The Breaking Point:

Land use and Sustainability in the Mayan City of Caracol.

By

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Abstract: Right now, there are more people living in cities than outside of them. At the same time, the sustainability of our cities continues to become less and less certain. Low-density urban settlements have been held up by some as a model for how we could redesign and reimagine our current cities to solve the greatest challenges of the modern urban environment. The problem with using the low-density model is the ‘collapse’ that appears to have occurred in the greatest examples of these cities, most obviously the Classic Maya, and Greater Angkor. This Thesis aims to provide insight into how the agricultural component of Mayan low-density may have been a vital component that led to the ‘collapse’ of the Classic Maya.

This project argues that the rigidity of agrarian systems in the Mayan City of Caracol led to an overtaxing of the land as population levels reached their peak exhausting the soil throughout the entirety of the urban polity. At the same time, changes in the trading systems of the region and the onset of a drought that strained the entire region. The factors came together to fracture the bonds of political power, and force individuals to leave the cities altogether.
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Introduction
Cities are something that most people, especially in the West, know innately, or at least think they do. Even without prompting, most of us will have a similar idea of what is meant: small buildings, narrow streets, huge masses of people crammed together. If these people were asked about what an ancient city might look like, they may add some massive city walls, and pyramids or temples. There has been a growing movement towards adding more green and green space to cities, as well as inserting agricultural production, at least on a small scale. The hope is to make cities more livable and sustainable as the human population grows and land becomes more scarce. While there is plenty of Historical and Archaeological evidence of the “classic” idea of a city the first known cities in the world in Mesopotamia follow this mold, but there is also evidence of so-called “garden-cities” throughout the Yucatan, Southeast asia, and some parts of Africa. One of the mysteries of these cities, comes from the fact that, unlike mesopotamian cities which have clear documentation on why they were abandoned or destroyed, these “garden-cities” appeared to be abandoned without, in many cases, a clear reason. Understanding what happened there could be vital to the hopeful vision of the future.

The difficulty in understanding “garden-cities” comes from their other name low-density cities (garden-cities is a relatively romantic view of these cities, a closer approximation would be a Jeffersonian city, where every citizen is also a farmer. Each family group would hold a small plot of land surrounding their home, which they would farm for food for themselves and possibly for sale in markets. I will call this type of farming small shareholder agriculture. This goes directly against the notion presented above of cities inherently having high population densities. To explain why these can be called cities at all, we need to understand how the theory of city formation and development changed over time. The “classic” idea of the city, which goes back to the works of the 19th century historian Numa Denis Fustel de Coulanges and 20th century
archaeologist V. Gordon Childe (as cited in Marcus and Sabloff 2008), follows this logic. In his book *The Ancient City* (1864), based on his knowledge of Greek and Latin texts, Coulanges argued that cities were forged mainly through social ties, particularly shared religion (as cited in Marcus and Sabloff 2008). An example of his thinking in action, is one story of, the founding of Rome. “A man could not quit his dwelling-place without taking with him his soil and his ancestors. Thus, a circular pit was excavated on the Palatine Hill, and each man threw in a little earth brought from his former home….At this same place Romulus set up an altar, and lighted a fire upon it. This was the holy fire of the city” (Coulanges 1963 as cited in Marcus and Sabloff 2008, 5). Childe, on the other hand worked with Mesopotamian cities, all river based, walled cities and city states.

Later the models of cities and city formation evolved to encompass city formation for non-religious reasons. Childe was key to the maximizing of this change. Firstly he worked to study cities comparatively, and in doing so help understand their formation, growth, rise, and fall of these institutions(Marcus and Sabloff 2008) . This focus on generalities and commonalities allowed us to make testable hypothesis about city formation and fracture, outside of idiosyncratic religious events. Secondly, he introduced the idea of the urban revolution (Marcus and Sabloff 2008). While language as stark as ‘revolution’ may seem extreme, it is important to highlight the radical shift from non-urban to urban.

There were several models of city formation, and social complexity. These theorists were trying to explain/predict how wealth and various types of production would organize in a city organically over time. Some of these ideas include the concentric ring model, with the defining factor being distance from the city center (Burgess 1925), organically shaped districts (Hoyt 1939), and multiple-loci models (Harris and Ullman 1945, all as cited in Marcus and
Sabloff 2008). The modern definition, in *The Handbook of Urban Studies* Defines the City by three elements: ecological, economic, and social (Frey and Zimmer 2001). The ecological element focuses on high population and population density in comparison to the surrounding area; economic, on the high degree of production focused on non-agricultural production, compared to the surrounding area, and the diversity of production. The social element is the most nebulous, but basically, it says that urban spaces have some ‘urban mindset’ that is different from their associated rural counterparts. When considering modern cities, this can make sense. Take New York City, and it clearly displays all three elements. It has a giant, densely packed population, huge specialization, no agricultural production (urban gardens notwithstanding), and as anyone who does not live in New York City will tell you, think about things differently.

In the more recent decades, there has been a recognition of a different style of city, one that lacks the distinctive, concentrated, look of a classic Mesopotamian or European city, but still can encompass the three elements defining a city. These cities, called low-density cities, are found throughout the tropics (e.g., Mayan cities in Mesoamerica, Angkor Wat in Southeast Asia), but are not found in the father northern or southern latitudes (Fletcher 2011). These cities are typified by spread out neighborhoods, interconnected by built paths, with a landscape heavily shaped by human intervention, ranging from terrace systems, to reservoir complexes, to built earthwork fortifications, although they lack distinctive, city walls. They also have agricultural fields interspersed in between the urban neighborhoods, farmed by the residents of those same urban neighborhoods (Fletcher 2011). While cities like Caracol and Greater Angkor are incredible on their own, the unique problem with low-density urbanism comes from a common feature among the greatest examples of this type: their complete abandonment (Fletcher 2011). Due to this seemingly shared fate of low-density cities, there is a debate about the sustainability
of this type of urban design, and whether it is fated for some sort of inevitable “collapse” (Fletcher 2011; Isendahl et al. 2012).

