1 ANCIENT MAYA SUSTAINABILITY AT CARACOL, BELIZE: IMPLICATIONS FOR THE PAST AND FUTURE

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Long-term archaeological research at Caracol, Belize has revealed a sizeable city with over 100,000 inhabitants at A.D. 650 that practiced intensive agriculture within its urban boundaries. Over 160 square kilometers of the landscape within Caracol was anthropogenic, having been rebuilt to both provide agricultural sustainability for the city's inhabitants and to control the flow of rainwater over the karstic environment. Their landscape adaptions provided the base for half a millennium of sustainable occupation (here defined as the ability to feed family units and provide needed quotidian and prestige items to households). The ancient Maya technologies that promoted sustainable agriculture and habitation in largely rain-fed environments that lacked standing and running water have not been replicated by modern people, but hold the potential to significantly improve modern lifeways.

Introduction

The archaeological investigations undertaken at Caracol, Belize have the potential to offer alternative models of sustainability for the present-day inhabitants of Belize and elsewhere. Current academic literature views sustainability in terms of three realms (Purvis et al. 2019; see Figure 1). The first is ecological and refers to appropriately using existing natural resources in the environment so as not to compromise the future. The second is economic and concerns monitoring development activity relative to people and the environment to create a more usable future. And, the third area is social sustainability, which involves mitigating economic and political impacts, both positive and negative, on humans. All three of these realms are pertinent to the Caracol archaeological data.

Located at an altitude of over 1500 feet in the foothills of a currently unoccupied part of the Maya Mountains, the archaeological site of Caracol once supported minimally 100,000 inhabitants (A. Chase and D. Chase 1994a:5; A. Chase et al. 2011:395-396; D. Chase and A. Chase 2017:186; A.S.Z. Chase et al. 2024) or ¼ of the modern population of Belize in 1% of the area covered by the modern nation. Ancient Caracol housed over 100,000 people in one city covering 260 square kilometers; this compares to 397,483 people in the entire country of Belize (based on the 2022 Census) living in 22,800 square kilometers. The city was sustainable – capable of supporting its population and infrastructure for most of its existence. The agricultural fields within its borders were especially productive (A. Chase and D. Chase 1998; D. Chase et al. 2023; Murtha 2009), partially answering the question of how the ancient Maya were able to sustain

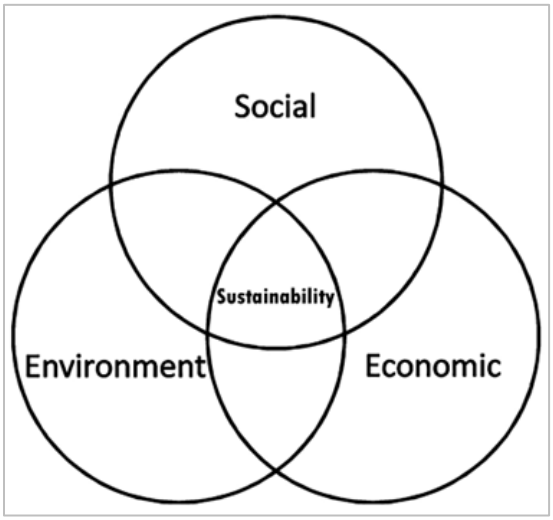

Figure 1. A heuristic view of the factors involved in a consideration of sustainability.

themselves in this tropical environment. The city layout, infrastructure, and economic system further supported centuries of stability.

There are, of course, issues in comparing the ancient Maya with contemporary populations. Modern polities and cities have different technologies, social norms, and institutions than ancient ones. The likelihood that a system that worked for the ancient Maya can be directly lifted out of the past and applied to current situations is low (see, for example, issues with trying to restore the ancient farming practices around Lake Titicaca - Erickson 1988; Erickson and Candler 1989; Chapagain and Raizada 2017). However, Maya civilization can be used to provide comparative inspiration for solving our present-day problems, perhaps even providing new roadmaps (e.g., Fisher 2020; D. Chase et al. 2023). While the ancient Maya of Caracol were dependent on producers outside of Caracol by the Late Classic Period for the bulk of their

