a terrace near San Bartolo, Guatemala, produced a maize kernel carbon-dated to 50 BCE–90 CE (Beach et al. 2015; Garrison and Dunning 2009). Maize, manioc, and cotton pollen have been recovered from bajo-edge reservoirs, some near terraces (Dunning et al. 2019:142). Some studies used carbon isotope ratios indicative of maize (C4 taxa) from dated terrace sediments to hypothesize maize cultivation (Beach et al. 2011; Webb et al. 2004). Near Tamchén, Šprajc et al. (2021) recovered squash phytoliths and maize starch from a ridge. These species represent just a few of the cornucopia of cultigens grown and consumed in the lowlands (Fedick 2020).

### *Ridges*

Linear stone features positioned such that they were not intended to impound soil or water nor create flat planting surfaces have been called ridges. They often run diagonal to contour lines or perpendicular to them, essentially ascending or descending hills. Many are found on relatively flat terrain. Ridges have rounded tops and slope downward on both sides. We use this bilateral slope, easily visible in a digital elevation model (DEM, or topographic map) that has been transformed to show slope, as the key criterion for distinguishing ridges from terraces (Figure 3). Ridges are often more massive than terraces, reaching 2 m high and 5 m wide, though some are only 0.5 m high and 1.5 m wide (Lemonnier and Vannière 2013:402; Thomas 1981:87). Often one portion of a single, continuous linear feature is a ridge while another portion is a terrace. Ridges are common in northern Belize (Tourtellot et al. 1994:120), where they are called "berms" (Beach et al. 2002; Horn and Ford 2019; Kunen 2001; Kunen and Hughbanks 2003) and *albarradas* (Guderjan 2018). Excavations show that most ridges around Becan are constructed on bedrock using limestone cobbles, pebbles, and soil (Thomas 1981; Turner 1983), though some consist of larger stones and a few have retaining walls of unshaped stone or facing stones (Šprajc et al. 2017:17). Ridges with crude retaining walls are common at Río Bec, where they are normally built on paleosols or backfill (Lemonier and Vannière 2013:402). About 20% of those at Becan are made of chert cobbles. An excavated ridge in Northwest Belize had a "nucleus of double retaining walls built of boulders, filled with chert gravel and covered by a rounded heap of broken chert nodules" (Beach et al. 2002:389).

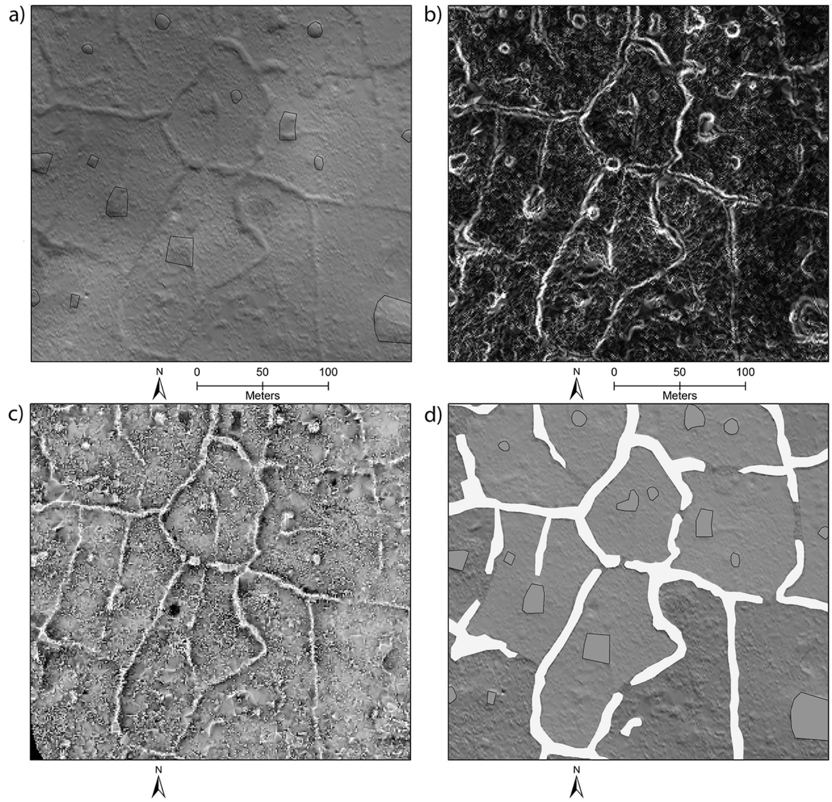


Figure 3. Ridges rendered in (a) hillshade from 16 angles and 70% transparent DEM color ramp, (b) slope raster, (c) positive openness, and (d) hillshades highlighting probable houselots and architecture.

Different ridges likely had different functions. Some have argued that they accumulated as a side effect of farmers clearing rocks from fields (Carrasco Vargas et al. 1986:24; Sanders 1979:495). Others argue that the quantity of stone is too large for them to have formed this way at both Río Bec and in Turner's survey area (Lemonnier and Vannière 2013; Turner 1983:91). Ridges running diagonally to the slope could have directed runoff laterally to avoid pooling of water in one place (Thomas 1981:88; Lemonnier and Vannière 2013:403). Near La Milpa, Belize, Dunning and Beach (2004) describe a ridge that directs runoff and eroded soil onto footslope terraces. At footslopes at Chactún, ridges occasionally merge with ditches that continue into bajos (Dunning et al. 2019: 141; Šprajc et al. 2021). Several ridges running perpendicular to the slope of a hill prevent too much water from accumulating in one area of the hill (Turner 1974:120). In other cases, ridges could serve to demarcate agricultural plots or delineate boundaries between household units (Carrasco Vargas et al. 1986:24; Lemonnier and Vannière 2013:406; Lundell 1933; Thomas 1981:88). Though some of these ridges can be small, it is important to differentiate them from the much less voluminous walls, often called *albarradas*, that serve as houselot boundaries at sites such as Mayapan and Chunchucmil and agricultural fields on Cozumel Island (Freidel and Sabloff 1984:84–90; but see Batun Alpuche 2009 and Batun Alpuche et al. 2020 for residential structures among the Buena Vista walls on Cozumel). Given that they are composed largely of stone fill, ridges would have provided dry walking surfaces in the rainy season and given people paths that avoided crops and potentially unstable terraces (Thomas 1981:101; Turner 1974:120, 1983:91). Yet ridges are overbuilt if they functioned merely as boundaries and walkways. For this reason, Turner (1983:91) suggests they served as windbreaks, especially if planted with hedgerows, that would help protect crops from high winds and maintain higher soil moisture by reducing evapotranspiration. Everyone who has written about ridges in the Río Bec area agrees that most of them serve agrarian purposes of some kind. In fact, the excavation of a ridge in northwestern Belize, near Xnoha, revealed a low feature with gravel and rough stones in a clay soil matrix with high organic content. The extension of the trench over a crude retaining wall and about 60 cm into the adjacent plot showed a comparatively less attractive planting surface with a shallow brownish matrix, at least in that location (Kwoka et al. 2021).