Low-density-based urbanism differs from classic Western conception of cities, in two key ways. They lack a densely populated urban centers, and contain interspersed farmland instead of outside agricultural regions for the food surpluses that feed all the citizens (Fletcher 2011). Furthermore, a low-density urban settlement is typified by a large, built up central building complex, like the Temple of Angkor Wat in Cambodia, or the pyramid complexes of Mesoamerica, surrounded by a vast interconnected set of urban neighborhoods each adjacent to intensively farmed land, farmed by family groups residing in those small urban neighborhoods (Fletcher 2011). In the case of the Maya this took the form of the plaza mound, a built up enclosure, generally with about 3-4 buildings in it, but with some of the largest having more than 30 (Murtha 2002).

Low-density cities were first recognized and used to describe the cities of the Classic Lowland Maya in the 1960’s (Fletcher 2011). As such they are one of the best understood civilizations when it comes to this type of urban design. With the advent of better surveying techniques, and now with LIDAR, the true extent of many Mayan cities have been revealed from under the jungle, showing that low-density cities were part of not only the Classic Maya, but is typical of settlement throughout the Mayan period (Martin 2017).

This thesis will focus on one Mayan city in particular, the city of Caracol due its intensive use of terracing to improve agricultural production (Murtha 2002), and the question of how low-density urbanism interacts with “collapse,” or rather abandonment, of the low-density urban centers. The area of the city of Caracol covered approximately 177 km² (the size of approximately Manhattan and the Bronx (NYS DOH) along the western edge of modern day
Belize, and has over 9,000 identifiable structures throughout the entirety of the settlement, with an extensive terrace network interweaving all the plaza mounds. The city is a vast interconnected system of markets, causeways, settlement groups, and agricultural terraces, with a large built up epicenter similar to other Mayan sites (Chase et al. 2011). It is believed that at its peak in the early 600’s AD, it was home to at least 100,000 inhabitants, with a population density of almost 600 people/km$^2$. This is a higher density than 52 of New York’s 62 counties (NYS DOH). Yet the city was not discovered until 1937, when a woodcutter stumbled upon it by accident (Chase and Chase 2017). The reason the remains of this city were so well hidden is in part because it was a low-density, agrarian city, one that was spread out under a vast area of overgrown jungle. Research has been carried out systematically at the site since 1983 (Chase and Chase 2017).
Figure 1: Map projecting the full extent of the Caracol polity, with a projected radius of 7.5 km. Adapted From Murtha (2002, 131).

Caracol was abandoned earlier than other Classic Maya cities like Tikal or Copan, before the hypothesized drought blamed for the abandonment of those later-surviving cities, which means that we are still unclear as to what precipitated its collapse. This project will be an investigation of the relationship between the intensive use of local farm land by non-mobile farmers, and the demands that cities place on their environment.-Family units at Caracol intensively farmed localized patches of land, which they terraced and worked themselves, unless they lived so close to the epicenter of the city that they were employed in the service professions (Chase and Chase 2017). Because low-density cities such as Angkor Wat, Anuradhapura, or the Classic Maya cities, all dramatically shrunk in less than 100 years, this begs the question: how sustainable is this type of urban design? Did low-density urbanism, specifically localized family farming, in some way contribute to its collapse?

That question requires a multitude of cultural, environment, and political factors to analyze properly. However, if there is any evidence to support the idea that low-density urbanism contributed to its own collapse, then the intensive local farming may have been a factor contributing to its demise (Fletcher 2011). The design of low-density cities meant that citizens did not have easy fall back options if they exhausted the soil, other than leaving. My project seeks to answer the question, did low-density urbanism lead to overtaxing the local environment at the Mayan city of Caracol, thereby forcing the rapid decline and eventual abandonment of the city?

Demystifying “collapse” has been a project among Mayan archaeologists for a long time (Chase and Chase 2017). Firstly, we do not adequately understand what happened during the
process of decline that saw the shift from the massive cities of Caracol, Tikal, etc., to the spread out, slash-and-burn agriculturalists found by the first European explorers (Emerson 1953). Although there are a many possible reasons why each individual city was abandoned, there are some use practices inherent to the low-density type of urban design that exist across all of these cities (Fletcher 2011). This may allow us to test how the particularities of low-density urbanism reflect and influence their long term sustainability. This is important not just for furthering our understanding of the Classic Maya and low-density urbanism in general, but to be able to scientifically assess the sustainability of these so-called garden cities could be incredibly valuable for sustainable urban design in the future (Isendahl et al. 2012). Additionally, it is important to dispel earlier, oversimplified, ideas of “collapse”, exemplified recently in Jared Diamond’s book *Collapse* (2005). Diamond argued that survival was a choice, and that the collapse of cities and civilizations was due to the mistakes and short-sighted decision making. He argued that poor city planning, lavish expense on the part of local elites, led to overpopulation and the failure of the local area to sustain the population (Diamond 2005).

Regardless of the broader implications, the goal of this study is to shed light on the abandonment of Caracol, a Classic Mayan city that experienced its decline unusually early (Chase and Chase 2017). Instead of assuming cities such as Caracol were destined to fail, I will examine whether urban agricultural production typical of low-density cities led to the over-exploitation of local environments to a point where the cities were not able to sustain a growing population past certain density, leading to their abandonment.
Literature Review

Concepts and definitions of cities

Explaining cities, how they develop, and defining exactly what they are was key to the development of urban studies. The General idea of a city describes a politically defined space, with high concentrations of people, segmented into districts by economic class and type of economic activity that occurs there (Frey and Zimmer 2001). Most of the models of city development do not and cannot wholly describe the development of low-density cities, because these cities do not develop distinct districts, are relatively homogenous throughout, and are not highly dense (Fletcher 2011). There is not even an obvious differentiation between elite and non-elite areas within most Mayan cities (Arnold and Ford 1980). In general there are more large residences closer to the epicenter, but these elite residences are scattered throughout the entirety of the city (Arnold and Ford 1980). There is a bigger question, though: Why are low-density cities, called cities?