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quotidian goods (A. Chase and D. Chase 2015; D. Chase and A. Chase 2020), each Caracol residential group could be self-sufficient in terms of the production of food (e.g. Murtha 2002, 2009). The terraced agricultural fields associated with their households also could create a surplus. Along with surplus items produced through household craft production (see A. Chase and D. Chase 2014; A. Chase et al. 2015), this agricultural surplus could be used to procure quotidian and prestige goods at local markets. The agricultural terraces that surrounded Caracol's residential groups would have required some level of labor organization to construct and, especially, to maintain. The soils in these agricultural fields were all manipulated and laid down as the terraces were constructed on bedrock with the supporting terrace facings and fills built to handle seasonal rainfall and to limit the potential for bursting due to the swelling of saturated soil (Healy et al. 1983:402-406). Technology was, of course, different; the ancient Maya of Caracol did not have modern farm tools and machinery or chemical fertilizers. They relied instead on nightsoil for fertilizer, stone and wood tools for construction, and human labor for farming and harvesting.

While the ancient Maya of Caracol did not have the wheel, beasts of burden, or metals, the level of sustainability, investment in landesque capital, and longevity of the ancient Maya systems can certainly inspire modern solutions. A focus on using Maya archaeological data to inform sustainability issues can look at several aspects of their ancient society, but the most important takeaways from Caracol are water management for rainfall-runoff, nearby fields for local food production, the use of nightsoil and effective waste management, landesque capital improvement of the landscape to enhance agricultural potential, and infrastructure that provided walkable access to markets and other key resources. These systems worked together to decrease inequality for several hundred years.

Sustainability Lessons

Starting with water management, we would note that Caracol did not practice "hydraulic" water management because the features created never utilized pressurized water flow (A.S.Z. Chase and Cesaretti 2019). Instead, the water management at Caracol focused on rainfall-runoff (A.S.Z. Chase 2016a; A.S.Z. Chase and Weishampel 2016). There are no canals or irrigation channels at the site, nor are there large dams or floodgates. However, the full utilization of rainfall through the construction of gently sloped agricultural terracing and constructed reservoirs did allow for an increase in urban green space throughout the city (Stanley et al. 2012: Figure 1). These features created a "garden city" (A. Chase and D. Chase 1987:53). While deforestation may have led to an increase in overall temperature (Oglesby et al. 2010), the soils in the agricultural terracing would have retained groundwater with little effect on the water cycle despite other factors (see Kuang et al. 2024). Both deforestation and the multitude of plants growing on the terracing would have further increased evapotranspiration, adding to an already complicated climatic mix relative to seasonal rainfall predictability and likely having the effect of increasing precipitation (Braun et al. 2023). Caracol's landscape was neither fully denuded nor a modern concrete city where grey spaces negatively impacted the water cycle (see Bogardi et al. 2021). Only the monumental plazas and public building concentrations at the site required overt control of potentially contaminated rainfall run-off. The placement of reservoirs usually atop or on the side of hills in the outlying residential settlement implies that the Caracol Maya recognized the necessity of collecting rainwater that was not soiled by waste. The locations of these constructed features helped the population remain healthy.

Stagnant water can pose health risks if improperly handled, and, as such, modern water management is often a centrally managed urban service (sensu A.S.Z. Chase 2016b; Stanley et al. 2016). While the ancient Maya at Caracol practiced water management at the local level, they also created and maintained large district-level reservoirs near monumental architecture (A.S.Z. Chase 2019: Figure 3; Seefeld 2018:425). While agricultural terracing began as local family construction efforts, as the population increased there would have been some supervisory overlay, especially as the surface flow of water was changed by the construction of these features. Terrace-drainage-level issues were "likely" resolved either through neighborhood norms or through more formal court or political processes at the district level (see A.S.Z. Chase 2024).