### *Rockpiles*

Rockpiles are often discussed in the context of agrarian features though their functions are difficult to discern (Turner 1983:91). On the surface, they lack stone alignments or sharp corners. As possible planting surfaces for fruit trees, they may conserve moisture and help stabilize roots against strong winds (Kepecs and Boucher 1996). Rockpiles may also represent storage piles for stone mulching, another soil/water conservation strategy (Dunning 1992; Dunning and Beach 2004). Given that small rockpiles and natural features are difficult to tell apart in lidar imagery, we do not pursue them closely in this paper.

### *Canals and Wetland Features*

Wetland canals have also been documented in this region, though their form and frequency vary considerably from east to west. In the far eastern portion of the region within the large bajos Morocoy and Acatuch (Figure 1: between Dzibanche and Nicolas Bravo), wetland fields and canals are very common (e.g., Turner and Harrison 1981; though the figure of 2,400 km$^2$ of fields was reported in error instead of the actual 240 km$^2$). These bajos are much lower in elevation than those further west and have a more perennial soil moisture regime which probably allowed them to be developed in a manner similar to the riparian wetlands in nearby northern Belize (Dunning et al. 2006). The development of these eastern fields may be related to the growth of the major urban center of Dzibanche in their midst in the Early and Middle Classic periods (Dunning and Beach 2010). Like the Belizean fields, the Dzibanche area fields are interwoven with canals, some of which tie into the Río Escondido. Probable channelized fields are visible in the NFI 6s G-LiHT strip just east of Dzibanche (Dunning et al. 2019). Yet canals are rare in the two AMIGACarb_Yuc_Centro_GLAS_Apr2013 strips (0s and 1s in Figure 1) that are the key focus of this paper (see below). It may be that wetland modifications tend to cluster near larger sites, such as Dzibanche in the case of the NFI 6s examples, or may reflect the moister conditions of the large bajos in this area.

Near Chactún, Tamchén, and Lagunita, Šprajc et al. (2021) have recently used lidar to document canals that likely drained flooded areas in the wet season, opening fertile soils for farming (Figure 1). Most of these canals are notably different from their larger counterparts near Dzibanche; they are typically less than a meter wide and only 30–40 cm deep, and all occur on at least slightly sloping land along bajo margins or toeslopes. Often the canals articulate with ridges extending into the bajos from adjacent uplands. In short, these canals were clearly intended to drain excess water from the fertile lands around bajo margins and were not part of a system of perennial wetland farming such as those near Dzibanche (Dunning et al. 2019). The bajos in the Chactún area are notably higher in elevation and more seasonal in their moisture regime than those farther east. Some canals in the Chactún area also flow into reservoirs, as is the case for a canal at Becan (Thomas 1981:23). Since wetland features are scarce to absent in the lidar captures we focus on in this study, we discuss them sparingly below.

### *Chronology*

While there is evidence of terrace construction in the Late Preclassic in other parts of the Maya world (Beach et al. 2015; Wyatt 2008), Río Bec agrarian landscapes were predominantly constructed in the Late Classic period. At Becan, Thomas trenched eight linear features, and pottery from these trenches indicates Bejuco phase construction dates (600–730 CE; Ball 2014). Šprajc (2020) trenched three terraces near Chactún, all of which were Late Classic features. Turner's excavation data also suggest that major terrace construction occurred in the Bejuco phase but may have begun in the preceding Sabucan phase (450–600 CE; Turner 1974:121–22, 1983:118). Eaton's excavations of houses located east of contemporary Xpujil and directly associated with the terraces excavated by Turner revealed pottery dating exclusively to the Bejuco phase, with the exception of one structure, Op21d, which had subfloor pottery dating to the subsequent Chintok phase (730–830 CE) (Eaton 1975:70). The ridges, terraces, and elliptical rockpiles excavated in the nuclear zone at Río Bec all date to the Late Classic (Kanlol, 550–700 CE, and Makan, 700–850 CE, phases), contemporaneous with most of the architecture in this 159 ha zone, though circular rockpiles date to the late part of the Early Classic (Iximche phase: 425–550 CE) as well as the early part of the Late Classic (Kanlol phase) (Lemonnier and Vannière 2013:402). Taladoire et al. (2013:361–63) believe that occupation prior to the Late Classic has been underestimated (see also Carrasco Vargas et al. 1986); the circular rockpile might be a "dwelling system built with unworked stone and perishable materials, largely abandoned by the beginning of the Late Classic period" (Nondédéo et al. 2013:386). Of course, some large Río Bec region sites, such as Kajtun, have evidence of substantial Preclassic and Early Classic settlement (Nondédéo et al. 2013:379). Even so, we accept the conclusions of all previous authors that the terraces, ridges, and directly associated housemounds date to the Late Classic period, likely with a seventh century/Bejuco phase apogee (see also Turner 1990).