As mentioned earlier, the first theory of city what defines a city was based on religion. In The Ancient City, published in 1864, French historian Fustel de Coulanges argued that cities could only exist once there is a god sufficiently large enough to have power over everyone in the city. This is based on his idea that cities are born through acts of religious ritual (Marcus and
Sabloff 2008). This method had little by way of predictive or categorical power, since it
describes based on one category, and one particular event. Work was done to try to improve on
this model culminating with V. Gordon Childe, and his idea of the “urban revolution” almost a
hundred years later (Childe, 1950). To him the key factors were:

- Cities must have been more extensive and more densely populated than any previous
  settlements
- Evidence for full-time specialist craftsmen, transport workers, merchants, officials and
  priests.
- Collection of taxes for…
- Truly monumental public buildings
- A ruling class made up of priests, civil and military leaders, and officials
- A system of writing.
- The elaboration of exact and predictive sciences – arithmetic, geometry and astronomy.
- Conceptualized and sophisticated styles of art
- Regular “foreign” trade over long distances.
- A state organization based on residence.

This model is very close to the three element model used by the modern discipline of
urban studies, but places greater emphasis on bureaucratic infrastructure, with his trade
subsidization, system of counting and recordkeeping, and writing system requirements. It is very
useful though in its defining of cities as not just large agglomerations of people, but spaces with
unique, city-specific institutions to tie those people together in the same place (Marcus and
Sabloff 2008).
This model has become further refined, and broader, with the three elements approach focusing on relative population and population density, creative production, and a certain different urban outlook (Frey and Zimmer 2001, 26). Essentially, a city is a place with a lot of people compared to its hinterland, produces lots of interesting things the hinterland does not, and has somewhat different hopes, dreams, ideals, than the hinterland.

Mayan cities

The Maya region stretches from southern Mexico, through Belize and Guatemala, and into northern Honduras and El Salvador. Broadly the Maya are split into lowland and highland, this distinction is not so much spatial as cultural or linguistic (Thompson 2012). The lowland Maya are the great City builders of the Maya region, they built most of the structures associated with the Maya now. Most highland sites are smaller and denser, with a greater focus on mineral resources, where lowland sites exist in two main forms, small scale slash and burn agriculture, called milpa (which still exists today) a three years on 18 years off farming technique (Emerson 1953). The other is low-density peri-urban or urban settlements surrounding huge built up political and ceremonial centers with large common spaces temples and pyramids (Martin 2017). Figure 1 shows the layout of sites throughout the Maya region.
The history of the lowland Maya is divided into three segments the Preclassic (2000 BC-250 AD), Classic (250 AD-950 AD), and Postclassic (1000 AD-Spanish Conquest), with each segment subdivided into early, middle and late (Martin 2017). The Preclassic stretches from the origins of agriculture in the region at around 2000 BC up to the first wave of city building. The largest Temple pyramid of all of the Maya, La Danta was built during the period at El Mirador, and was likely just as large as later cities like Tikal and Caracol (Martin 2017). The Classic period marks two separate periods of dramatic growth in building and settlement size separated by a ‘hiatus’ marking a slowdown in monument building. It is during this period that most of the biggest and most famous Mayan sites were built, particularly Tikal and Copan, and this period was the greatest period of art, writing, and architecture (Webster 2018). The main cultural centers for both the Preclassic and Classic periods were in the more central and southern
parts of the Maya lowlands where there was greater water access due to having actual rivers. In between the Classic and the Postclassic is the “collapse” that I will be focusing on later. The collapse includes a cessation of monument building, including the building of stelae declaring kingships, war victories, or political decrees, coinciding with a rapid and almost complete abandonment of all large political centers of the Classic period (Fletcher 2011). In the Postclassic the main political centers moved to the northern end of the Yucatán peninsula it was during this period that Chichen Itza was built (Martin 2017). There was a significant revival of Mayan culture during the post classic, with the settlements also growing to huge sizes (although they grew denser than their Classic era counterparts), with impressive public monuments, some surviving all the way until the arrival of the Spanish, while their counterparts from the Classic period were swallowed by the jungle and remained undiscovered for hundreds of years (Martin 2017).

While there is a Maya region, and a Maya culture, there is no “Mayan empire” like the Inca or the Aztecs (Chase and Chase 2017). Instead each political center of the Maya existed as a city-state, controlling a hinterland territory and competing with the other large and powerful city states for power and prestige (Chase and Chase 2017). These cities were ruled by kings and a small group of political elites, but practiced symbolic egalitarianism, sharing prestige goods and working to keep up a facade of relative equality among citizens (Chase and Chase 2017).

The enormous and empty monumental centers seem to be the main attraction of many of these sites. They can easily capture the imagination of both the first European explorers, and modern tourists, who flock to some of these places today (Fletcher 2011). More significantly, the monumental centers are just that, centers. They are encompassed by truly massive cities. Mayan cities had a central temple complex, nested within a network of urban neighborhoods, markets,
plazas, and ballcourts, integrated within a network of intensively farmed agricultural land (Chase et al. 2011; Fletcher 2011). ‘Intensively’ farmed takes a number of forms, from extensive hill based farming, swidden agriculture, or extensively terraced. These methods are used to maximize the yield of limited agricultural land, and prolong the viability of the land for cultivation into the future (Fletcher 2011). To understand the significance and viability of low-density Mayan cities, I will be looking away from the centers and focusing on the urban neighborhoods and their relationship to the land.