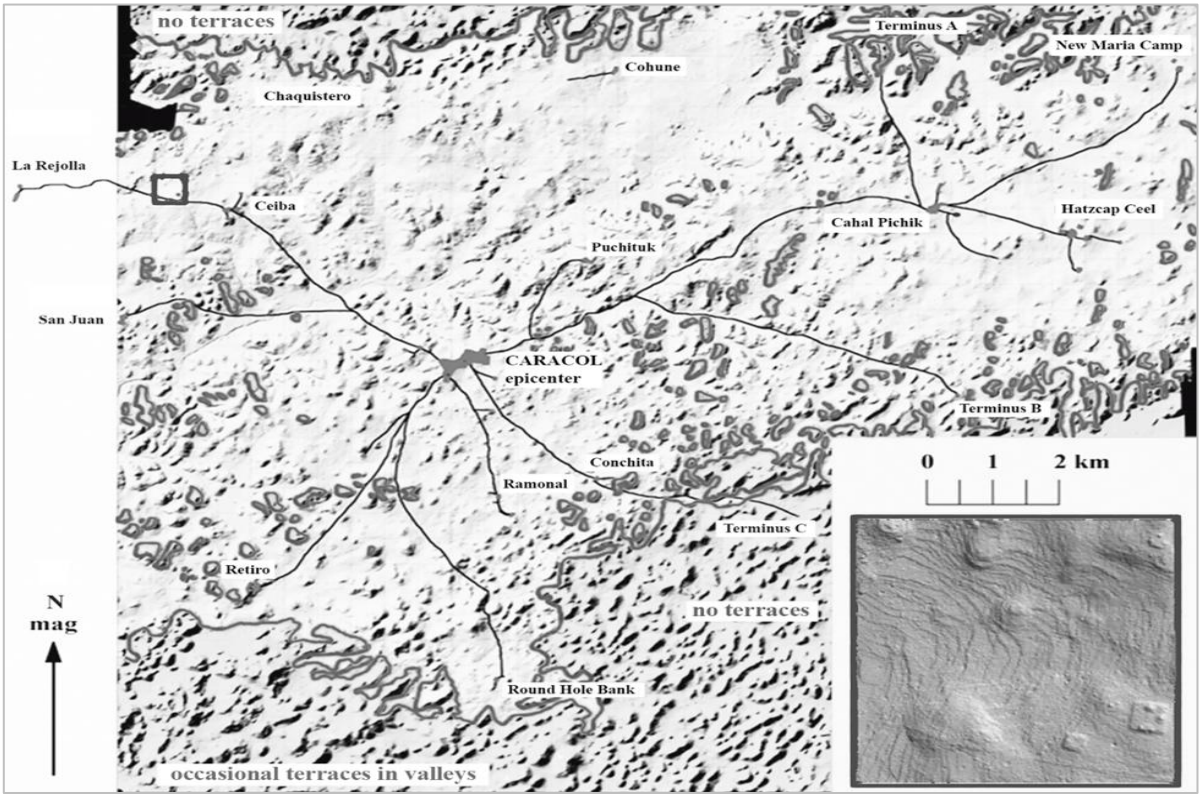

Figure 2. The distribution of agricultural terracing in the core region of Caracol based on the 2009 lidar program, showing that agricultural terraces cover approximately 160 square km of the city's landscape.