## METHODS

Publicly available G-LiHT lidar data (Cook et al. 2013) have yielded a large sample of settlement and agricultural features. Chase et al. (2011) have demonstrated the remarkable value of lidar data for documenting ancient landscape modifications, and the technique is now common in the Maya area. Though the G-LiHT data were collected to estimate forest biomass in the continental US and Mexico (Nelson et al. 2017), the bare earth digital terrain models (DEMs) are a valuable resource to archaeologists (Golden et al. 2016; Schroder et al. 2020). Discrete, multiple-return laser data were acquired with a VQ-480 airborne laser scanner (Riegl Laser Measurement Systems, Horn, Austria). Data were acquired on April 28, 2013, from a nominal altitude of 335 m AGL, which produces a laser footprint of approximately 10 cm. Each of the transects was flown twice, producing a sampling density of 10 to 15 pulses per $m^2$, with an absolute geopositioned accuracy of <0.5 m based on pre- and post-flight boresight alignments. Ground returns were classified using a progressive morphological filter, and Delaunay triangulation was used to linearly interpolate DEM elevations to a 1 m raster grid (Cook et al. 2013). G-LiHT classified point clouds and higher-level raster products are available for download at https://gliht.gsfc.nasa.gov.

The data used in this paper come from flights made over the states of Campeche, Yucatan, and Quintana Roo. The G-LiHT lidar coverage takes the form of long transects that, while narrow, extend further than most contiguous areas of lidar coverage, which often focus on ancient urban centers. Since the G-LiHT strips were not selected with archaeological goals in mind, they have the advantage of not being biased toward large sites and therefore provide useful information about non-urbanized landscapes and the distribution of cultural features in rural areas (Golden et al. 2016:295). We focus on the lidar strips depicted in Figure 1 (AMIGACarb_Yuc_Centro_GLAS_Apr2013, AMIGA Carb_Yuc_South_GLAS_Apr2013 3s, and AMIGACarb_Yuc_Centro_NFI_Apr2013 5s and 6s), with particular attention to AMIGACarb_Yuc_Centro_GLAS, which consists of two north/south transects (labeled GLAS 0s and 1s in Figure 1), each approximately 300 m wide, covering a total of about 113 $km^2$. We created DEM visualizations using the Relief Visualization Toolbox (Kokalj and Somrak 2019). We used ArcGIS 10.7 to examine the visualizations, mark features, and make calculations.

Several archaeologists (Horn and Ford 2019; Reese-Taylor et al. 2016), ourselves included (Hutson 2015; Hutson et al. 2016), stress the importance of ground-truthing lidar data. Though we have not personally ground-truthed the data in the G-LiHT transects, each of the major types of features we focus on—terraces, ridges, and architectural platforms—is already extremely well-documented by on-the-ground mapping in the same area (Benavides 1995; Carrasco Vargas et al. 1986; Eaton 1975; Lemonnier and Vannièrre 2013; Thomas 1981; Turner 1983). In particular, ground-truthing of lidar data (some done by coauthors of this paper) in and around Yaxnocah (Reese-Taylor et al. 2016), Xnoha (Guderjan 2018), and Chactún (Šprajc et al. 2017) shows that features with the exact same lidar signatures that we have interpreted as terraces, ridges, and architectural platforms in the G-LiHT transects are indeed terraces, ridges, and platforms on the ground. In other words, rather than purporting to find previously unknown feature types, we are merely documenting larger-scale patterns of feature types that have been confirmed on the ground many times over. Furthermore, linear features such as terraces and ridges are easily spotted when a variety of DEM visualizations are used simultaneously (see Figure 3; Chase et al. 2017; Millard et al. 2009). Horn and Ford (2019: 174) found that lidar visualizations did not clearly show many ridges in the vicinity of El Pilar, Belize, yet these particular ridges appear to be substantially smaller than the clearly visible ones in our area. In any event, Horn and Ford's results suggest that the number of ridges located might be an underestimate. As a final precaution for working with data that we have not personally ground-truthed, we take a conservative approach for trickier interpretations, such as what counts as a probable housemound. Excavations by Eaton (1975) are important here because he focused on housemounds in the same rural uplands that appear on the lidar transects. Excavations of small structures by Thomas (1981) near the monumental core of Becan and by Lemonnier and Vannière (2013) at Río Bec are also important, though these come from areas of higher settlement density as compared with the G-LiHT transects (see below). The G-LiHT DEMs contain many housemound-like features larger than 50 $m^2$ and many features smaller than 50 $m^2$ with the elliptical or quadrilateral forms that are hallmarks of houses excavated in the region. Yet because lidar DEMs can be ambiguous with regard to small buildings (Hutson et al. 2016), we used 50 $m^2$ as a cutoff. In other words, we digitized features less than 50 $m^2$ but did not include them in counts of potential housemounds. Such a cutoff is overly cautious since excavations show that many houses have a footprint that is well under 50 $m^2$ (Eaton 1975). Thus, the 50 $m^2$ cutoff generates many false negatives (overlooked housemounds) while drastically minimizing false positives (non-housemounds [natural features, anthropogenic but non-domestic rockpiles, etc.] incorrectly classified as housemounds). To adjust for false negatives, we used data from on-the-ground mapping projects to derive a correction factor (see below).