The abandonment of the great ceremonial centers of the Classic Maya began generally in the 9th century AD (McAnany 2010). This abandonment generally began and proceeded largely non-violently (Fletcher 2011). There is no strong indication that any of these cities were destroyed (Chase and Chase 2017). Caracol, the focus of this study, went from a population of over 100,000 in 700 AD to being completely abandoned in 1000 AD, with evidence of political failure before 900 AD. Interestingly, this is earlier than other great cities, namely Tikal and Copan, which began their declines roughly a century after Caracol. This is part of a global trend of abandonment among tropical societies that follow the model of low-density agrarian urbanism, with Greater Angkor as another key example (Fletcher 2011). To be clear, these cities are not abandoned concurrently, and do not have the same external cause. This does not mean that all examples of this phenomenon disappeared before they could be recorded by Westerners, as Addis Ababa, Ethiopia and Ouagadougou, Burkina Faso, continued to existed as low-density cities into the 19th century. The existence of these cities and their collapse draws two questions: why do these cities appear in these tropical environments, and is there some through line that can explain their abandonment. The spatial confinement of these cities to the tropics seems to be
connected to the productivity of the soils of these regions (Hoy 1984). The Abandonment though, is a far more contentious and unsolved issue (Turner and Sabloff 2012).

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**Hypotheses surrounding the abandonment or “collapse” of Mayan cities**

The mystery of abandonment or “collapse” led to some fantastical, and some catastrophic ideas to explain the seemingly unprompted failure of these incredible centers (McAnany 2010, 144). Part of this misconception is based on misunderstandings of both the speed and the scale of the “collapse”. “Collapse” happened over several hundred years. Figure 1 demonstrates this
using the city of Tikal as an example:

Figure 3: Fry’s conception of the Demographic History of Tikal. Adapted from Fry 1990.
While the decline of these cities was certainly rapid, it was not instantaneous, and it took a long time for them to be completely abandoned. Even so, this narrative of catastrophe, and corresponding mystery, has been brought up about the Classic Maya, as well as in places like greater Angkor, perhaps the greatest archaeological example of a low density city (Fletcher 2011).

Even one of the more careful proponents of “collapse,” Jared Diamond, has had basically all the tenants of his theory, regarding the Classic Maya in particular, challenged by McAnany (2010), Fletcher (2011), Yaeger and Hollodel (2008), and Chase and Chase (2017). His argument is based largely on the failure of the political institutions of the Maya, arguing that they could have and should have foreseen and worked to counteract the ecological damage they were causing to their environments. That would then be compounded by some ecological calamity like a drought, would lead to the implosion of the social and political structure of the cities (McAnany 2010).

In spite of arguments for “collapse” being largely dismissed and countered by Archaeologists, there is still the archaeological evidence of abandonment over a span of a few hundred years, and thus an archaeological mystery to be solved (Fletcher 2011; Chase and Chase 2017). This has led to questions about the sustainability of low-density agrarian urbanism, the breakdown or reorientation of trade relations, and climatic factors (Fletcher 2011; Chase and Chase 2017; Yaeger and Hollodel 2008). Others argue that this type of urban actually is uniquely sustainable due to its relationship to land use, its avoidance of densely packed populations, and ability to avoid the dangers of food shortages, and that “collapse” happened in spite of the advantages of low-density urbanism (Isendahl et al. 2012).
There are also plenty of hypotheses have been raised to explain the data that have nothing to do with the Maya having low-density cities. One of the most successful ideas centers around environmental issues. Drought is a popular explanation, one that was investigated in the Yucatán by Yaeger and Hollodel (2008), with conflicting results, given climatic variation within the Yucatán itself. Some have argued that the decline was largely the result of political forces, changes in trade dynamics and in elites’ behaviour (Chase and Chase 2017). There have also been arguments about soil degradation that center on the long term damage of intensive farming on the same land (Fletcher 2011, 314; Emerson 1953, 58; Douglas et al. 2018, 648). There is some disputation of this due to the advantageous effects of terracing and other practices that at least some Lowland Maya practiced (Macrae and Iannone 2016; Beach et al. 2006; Dunning and Beach 1994).

One serious test of the importance of terracing and the sustainability of Mayan agriculture came from Tim Murtha Jr.’s dissertation (Murtha 2002). He spent several chapters of his dissertation examining the long term contours of agriculture at Caracol. He started by testing the purpose of terracing. He showed through the use of the Erosion Productivity Impact Calculator (EPIC), a model for predicting changes in agricultural productivity, in relation to soil chemistry, rainfall, slope, farming strategies, and crop rotation system, that terracing, at least at Caracol, did not significantly change the yield. Terracing did dramatically improve the long-term sustainability of the land, showing that it was in fact hugely beneficial, and necessary for Caracol to have survived as long, and grown as large as it did. In addition, he created a model for estimating carrying capacity of the land, so he could explain how many individuals, given a specific diet and productivity the land could feed. This model is particularly useful to this project because it both deliberately overestimates the population size, and underestimates the caloric
need per person, ensuring that the result is skewed towards a population size that is below carrying capacity. From this model, he then developed a framework, based on his results from Cohune ridge, on the fringe of Caracol, to describe the decline of Caracol based on changes in agricultural practices to keep up with rising population (Murtha 2002).

For this Project I will be using Caracol as the test case. Caracol is rather unusual among Classic Maya cities. It has extensive terracing systems, which started being used especially early (Murtha 2002). It also peaked early, reaching its maximum population at 600 AD, and beginning its decline by 700 AD, ahead of the proposed drought (Chase and Chase 2017). This means that the collapse of Caracol was not caused by some potentially historically severe drought, and that Caracol had what could be the ideal farming strategy for the weak soils of the Maya region, making its abandonment more surprising, but also a better challenge for low-density urbanism itself, due to the deck seeming to be stacked in the city's favour (Chase and Chase 2017). I will be working to see if something similar to Murtha’s conclusions are applicable when using survey areas from across the entirety of Caracol.

Materials and methods
For this project, I used existing terrace survey maps of Caracol by Chase and Chase (1998), and Murtha (2002). The Chase maps provide a good cross section of different areas of the city, covering four areas (three 1 km² and one ½ km² sections) radiating outward from the epicenter of Caracol named Areas 1, 2, 3, 4. Their relationship to each other is shown in Figure 3. Area 1 is right on the edge of the epicenter, and has the highest population density, and on its northern border, has one of the large political buildings of the actual epicenter with two cause ways extending out from it. Area 2 is sandwiched in between two causeways and is solidly in the most concentrated central portion of the city itself. Area 3 is on the edge of a plateau and is bounded by a causeway on its north west edge in relatively steep terrain. The difficult terrain likely led to a lower than normal density of settlement in this area. Area 3 also contains the end of that bounding causeway on its northern edge, leading to a large open complex not used as a any families home. Area 4 is the farthest of these four from the epicenter and is an area of heavily terraced rolling hills. In all the maps the ring shaped structures with darkened rectangles are house plaza mounds. Each plaza group contains some number of structures and a family or extended family (Murtha 2002).
Figure 4: Map of Area’s 1-4 in relation to each other within the city of Caracol. Adapted from Chase and Chase 1998.
Figure 5: Area 1 (from Chase and Chase 1998)

Figure 6: Area 2 (from Chase and Chase 1998)
Figure 7: Area 3 (from Chase and Chase 1998)

Figure 8: Area 4 (from Chase and Chase 1998)
Murtha did an in depth survey in two 1km² sections of one particular area on the outer edge of the Metropolitan area of Caracol, called the Cohune Ridge (2002). The Cohune Ridge (Figure 7) is far more north than Areas 1-4 and is located near the periphery of the city, with Cohune 1 (Figure 8) being on the east side of the ridge, and Cohune 2 (Figure 9) on the west side. There is a lot going on in the Cohune maps, with their most significant difference from the others being the walled hill strongholds (marked Hill).

Figure 9: Map of Survey at Cohune Ridge (from Murtha 2002)
Figure 10: Cohune 1 (from Murtha 2002)

Figure 11: Cohune 2 (from Murtha 2002)
From these maps, I was able to calculate total terraced area using GIS, a software that integrates spatial data together in one platform and allows for easy mathematical manipulation of that data. With the total terraced area I could then estimate population size, and ideal carrying capacity of each map section.

My methodology will be leaning heavily on the methods of Chase and Chase (1994), their surveying in 1998 and the doctoral thesis of Tim Murtha Jr. (2002). Murtha’s thesis involved estimations of carrying capacity, productivity, and revisions to existing population models, all specifically focused on one outlying ridge of the city. This thesis will be tweaking Murtha’s methodology, due to an inability to carry out any surveys, excavations, or tests at the site itself, and applying this methodology over regions across the entirety of the city. From each of my chosen survey sections, by taking the difference between population and predicted carrying capacity, as a percent of carrying capacity, I could gain a sense of the degree of over/under population for the city at that radius. In order to do this three different values need to be determined for each map section: terraced area, population, and carrying capacity.

Estimated terraced area

To find total terraced area of a map section, I started with one fundamental basic assumption: once at peak population levels, all land that could/needed to be terraced, was terraced. We also know from the existence of home gardens alongside farm fields that all arable land (terraced or otherwise) would be used to grow crops (Murtha 2002). The reason why I did this was that, though reconstructions of Caracol show that there was land within the city limits that was too steep to be terraced, I wanted to overestimate where I could, to guard against the possibility that the final results could be an underestimation, and saying that the land was overtaxed when it was not. In practice, this decision meant that all land other than those areas
specifically marked as not agricultural, including built causeways and plaza complexes, would be counted as farmed agricultural land. This method of intentional over or underestimation, is borrowed from Murtha (2002).

In order to achieve this the map data were loaded into QGIS and, since no georeferencing data were available, they were scaled and measured using the pixel resolution as a ruler. Since each map section was either a 1 km x 1 km or 0.5 km x 0.5 km square 1 pixel became 1 m. To quantify the terraced agricultural land, polygons were hand drawn in QGIS. I took care to keep overlap and gaps to a minimum, as hand drawn polygons are by their nature imperfect for highly precise measurements, but since even with some small loss from gaps in polygons this method is likely still an overestimation of available farmland, this seemed like acceptably small error.

*Estimating population size*

To determine the population of each map section I followed the method developed by Murtha for his doctoral thesis (Murtha 2002). His method diverged from the general standard:

\[
\text{# of structures in survey area} \times 0.8353 \times 5 \text{ (or 7) people per structure} = \text{population of survey area}
\]

The more standard method produced, in his eyes, unrealistically high estimates of population, and I was hoping to use a method that gave me an underestimate. The frameworks for both methods are the same, but the coefficients they use to scale structure counts to human population numbers are different. To start, all the structures within our mapped area need to be counted. I tried to undercounted structures in the map sections. The differentiation between different structures was poor, due to the graininess of these maps at high zoom, so they were counted as one whenever differentiation was difficult. Then the total number of structures is
reduced by some coefficient, in Murtha’s case 25% (vs. 16.65% in the standard model), to account for disuse, non-contemporaneity, demographic variability and structure function. (Murtha 2002, 135). This gives you the number of occupied structures. To then find total population, you multiply the number of occupied structures by the number of occupants per structure. The standard here is 5-7 people per structure, Murtha instead used 3 individuals per structure as a low estimate (low estimate method), and 5 individuals per structure as his high estimate (high estimate method) (Murtha 2002). For the purposes of this project every structure in each map section will be counted, reduced by 25%, and then multiplied by both 3 and 5, to come up with my population estimates.