## RESULTS

### *Intensive Agriculture*

We begin by showing how the G-LiHT data and other lidar mapping largely confirm Turner's (1983:61) conclusion that the Río Bec zone is indeed a broad area of intensive agriculture. Turner's findings suggested that the area of dense agricultural features extends 62.5 km north of the town of Xpujil, 13.8 km to the south, 77.7 km east, and 96.2 km west—a total of about 10,000 $km^2$. The G-LiHT data add more detail about the extent and nature of the area of dense agricultural features. The northern extent is comparatively clear and marked by "Northern Limit" points in Figure 1 on the transects labeled GLAS 0s and GLAS 1s. South of these two points, the average terrace and ridge density is 96 linear meters per hectare of uplands whereas north of these two points, the density is 2 linear meters (lm) per hectare. On the transect labeled GLAS 0s, the area north of the "boundary" (Northern Limit 2) is marked by a 16 km stretch of bajo-like flatland with no settlement whatsoever; further north, the intensive agricultural landscape does not resume. Further to the east, on the transect labeled NF1 6s, located 76 km east of Xpujil, terraces and ridges are abundant and possible wetland fields can be seen in the Bajo Morocoy wetlands (Dunning et al. 2019, fig. 20; Turner and Harrison 1981). In the transect labeled NF1 5s, agricultural features are far less common, with a density of 22 lm per hectare of uplands. To the south, the G-LiHT strips end approximately 37 km southeast of Xpujil, where terraces and ridges continue to be abundant. In fact, 40 km south of the southern end of the G-LiHT transects (68 km southeast of Xpujil), terraces and ridges fill the uplands near Xnoha, Belize (Guderjan 2018). About 47 km west of Xpujil, linear features are rare in the strip labeled GLAS 3s in Figure 1. There are 1,002 lm of terracing and 202 lm of ridges in a 24.7-km-long lidar strip covering 9.15 km$^2$—a combined density of only 1.3 lm per hectare. Lidar mapping in the Chactún area, 20 km northwest of Xpujil, reveals extensive terraces and ridges (Šprajc et al. 2017). In sum, lidar data suggest that the Río Bec zone of intensive agricultural features extends less far to the west than Turner noted, but at least as far to the east, about as far to the north, and further to the south or southeast, encompassing an area of perhaps 7,000 km$^2$ or more. Notably, this zone of concentrated agricultural landesque capital is not tightly bounded but grades into surrounding areas where ridges and terraces are less common. Its spatial correspondence with examples of Río Bec style architecture is fairly strong, but imperfect, with outlying examples of structures extending as far south as Calakmul.

Based on a sample of 12.8 ha (sites 1, 2, 10, 12, 14, and 16), Turner (1983) reported a density of 424 m of linear agricultural features (both ridges and terraces) per hectare. In the 1,332 ha of uplands in the segment of the G-LiHT transects with concentrated agricultural features, we recorded 96 lm of agricultural features per hectare, as noted above. In other words, Turner recorded a density more than four times higher than we did. Part of this discrepancy results from ground mapping of plots that had many visible features but not observing areas beyond these plots where density drops. In other words, ground mapping captured areas of higher density while the lidar mapping captured more of the variance across the landscape. To estimate what portion of this discrepancy has to do with the vagaries of sampling and heterogeneity in the density of agricultural features across the region, we compare an area where the G-LiHT transects come very close to one of Turner's mapped areas: site 14, located 34.7 km east of Xpujil and approximately 200 m from a G-LiHT transect. The density of linear agricultural features in site 14, which measures 6.187 ha, is 228 m per hectare. In the G-LiHT upland area closest to site 14 we recorded a density of 156 m per hectare (in an area of 60.5 ha). Thus, in this area, Turner's density is in fact only 50% greater than ours, as opposed to more than four times greater. Small linear features not visible in lidar imagery (Horn and Ford 2019) could account for some of this 50% discrepancy. Thus, the G-LiHT results approximate Turner's results on the eastern part of the Río Bec terracing zone, leading us to conclude that the amount of linear features in this eastern area is indeed lower than to the west.

Though many earlier projects in this area have not commented on wetland fields, candidates are visible in bajos in the G-LiHT transect labeled NFI 6s in Figure 1 (Dunning et al. 2019) and have been ground-truthed in the Chactún area (Šprajc et al. 2021). Though they are extremely rare in the strips labeled GLAS 0s and GLAS 1s in Figure 1, there is evidence for the use of bajo margins in the form of footslope terraces (Figure 4a). Ridges descending hillsides sometimes extend a few meters into bajos (Figure 4b). Dunning et al. (2019) note that aggradation of eroded sediment on bajo margins often creates deeper soils that would have been advantageous for crops such as manioc and malanga, which do not thrive in thinner upland soils (see also Sheets et al. 2011). These cumulic soils would have been well suited to other crops as well, including maize and cotton (Dunning et al. 2019).

Table 1 compares Turner's data and the G-LiHT data with two other carefully mapped agricultural landscapes in the Río Bec region, not to mention other locations. Around Río Bec Groups A, B, C, and D, the Río Bec Project (Lemonnier and Vannière 2013) very carefully mapped 50 ha (including 44.6 ha of uplands), and Thomas mapped 171 ha of uplands at Becan. Our digitization of linear features at Becan and Río Bec yielded the data in Table 1. It should be noted that Thomas's maps do not distinguish between terraces and ridges. Río Bec clearly has more terracing than the G-LiHT transects, and the G-LiHT transects have more ridges. In any event, Río Bec has nearly double the linear features per hectare than the G-LiHT area, whereas Becan has only slightly more features than the G-LiHT area. We return to a discussion of intensity of agricultural features as a proportion of population in the discussion section, following the presentation of population data.

The pattern of ridges found in the G-LiHT transects throws light on their function and the social circumstances of their creation. In many places the ridges create enclosures (Figure 3d), and we have documented dozens of enclosures that contain structures. There are also enclosures without architecture inside. Occasionally terraces serve as parts of the enclosure boundaries. Thus, as others have noted, ridges (and occasionally terraces) served as boundaries for both houselots and farm plots (other functions are also possible but not tested by the current data). Enclosed spaces often abut each other such that they share the same ridge as a boundary. As presented previously (Golden et al. 2016, fig. 12), ridges conjoin and diverge in several directions, forming interconnected networks as opposed to a series of discrete segments. A single network or web can contain more than a linear kilometer of ridge (Figure 3). This important detail signifies that multiple households coordinated with each other in the construction of ridges. More than the result of desultory rock-clearing, ridges imply community relations. On the other hand, terraces are generally less interconnected and do not necessarily imply community cooperation.

Agricultural features that run for hundreds of meters clearly imply cooperation above the level of the household, but how far above? At Caracol and elsewhere, long terraces as well as their vast scale and uniform spacing have led some to suggest the existence of centralized management (Chase and Chase 1998:73; Healy et al. 1983; Macrae 2017:207; but see Murtha 2015). At the same time, impressive wet-rice terrace systems in Ifugao (Phillipines) and Bali result not from centralized intervention but village-level work groups and self-organizing processes (Acabado 2013; Conklin 1968; Lansing

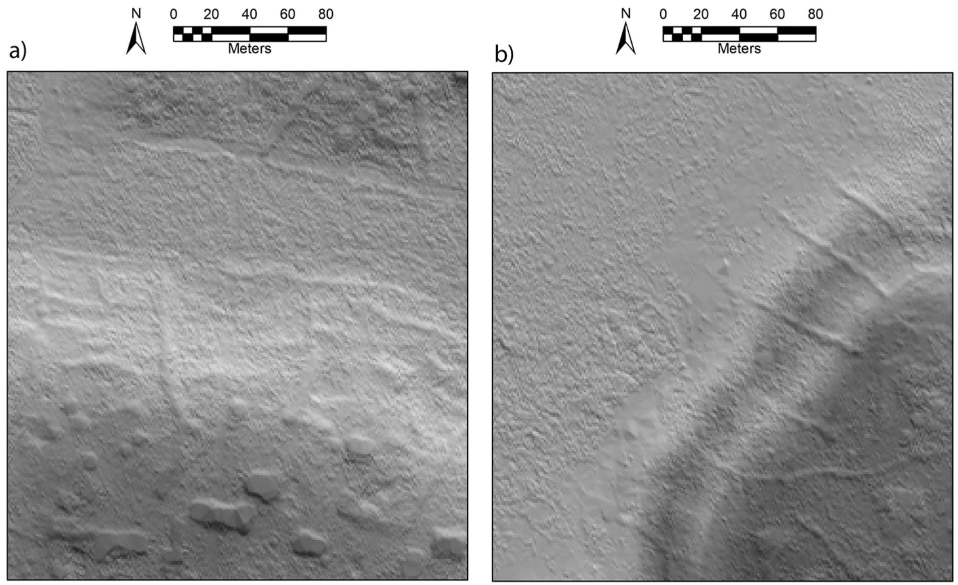


Figure 4. (a) Footslope terraces and (b) ridges extending a few meters into bajos.

Table 1. Agricultural features across several Maya sites and regions

| | Becan | Turner's milpas | Río Bec | G-LiHT terrace zone | Caracol | Guijarral | Barba | La Milpa F.W. Bajo | Waybil | Chan | G-LiHT NFI 5s |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sytematically mapped uplands (ha) | 171 | 106 | 44.6 | 1332 | 92 | 45 | 24 | 36 | 25 | 320 | 475.6 |
| Terracing, linear meters (lm) | — | — | 5646 | 36817 | 54916 | — | 431 | 669 | 31801 | 44040 | 3977 |
| Terracing, lm per ha uplands | — | — | 126.6 | 27.6 | 596.9 | — | 18 | 18.6 | 1272.0 | 137.6 | 8.4 |
| Ridges (lm) | — | — | 2508 | 91089 | — | — | — | 875 | — | — | 6693.0 |
| Ridges, lm per ha uplands | — | — | 56.2 | 68.4 | — | — | — | 24.3 | — | — | 14.1 |
| Total linear features (lm) | 20677 | — | 8154 | 127906 | — | 5940 | 431 | 1544 | 31801 | 44040 | 10670.0 |
| Total linear features, lm per km$^2$ | 120.9 | 424 | 182.8 | 96.0 | 596.9 | 132 | 18.0 | 42.9 | 1272.0 | 137.6 | 22.4 |

1991). Either way, the Río Bec area lacks the scale and uniformity found on the Vaca Plateau, so centralization at the level of the polity seems out of the question. In the Far West Bajo near La Milpa, where intensive features are less widespread than in the G-LiHT area (Table 1), Kunen (2001:342) infers community-level management of terraces and ridges. The bridging argument behind Kunen's inference runs as follows: the absence of houses interspersed among areas with terraces and ridges and the lack of delimited houselots imply that specific households did not claim specific farmed plots. Following the suggestion that farmed plots were not claimed by specific households, Kunen believes these plots were managed by small communities consisting of multiple households and that these households pooled their labor. The situation in the Río Bec area differs since houses are interspersed among ridges and terraces, and these linear features occasionally delimit houselots (Figure 3). Thus, while households on the G-LiHT transects must have coordinated with each other in the construction of features that stretch for hundreds of meters, they may not have farmed cooperatively. Intervention by authorities from distant population centers seems unlikely, as Turner (1983) concluded, and would probably have been counterproductive. The pattern of households sprinkled among demarcated land with diverse slope conditions and using varied combinations of terraces, ridges, and rockpiles suggests a smallholder system (Netting 1989) where the imposition of centralized control could disastrously negate each family's hard-won local ecological expertise accumulated over generations (see also Dunning and Beach 2004:7). We do not imply, however, that such farmsteads were totally independent. Many were likely part of regional political economies (Garrison et al. 2019) and/or commercial systems (King 2015). In sum, we have suggested three social relations of labor: (1) polity-level centralization, (2) cooperation between neighbors, and (3) householding/smallholding organization. We see evidence for the second and third options.

In addition, the patterns formed by interconnecting ridges and terraces are not simply imposed over the landscape by the Maya. Their irregularity, the occurrences of non-enclosed units, the absence of structures in others, the conceptualization of an animate environment, and observations on the ethnoecology of the Yucatec Maya (Barrera-Bassols and Toledo 2005) suggest the likelihood of a pattern that follows an emic perception and classification of the environment and is organized at the community level, through cooperation. Mayanists classify major types of terraces based on their relationship to natural slopes as a way of highlighting a terrace's impact on a planting surface, but the slope is only one factor among others (such as soil and vegetation) that can also be thought to have an impact and that combine to form a mosaic of different possible planting surfaces or landscape units, each with their own characteristics. The patterns we see might be a vestige of this perception of the environment.