**Estimating carrying capacity**

Carrying capacity is the maximum population size of a particular species that can be sustained by its environment without environmental degradation. In this example, it refers to the maximum population size of Caracol (or an individual map section) that could have been supported through urban agriculture in a long-term sustainable fashion. Now this does not include trade for foodstuffs, but the question here is whether Caracol could support its population without importing food from other cities and the surrounding hinterland. Basically, testing carrying capacity is checking whether the cities local agriculture provides it with a safety net, or an achilles heel. Calculating carrying capacity relies on a number of informed assumptions: The percentage of total calorie consumption that comes from production in the fields, as opposed to other sources the total calories required per person, and productivity of the fields themselves.

Bone collagen studies showed that more than 60%, and maybe significantly more in an average citizen of Caracol’s diet, consisted of maize (Chase et al. 1998). At this stage I will use
the minimum possible percent Maize, following Murtha (2002), and assume that maize (the main, if not sole product of Mayan farming, excluding home gardens) makes up 60% of the individuals’ diets, with the rest coming from hunted meat, home gardens, and potentially off season bean crops (Murtha 2002). This means that, for my purposes, the total arable land only needs to support 60% of the population for it to be considered viable and the agricultural model to be sustainable.

To find the maize needed per person per year, we can start by looking to more modern ethnographic examples. It has been estimated that between 210 and 250 kg of maize were consumed by modern day Maya populations in the Yucatan, as part of a diverse diet (Benedict and Steggerda 1936). I will use 60% of that high number, 250 kg per year, which amounts to 150 kg per year. This number is in line with Murtha, who uses both 120 and 150 kg/year in his estimates (Murtha 2002).

To calculate the total production, we can again look to the present day for guidance. In modern Belize, the productivity of the maize-producing land is 1237 kg per hectare. Some estimates have placed classic Mayan productivity higher, in the 2,000 to 3,000 kg per hectare range for their home gardens, but estimates for general productivity, of first year milpa at between 900 and 1200 kg per hectare. I will again be taking the high option here, and will take ideal production as 1200 kg per hectare. Carrying capacity can then be found simply by dividing the total agricultural production of the area (mapped terraced area, in hectares, multiplied by 1200 kg per hectare) by 150 kg per person per year.

There is a lot of intentional over an underestimation in this methodology. This is an attempt to mitigate the limitations of a small scale (4 km² of a 177 km² settlement), the lack of soil data (to determine used vs unused land), and limited dietary information. Taken together
these corrections should increase the likelihood of a null result i.e. that the different map sections being tested were all below carrying capacity at peak population. Conversely, if a map section has a population above or very close to carrying capacity it greatly increases the likelihood that the map section was actually above carrying capacity and not placed there due to an error with the model.

**Results**

Using QIS and available maps of Areas 1-4 and the Cohune Ridge, I estimated the Population, with both the high and low estimate methods, and Carrying capacity for those areas (Table 1). All estimates would be for the peak population size, at around 600 AD.
Table 1: Summary of Results

<table>
<thead>
<tr>
<th>Map</th>
<th>Carrying capacity</th>
<th>Population high estimate method (N/%)</th>
<th>Population low estimate method (N/%)</th>
<th>Difference between high estimate and carrying capacity (N)</th>
<th>Difference between low estimate and carrying capacity (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohune 1</td>
<td>368</td>
<td>360 (98%)</td>
<td>216 (59%)</td>
<td>8</td>
<td>152</td>
</tr>
<tr>
<td>Cohune 2</td>
<td>461</td>
<td>401 (87%)</td>
<td>241 (52%)</td>
<td>60</td>
<td>220</td>
</tr>
<tr>
<td>Area 1</td>
<td>125</td>
<td>289 (231%)</td>
<td>173 (138%)</td>
<td>-164</td>
<td>-48</td>
</tr>
<tr>
<td>Area 2</td>
<td>374</td>
<td>604 (162%)</td>
<td>362 (97%)</td>
<td>-230</td>
<td>12</td>
</tr>
<tr>
<td>Area 3</td>
<td>262</td>
<td>191 (73%)</td>
<td>115 (44%)</td>
<td>71</td>
<td>147</td>
</tr>
<tr>
<td>Area 4</td>
<td>417</td>
<td>574 (138%)</td>
<td>344 (83%)</td>
<td>-157</td>
<td>73</td>
</tr>
<tr>
<td>Total</td>
<td>2007</td>
<td>2419</td>
<td>1451</td>
<td>-412</td>
<td>556</td>
</tr>
</tbody>
</table>

The “high estimate method” (5 individuals per structure), suggests three out of the six map sections (Areas 1, 2 and 4) are over carrying capacity. All three exceed the carrying capacity by a significant percentage: 131% over carrying capacity for Area 1, 62% for Area 2, and 38% for Area 4. One other map section, Cohune ridge 1, is close to carrying capacity.

When using the “low estimate method” (3 individuals per structure), we get markedly different results. Only one map section, Area 1, appears to be over carrying capacity (by 38%), and only one map section, Area 2, is close to carrying capacity. To test whether the carrying capacity model might be flawed, I found the average of unusable land versus total land in each plot, and got an average of about 80% in each map section, and then used that number to estimate Caracol’s total carrying capacity. This is not including the area of the epicenter, or ball courts and marketplaces. Extrapolating that over the entire projected 177 km² of the city, the carrying capacity for the entire city is predicted to be 112,572.
Discussion

While the limited nature of this study means that I can provide no definitive answers, the results to point in very interesting directions. Considering the effort put into overestimating Caracol’s, and each individual map section carrying capacity, and in underestimating the population, even limited results could point to far more significant real world consequences.
Implications from models using the low population method

Taking the low estimates as an example. On they own, they seem to imply that even near the height of occupation of Caracol around 600 AD, there was significant surplus, or at least potential for surplus from the arable land in these different areas of Caracol. This seemingly straightforward interpretations becomes more complicated when considering the results of the EPIC simulations by Murtha (2002), meant to test how terracing altered the productivity of soils in the Maya region. Murtha showed that under fallow management systems, where after 1-3 years of cultivation, the land is left untouched for anywhere from 3-18 years, soils still declined between 0.5-2.5 kg of maize production per year. If this is accurate, then by 600 AD, some lands that had been used from the foundation or from early stages of Caracol’s development, could have lost almost half of their productivity, even when using a system that could by no means support the burgeoning population.

Once more intensive annual cropping regimes, where for at least one growing season per year, maize is planted, began to be used throughout the site, let’s say at 600 AD for simplicity, the decline accelerates to between 1-6.3 kg per year. The sustainability of this model is greater in the tropics than at more northern and southern latitudes, because there is often two growing seasons instead of one (Hatfield et al 2017). We believe that this switch happened because there is no other way to support the population at that level without this degree of intensification without significant importation of foodstuffs that is not indicated by the archaeological of epigraphic records. In this case, it would only take 30 years to lose the ability to support one person (150 kg per year) for every hectare of land (Murtha 2002). For the area of the six map sections, this would be a reduction in carrying capacity by 315 individuals out of the 2,007 individual carrying capacity total for every map section used in this project, a reduction of 16%.
While such a decline would not necessarily be catastrophic, it could easily force a change to an even more intensive style of farming like double cropping, where both growing seasons are used to produce the primary food crop, in this case Maize. For any neighborhood, family, or region that was forced to adopt this strategy, their problems would quickly get worse. While double cropping would initially allow for greater production, based on EPIC calculations (that do not include soil exhaustion from mineral depletion), we can predict a loss of almost 20 kg per year of production (Murtha 2002). After 15 years of double cropping, the carrying capacity would be lowered by another 630 individuals, reducing the original 2,007 to 1,062. This is the best case scenario.

Implications from the high population method

Using the higher estimate, the one closer in line with traditional estimates of population size, though still with a higher degree of structure reduction in the model (25% vs 16.65%) (Chase and Chase 1994; Murtha 2002), there are only three map sections that are not over carrying capacity. Area 3 is the only map section relatively close to the epicenter that is not overpopulated.

The high estimate seems to portend catastrophic consequences, but we know from the Archaeological record that the population of Caracol declined slowly over the next century, the decline only picking up after 700 AD (Murtha 2002). So where is the resilience coming from?

Reconciling population estimates with the Archaeological record

There are two main, interrelated possibilities for how Caracol could have continued to exist, albeit with a decreasing population, over a period of approximately a century: external
trade and exchange, and/or internal trade and either sharing or redistribution of food. Both intra-site exchange and regional trade could have propped up failing agricultural lands for some time, but evidence suggests that during the terminal Classic, these trade networks were breaking down (Chase and Chase 2017). This coincides with the ending of symbolic egalitarianism at Caracol (Chase and Chase 2017). Symbolic egalitarianism was a key aspect of many low density Maya cities. Not only was there a lack of sub-regional class divides within the city, but there was a symbolic commitment to making all citizens appear equal. It is known to have ended around this time due to changes in access to prestige goods among commoners, and due to the language of official proclamations. Taken together, with a breakdown in cross-city trade, residents of Caracol would have had to get any extra food they needed from the Caracol hinterland. Depending on the types of agriculture practiced there, however, there may have not been enough to give. At this point in time (around 700 AD), the drought that is believed to be the driving force behind the abandonment of much of the Classic Maya cities was beginning to set in. Without a meaningful support network, Caracol, already starving, faced a choice: stay on land that cannot support you anymore, with elite systems that did not share their wealth, even symbolically, with the rest of the population, or leave, and take your farming skill into the empty spaces of the Yucatán.

Since low-density cities were based on small shareholder agriculture, most of the population spent a significant amount of their time farming, with very few places on the landscape being so densely packed so as not to support this style of city design. At the same time, as population and population density increases, what you have is what you get; if the land a plaza group possess and farms cannot provide for said plaza group, then they either will need to be able to buy the difference in the market, or they need to move, either in part or in entirety, to the periphery of the city or into the hinterland. While daunting, this is not equivalent of asking a
dock worker in Boston during the colonial period to go out into the wilderness and plant wheat, a not wholly uncommon occurrence in that period (McCullough 2001). These citizens of low density cities were already farmers; even if they were artisans or craftspeople, fundamentally farming was a significant component of all of these people's lives (Murtha 2002). With the skills necessary to strike out from the dying city, and mounting reasons to do so, is it really so surprising that cities like Caracol were abandoned?

One important question is whether Caracol, and my approach are likely to be representative of Mayan Cities in particular, or low-density cities in general. My population estimates are meant to be deliberately low, even the ‘high’ estimate method, and to ensure that I undercounted structures when the differentiation between them was poor, due to the graininess of these maps at high zoom, so they were counted as one. Generally there is about 3.6 structures per plaza group (Murtha 2002), and all of my structure counts were under that threshold. Remember that by generalizing my carrying capacity projection over the entire city, I predicted carrying capacity to be 112,572. This number being between the two main population estimates for Caracol, 120,000 and 100,000 (Webster 2018) suggests that my predictions are not significantly over- or underestimating the carrying capacity.