### *Architecture and Population Density*

The G-LiHT strips contain a large variety of architecture, including isolated structures, patio groups, basal platforms, and causeways. Eaton (1975) excavated several structures in this area and found that most were housemounds. It is therefore likely that the majority of the structures visible in lidar are also housemounds. Yet before tallying probable housemounds as a way of getting at population density, we have to confront the problem, discussed in the methods section, of false negatives. Recall that, unable to ground-truth structures personally, we digitized anything that looked like a structure but took the conservative approach of including in the present analysis only those entities larger than 50 $m^2$. Since many features smaller than 50 $m^2$ (including all eight houses excavated by Eaton) are housemounds, our 50 $m^2$ cutoff means that we have undercounted the number of housemounds, inviting the creation of a correction factor. Of the 189 structures that Turner mapped, examination of his maps shows that roughly 50 (26.5%) measured less than 50 $m^2$. Thus, we could add 26.5% to our lidar counts to correct for false negatives. Near Becan, of the 422 rectangular platforms, 59 vaulted structures, and 198 type 4 elliptical/circular structures mapped by Thomas, our digitizations show that 49% of these are less than 50 $m^2$ (and larger than the proposed 20 $m^2$ minimum for a nuclear family; Ashmore 1981:47). At Río Bec, our digitizations of the mounds in the 1.59 $km^2$ mapped by the Río Bec project (Lemonnier and Vannière 2013) show that 23.4% measured less than 50 $m^2$. But this area represents one of Río Bec's two main concentrations of monumental architecture (the "central concentration") and contains three of Río Bec's mostly highly ranked monumental groups (A, B, and C; Merwin 1913; Nondédéo et al. 2013:381), skewing the sample toward larger buildings. Therefore, this sample does not serve as a good analogy to the G-LiHT terrain, which has far fewer monumental groups. Splitting the difference between Thomas's and Turner's percentages (26.5 vs. 49) yields a correction factor of 37.8%.

In the G-LiHT transects labeled GLAS 0s and GLAS 1s in Figure 1, we located >2,500 structures in the entire 113.4 $km^2$. In the area of dense agricultural features, which covers 37 $km^2$ and contains 1332 ha of uplands, 1178 structures larger than 50 $m^2$ are identifiable in the lidar imagery, as well as 74 basal platforms. These platforms support 117 structures, with between 0 and 8 per platform; the most common number of structures per platform is 1. The 37.8% correction factor for structures likely to be smaller than 50 $m^2$ brings the total up to 1,623. Assuming that each of the 10 basal platforms without structures on top supported a single housemound made of perishable materials, we would add 10, bringing the total to 1,633, or about 123 structures per $km^2$ of uplands. Across the entire 37 $km^2$ area of dense agricultural features in the G-LiHT strips, including bajos, the structure density is 44 structures per $km^2$. In their 144 $km^2$ lidar swath around Chactún, Šprajc and colleagues (2021) counted 8,794 structures, a number they believe is conservative, yielding a density of 61 structures per $km^2$. One possible reason why this density is higher than the 44 structures per $km^2$ we found is that Šprajc's area includes three large centers (Chactún, Lagunita, and Tamchén). Turner (1983:91, app. 1) identified 142 housemounds and 47 larger structures (>10 m on a side) in an area of 1.06 $km^2$ of uplands, yielding a structure density of 178 total structures per $km^2$ of uplands as compared with our figure of 123 per $km^2$. Though most of Turner's mapped plots were rural, eight of them fell within a swath along highway 186 within a few kilometers of Becan, Xpujil, and Chicanna. Discarding these eight parcels drops the density to 170 structures per km$^2$ of uplands. Thus, Turner's and Sprajc's densities are higher than ours, but not wildly so.

We now compare the G-LiHT data with two nearby settlement areas much more closely associated with monumental architecture: Becan and Río Bec. The Becan sample consists of the 3 km$^2$ area mapped by Thomas outside of the ditches. Thomas (1981:109) calls this Becan's sustaining area. The Río Bec sample includes the 1.59 km$^2$ nuclear zone (Lemonnier and Vannière 2013:398). As noted above, this area contains one of the two main concentrations of monumental architecture at Río Bec and could potentially be called urban. Unlike Thomas's sample, the G-LiHT transects do not come close to any centers comparable to Becan and largely lack the kinds of monumental groups found at Río Bec, although the west G-LiHT transect does cross a dense (>200 structures per km$^2$) cluster of mounds, about 33 km east of Xpujil, with a causeway running at least 500 m long, terminating at a 7,000 m$^2$ basal platform supporting eight structures.

As Table 2 shows, Becan and Río Bec have similar settlement densities, which are about three times as high as in the G-LiHT transects when looking at uplands. Therefore, in the context of the Río Bec region, the G-LiHT transects pass through what might be called rural areas. In addition, Table 2 shows that if we look just at structures that are larger than 50 m$^2$, on average the structures in the G-LiHT area are about twice the size

Table 2. Architectural data from Río Bec area mapping

| | Turner's milpas | G-LiHT terrace zone | Becan | Río Bec |
|---|---|---|---|---|
| Hectares systematically mapped | 106 | 3700 | 300 | 159 |
| Hectares systematically mapped uplands | 106 | 1332 | 171 | 104.7 |
| Housemounds | 189 | 1558 | 511 | 332* |
| Number of structures per km$^2$ | — | 42.1 | 170.3 | 209 |
| Number of structures per km$^2$ uplands | 178.3 | 117.0 | 298.8 | 317 |
| Number of structures >50m$^2$ | 139 | 1153 | 287 | 147 |
| Total area (m$^2$) | — | 193101 | 22461 | 25450 |
| Area per structure (m$^2$) | | 167.5 | 78.3 | 173.1 |
| Structures m$^2$ per km$^2$ in uplands | — | 14497.1 | 13135.1 | 24307.5 |
| Number of basal platforms | — | 74 | 66 | — |
| Total area of basal platforms (m$^2$) | — | 76755 | 49357 | — |
| Average basal platform area (m$^2$) | — | 1037.2 | 747.8 | — |
| Area of platforms and off-platform structures (m$^2$) | — | 254458 | 55518 | — |
| Structures and platforms per km$^2$ of uplands | — | 19103.5 | 32466.7 | — |

*This figure does not include 153 rockpiles, many of which are likely residences as those outside the ditches at Becan. In other words, though the G-LiHT area has a lower structure density, its structures are larger and might have housed more people. Table 2 also shows that basal platforms at Becan and in the G-LiHT area are about the same size but much more common at Becan than they are in the G-LiHT area. Thus, in terms of total area of constructed space, the Becan area has more than double that of the G-LiHT area.