In fact, my results suggest that Caracol probably hit its carrying capacity, and overpopulation beyond this carrying capacity could have instigated the decline. Considering the effects of erosive processes on the soil, as well as decline in soil nutrients, the actual carrying capacity of Caracol at 600 AD, when the population reached its peak, was likely lower still. This hints that even before the actual decline of the city started, Caracol had expanded beyond its own capacity to be self-sustaining, making trade and control of the hinterland more and more important to the city’s survival. At we move later into the 600’s AD and the soil begins to get
more and more heavily overtaxed, this reliance likely became more pronounced. Once those systems began to break down, likely precipitated by the beginnings of the drought and the reorientation of trade away from the older political centers like Caracol, there is very little that holds individuals and family groups to their land within the city. Since the city was no longer self-sufficient on a large scale, citizens’ options were limited, with the best one being to migrate, literally and metaphorically, to greener pastures. Since the other powerful centers, including Copan and Tikal were likely reaching or surpassing their limits at this time (Fletcher 2011), the most logical option for a citizen farmer in Caracol would just be to move out into the hinterland and take up the slash-and-burn agriculture that has been continuously practiced in the Yucatán for thousands of years (Emerson 1953).

Consider the differences, for example, in the way rural and urban people live, their behavioural characteristics, their values, the way they perceive the world, and the way they interrelate. (Frey and Zimmer 2001, 26-27)

The social character of low-density cities is likely what makes them so vulnerable to dissolution once an agricultural turning point is reached. While there is a clear different between the urban and rural spaces in the Maya region, the diffuse nature of their settlements, and the attachment of local people to the local land for some non-significant portion of their livelihoods, narrows the gap between the urban and rural spaces in terms of world view. Recent LIDAR mapping across the Maya lowlands has shown that the degree of settlement throughout the region was higher than expected. Compare the known and ground truthed settlements from the northern area of the Maya lowlands to the settlement density maps post LIDAR mapping (Figs 12 and 13)
Figure 12: Known settlement from existing ground surveys in the northern area of the Maya lowlands

Fig 13: LIDAR mapping of the northern Maya lowlands

(Both figs 12 and 13 adapted from Canuto et al. 2018)
It is clear from Figure 13 that A: settlement is far more extensive throughout the Maya lowlands than previously thought, and B: The amount of what is classified as ‘peri-urban’ is huge, and far higher than expected (Canuto et al. 2018). Taken together with the style of smallholder agriculture practiced to some degree throughout the urban and peri-urban areas of these regions, which makes the distinction between ‘urban’ and ‘rural’ much more of a gray area. This would likely make the quasi-cultural differences that make up the social element far less significant than it otherwise might be. This helps explain why there was nothing holding the city together once trade networks began to change and the basic necessities became harder to come by. While the urban mentality may change how some people see the world in relation to the rural, everyone needs food, water, and shelter above everything else.

Caracol is a low-density city, possibly one of the biggest of the Classic Maya, but its experience of decline does not follow the same pattern as its main geopolitical competitors, Copán and Tikal (Chase and Chase 2017). Caracol began its decline early, before the drought that has been labeled the culprit, or at least an important factor, in the decline of Mayan settlements throughout the Yucatán peninsula (Chase and Chase 2017). Caracol is also unusual in its use of terracing. Caracol took up terracing early, and was more extensive with its use of terraces in supporting its agriculture than other cities (Chase et al 2011). Now, Murtha showed that terracing improves the long term sustainability of land in the Maya context, by dramatically reducing the soil lost to erosion, something that is especially vital in a region with thin soil (Murtha 2002). Because of this, the early decline of Caracol seems even more surprising. It was not uniquely dense, or even uniquely populous, and yet it declined first, despite using an agricultural strategy that should have left them better off in the long term compared to Tikal.
This begs the question of how good of a test case Caracol is for Mayan cities, let alone low-density cities in general.

In the end this result only describes one unique set of circumstances conspiring to bring down a great city. While this work provides hints regarding the fate of other low-density cities around the globe, and regarding the decline of other Maya cities throughout the Yucatán, however these findings should be further tested by examining other low density cities, ones with without terracing, different key crops, and ones in different parts of the world. One result does not make a pattern, which means that I cannot make any concrete claims outside of Caracol. But soil exhaustion and erosion, happen everywhere to differing degrees, and the design of smallholder agriculture is basically written in to the definition of low-density cities. If these two factors were significant contributors to the decline and fall of Caracol, than they could be responsible, in part, for the decline of other cities and societies.

Conclusion
So where does this leave us? What can be said about low-density cities in general, if anything, and what can be said about Caracol specifically from this work? To start, remember the three elements that define the city, the ecological, economic, and social elements. Of the three, the economic and social elements are not just ways to categorize a city, but they are also how and why individuals choose to live in a city. The economic element ensures that citizens have access to a greater diversity of economic opportunity and access to a wider array of goods than they would otherwise living in a smaller community somewhere in the hinterland. Greater economic opportunity has driven the migration to cities for centuries, and is responsible for the incredible growth of cities since the industrial revolution (Frey and Zimmer 2001). The Social Element is perhaps more interesting. The breakdown of trading relationships would have made the land’s ability to provide for the population of the city far more important, at a moment when that was becoming more difficult, making the outlying country seem far more favourable. Especially considering the diminished distinction between the urban and rural in this setting (Canuto et al 2018). Coupling that together with the failure and obsolescence of elites if there is no surplus to extract from the commoners in the cities, and the breakdown of whatever social bonds might have kept the city going past the carrying capacity of the land would not be able to hold the people together, leading to the dissolution of the city.

Overall, the cities of the Classic Maya had startling longevity lasting with their local land being farmed at varying levels of intensity for over 600 years before they began to strain its ability to provide for them. But the style of agriculture, trapped them once their cities grew too big for the relatively weak tropical soils to sustain. While there are flaws this type of City design they are by no means incurable in regions with better soils and access to better composting and fertilizing techniques. While low-density cities do not seem to the the panacea
for the challenges facing modern cities, they do certainly provide some lessons that can inform us today.

Bibliography


complexity as revealed by airborne laser scanning of northern Guatemala." Science 361, no. 6409


Appendix A: Map sections with marked house mounds.

Area 1
Appendix 2: Map sections with mapped in Terraces

Area 1
Note, due to a mistake, the overlapping polygon on the left side is meant to count for the cleared area around the plaza group