Nondédéo et al. (2013:388) note that within Río Bec, the number of domestic patio groups, representing 24.8% of the total spatial layouts of dwelling units in the 1.59 km$^2$ nuclear zone, is low compared with the southern lowlands. The G-LiHT data show a similar pattern: there are 63 patio groups in the area of dense agricultural features, and these groups represent 16.8% of the total structures. Thirty-three of these patio groups are on top of basal platforms. The rest of the basal platforms support one or no visible structures but could be considered just as formal in layout as a patio group. It would be possible to rank architectural groups, as Nondédéo et al. (2013) have done for the Río Bec micro-region and the Río Bec nuclear zone, but a ranking would not be very meaningful for the G-LiHT transects because the areas contained in these transects do not comprise a single micro-region or "site," much less a community. Lemonnier and Vannière (2013:398) conclude that the agrarian features in the Río Bec nuclear zone did not merely support agriculture, they also "determined both the form and structure of settlement as well as how it functioned at a local scale." In other words, agrarian features produced and reproduced social differentiation and gradients of power. This phenomenon is not evident in the less densely populated G-LiHT transects, where social differentiation is much less pronounced.

In sum, the density of settlement associated with agricultural intensification in the G-LiHT transects—44 structures per km$^2$—seems to qualify as rural in comparison with settlement at Becan and Río Bec. This assessment agrees with results of pedestrian surveys and more recent lidar initiatives across the Maya Lowlands which hold that settlement densities below 60 structures per km$^2$ should be considered "intersite" (Rice and Culbert 1990), "hinterland" (Hutson et al. 2016:133), or rural (Canuto et al. 2018). Certain details change this picture somewhat. First, at 15 structures per km$^2$, the density of structures on the northern two-thirds of G-LiHT strips 0s and 1s—the 76 km$^2$ area with minimal intensive agricultural features—is barely one-third the density of the area with intensive agricultural features. Second, the higher density in the area of agricultural features is artificially low because this area contains a relatively low proportion of habitable uplands: 35% as compared with 44% across 2,144 km$^2$ of lidar coverage in northern Peten, Guatemala (Canuto et al. 2018). In this context it is important to remember that there are 121 structures per km$^2$ of habitable uplands. Finally, the population density in this intensely farmed area is higher than the general population density of the northern Peten. To make this comparison, we follow the same estimation procedures as Canuto et al. (2018). This assumes that between 83% and 92% of the structures are Late Classic—very reasonable given excavations in this area (see Chronology)—and that only 80% to 87% of Late Classic (primarily Bejuco phase) structures were occupied at the same time. This also assumes that between 80% and 83.5% of housemound-like structures are in fact houses and that between 4.4 and 5.4 people lived in each house. Finally, the estimation procedure assumes that the number of structures should be increased by 10% to account for invisible housemounds (Johnston 2004; Pyburn 1990). Following these specifications, the population range would be 113 to 175 people per km$^2$, as compared with the northern Peten range of 80 to 120 people per km$^2$. Šprajc and colleagues' (2021) calculations based on carrying capacity in the area just west of the GLAS 0s and 1s strips suggest that a range of 113–175 people per km$^2$ is too high.

## DISCUSSION

Here we combine the results from the two preceding sections—agricultural features and architecture/population—in order to discuss broader themes such as intensity of landscape modification and regional exchange/interdependency. Intensity of landscape modification can be quantified in many ways, but all approaches should involve agricultural constructions in some kind of relation to population. Table 3 provides information on linear meters of agricultural features per architectural structure from a number of sites. These data are quite rough given that in many cases we do not know which structures are contemporary with which agricultural features. Furthermore, even when a set of terraces dates to the same time period as a set of structures, the terraces may have been built gradually across that time period, indicating relatively low labor investments per person per year, or all at once, indicating a more intensive labor investment for a particular generation of farmers. The case of Waybil, Belize, is interesting in this regard. Though Waybil's terracing is the most intensive according to Table 3, Macrae's (2017) excavations show that farmers built these terraces over a long period of time (from the Early Classic to the Terminal Classic) and details of construction changed over time. Finally, Table 3 does not include wetland canals, though these are absent or sparse at most of the locales listed.

The comparison between Becan, Río Bec, and the G-LiHT strips is illuminating given that the agricultural features in both areas date to the Late Classic. Río Bec and the G-LiHT area have roughly similar amounts of agricultural features per architectural structure whereas Becan has about half that density. To the extent that the number of structures serves as a proxy for the number of farmers, the G-LiHT transects have

Table 3. Density of agricultural features per structure from a variety of terraced areas

| | Río Bec | G-LiHT | Becan | Waybil | Barba | Chan | Guijarral |
|---|---|---|---|---|---|---|---|
| Systematically mapped uplands (ha) | 44.6 | 1332 | 171 | 25 | 24 | 320 | 45 |
| Number of structures | 84 | 1633 | 511 | 54 | 33 | 594 | 103 |
| Agricultural features (lm) | 8154 | 127906 | 20677 | 31801 | 431 | 44040 | 5940 |
| Linear meters per structure | 97.1 | 78.3 | 40.5 | 588.9 | 13.1 | 74.1 | 57.7 |

about as many linear features per person as Río Bec and many more than Becan. If accurate, this would indicate that people in the rural G-LiHT area were expending as much labor or more per person on agricultural features than in urban areas. This pattern contrasts starkly with recent findings from northern Peten, where the most densely settled areas contain the highest densities of intensive agricultural features (Canuto et al. 2018). Specifically, in the northern Peten, urban space (150–300 structures per $km^2$), which is equivalent to Río Bec and Becan, and peri-urban space (60–150 structures per $km^2$) contain far more features than rural space, like that of the G-LiHT transects, which contain fewer than 60 structures per $km^2$.

The finding that rural farmers on the G-LiHT transects built many more ridges and terraces per household and therefore invested more heavily in intensive agriculture than urban farmers at Becan connects with arguments for intraregional exchange of food (Dahlin et al. 2005; Drennan 1984; Freidel and Shaw 2000; Hutson 2017; Masson and Freidel 2013:204). The bridging argument runs as follows: when rural people farm more intensively than their urban neighbors, we presume that they produce a surplus and that the surplus helped feed their urban neighbors. Canuto et al. (2018) provide a similar bridging argument for regional food exchange in the northern Peten. Here, farmers in urban and peri-urban areas were unlikely to be able to support themselves, even with intensive agriculture, whereas rural areas could have produced a surplus. We assume the same situation holds for Becan and Río Bec, which were unlikely to be able to support their high population densities (ranging between 400 and 800 people per $km^2$) without inputs from rural areas such as those in the G-LiHT transects.

A different way to look at intensity of agricultural features is to quantify their volume and use this as a measure of the amount of labor invested. Turner published such calculations in 1983, using an admittedly conservative figure of 1.4 days of work per cubic meter of construction (a figure that should probably be doubled) and conservatively equating a linear meter with a cubic meter. Turner arrived at a figure of 20,000 to 40,000 person-days of labor per year to build all of the agricultural features in what he estimated as a 10,000 $km^2$ area. We take a slightly different route, restricting ourselves to the 1,332 ha of uplands in the intensively farmed G-LiHT strips 0s and 1s and comparing the work invested in linear features in this area with the population of this area. We begin with an ultra-conservative estimate. Staying with the 1.4 person-days of work per linear meter, we arrive at 179,100 person-days. Assuming a 200-year period of construction, this comes out to about 900 person-days of labor per year. Following the same population estimates from the previous section, the population for this 1,332 ha area comes to between 4,200 and 6,500 (probably overestimates: see Šprajc et al. 2021). This means that each nuclear family would need to provide only a day or two of work per year to get all the agricultural features built.

With lidar, we can get a less conservative but more accurate estimate of the volume of these features. We have calculated that most ridges amount to about 2 $m^3$ per linear meter. Doubling the work estimate to 2.8 person-days per cubic meter and assuming (via Thomas 1981 and Eaton 1975) that these features were mostly constructed in the

130-year-long Bejuco phase, we arrive at an estimate of 5,509 person-days of work per year. This would mean that each family would need to provide between six and seven days of work per year, plus additional effort for maintenance. This is more demanding, but not a severe burden. A final perspective on investment in landesque capital is worth considering: the ratio of the construction volume of agricultural features to the construction volume of house platforms. Calculating volume in ArcGIS, we found that the ratio to be slightly less than 1, which means that rural farmers invested nearly as much material in building ridges and terraces as they did in their homes.

## CONCLUSIONS

Lidar data collected by NASA greatly expands the sample of terrain with intensive agricultural features in the Río Bec area. Analysis of the DEMs permits a number of conclusions, some of which are of interest beyond the Río Bec region and the Maya world as a whole. At the local scale, the data strongly confirm Turner's original conclusion that the Río Bec area experienced broad-scale agricultural intensification using terraces and ridges. Canals are also present, but their distribution is much spottier. At a broader scale, previous research in the Maya area has led to the proposal of three forms of labor organization in regard to intensive agriculture: (1) centralized planning, as suggested for the Vaca Plateau; (2) planning at the level of small communities, as suggested for the Far West Bajo near La Milpa; and (3) planning at the level of the individual household, as suggested for the rural areas in this study. The interconnection of long systems of ridges documented in this paper, coupled with dispersed homesteads, suggests a mix of strategies 2 and 3, involving household-level planning but also coordination between neighboring households. This coordination took two forms. First, some households shared houselot boundary walls and would therefore have engaged in negotiations of such boundaries. Second, and more importantly, when ridge systems extend for hundreds of meters, passing through what we propose are the smallholdings of various households, neighbors likely pooled their intimate knowledge of local slopes and soils to jointly plan the course of such ridges. They may also have pooled labor for those segments where a ridge or terrace crosses from one smallholding to another. With regard to water-control features in the area around Chactún, Šprajc et al. (2021) produce additional evidence of cooperation. Lidar therefore helps identify collective action, but of a rather small scale often not discussed in archaeology's collective-action literature (e.g., Blanton and Fargher 2008; Carballo and Feinman 2016).

Comparisons of the intensity of terracing and ridges show that rural areas on the G-LiHT transects had agricultural investments on a scale similar to those of the Río Bec site and greater than at Becan. This conclusion contrasts with the pattern documented for the northern Peten, in which rural areas had far less investment in landesque capital than urban and peri-urban areas. At the same time, our findings in the G-LiHT DEMs are very much in line with an idea confirmed for the Peten as well as other areas, such as Northwest Yucatan: regional food interdependency. We do not deny the possibility that kings in distant cities attempted to collect food as tribute. Yet since we do not see evidence for the intervention of centralized authority in the rural agricultural landscapes of Central Yucatan, and since we join others in envisioning rural farmers as enterprising smallholders who could exercise a variety of options (Lamb 2020; Pyburn 1998; Robin 2012; Sheets 2000), it is not far-fetched to consider the existence of regional marketing systems and endorse a complex view of ancient Maya rural economies.

## NOTE

We thank David Stuart, Astrid Runggaldier, Samantha Krause, Timothy Beach and Shery Luzzader Beach for their contributions to the 2020 Sibley conference at UT Austin, where Hutson presented some of these results. Dr. Hank Margolis (Program Manager, NASA Terrestrial Ecology Program) oversaw the G-LiHT data collection with funding from a NASA Carbon Cycle Science award to PI Dr. Ross Nelson (Program Announcement Number NNH10ZDA001N-CARBON). Much of the analysis in the paper was supported by a sabbatical research leave awarded to Hutson by the College of Arts and Sciences, University of Kentucky. Fieldwork in the publications cited was permitted by the Department of Archaeology in Belize, the Insituto Nacional de Antropología e Historia in Mexico, and the Instituto de Antropología e Historia in Guatemala. We thank Tom Guderjan for allowing us to share data from Ruhl's excavations of a ridge at Xnoha. Tim Beach, Marcello Canuto, and Sheryl Luzzadder-Beach improved this paper by commenting on early versions. Bill Turner and two anonymous reviewers added useful suggestions.

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