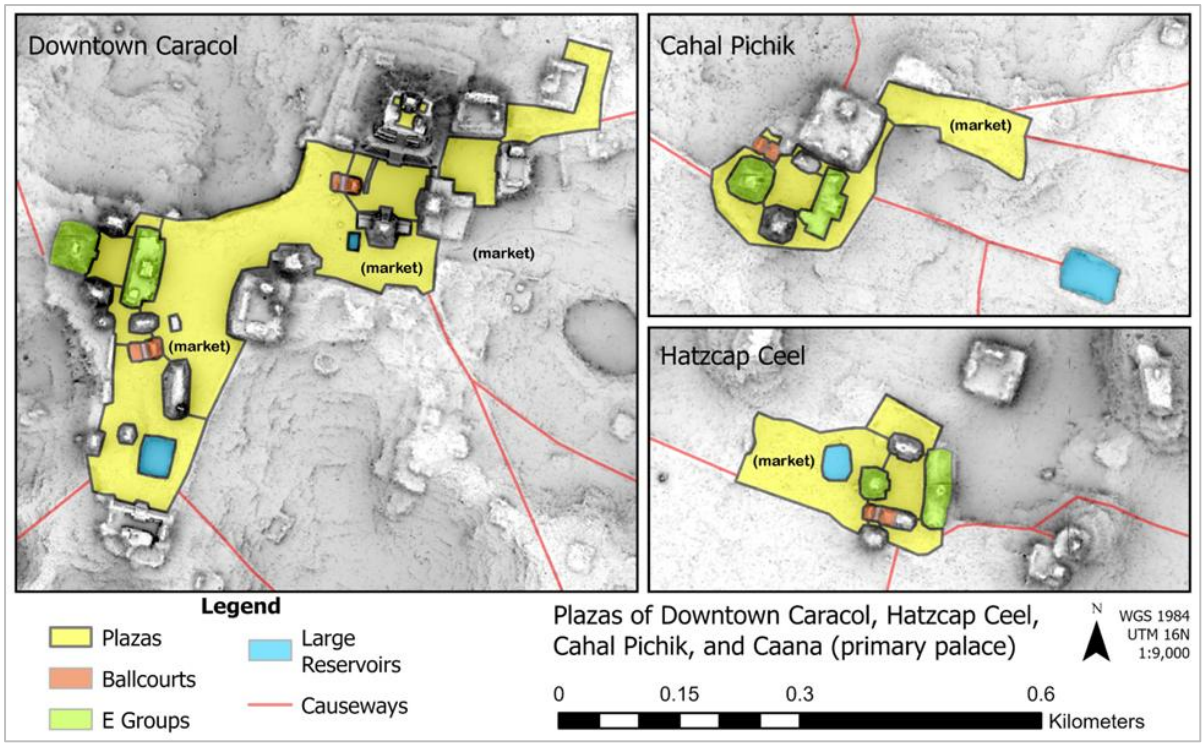

Figure 3. The Caracol epicenter and two of its termini groups (Cahal Pichik and Hatzcap Ceel) showing the distribution of infrastructure like ballcourts, E Groups, reservoirs, and market areas. The replication of infrastructure throughout the city, in combination with easily traversed causeways, make it similar to what is called a "walking city" in modern urban studies.

However, the management of rainfall through landscape planning helped alleviate water requirements, increased aquifer replenishment, and reduced local temperatures (at least in drier climates), partially ameliorating the effects of deforestation.

Caracol's agricultural system provided sufficient production to support its inhabitants (Murtha 2002, 2009). There was likely multi-cropping on the terraced agricultural fields combined with more localized gardens" for specific crops and herbs (Barthel and Isendahl 2013; A. Chase and D. Chase 1983, 1998). The Caracol residential plazuelas would have had access to basic foodstuffs and also could have obtained a wide variety of goods by trading surplus crops or crafts produced at the household level at markets located across the city. There was intensified agriculture at the household level with landesque capital investments (as represented by the agricultural terracing) that probably required neighborhood or district-level support as terrace systems became joined and land disputes ensued (see Figure 2).

Unlike at Caracol where most residential units were self-sufficient in foodstuffs, most urban dwellers today do not grow their food – at least not at large scale. However, small urban "kitchen gardens" like those that encircled Maya residences may be applicable and desirable for creating both green space and local environments for other species of potential use in modern urban contexts. While successful for their era, the household crafting undertaken in each of Caracol's residential groups represents a different level of economic development than is seen in today's large companies and corporations with their far more complex manufacturing and distribution systems based on product replication and standardization. Yet, the Caracol system may mimic in some ways the economies possible in modern urban areas without zoning (Qian 2010; Shertzer et al. 2022).

Soil, especially for agricultural purposes, was important to the ancient Maya (Evans et al. 2021; Vis et al. 2023). Nightsoiling practices allowed the ancient Maya to replenish the fertility of their fields and to dispose of human waste. This reuse closed the P (phosphorus) cycle, one of the elements that easily could have been depleted in tropical soils (Ruyan et al. 2012). Trash was collected and recycled both into fields and new construction projects. Garbage was not built up in the residential areas, presumably meaning that the ancient Maya recognized the health issues involved in leaving garbage in place.

The utilization of a Caracol-style refuse system today would require a restructuring of modern waste-management systems and would likely be viewed by modern social norms as unsanitary and odoriferous. However, the use of nightsoil was widespread before the Industrial Revolution; it was considered a valuable economic resource (Kawa et al. 2019) and was economically beneficial to non-Western countries that focused on this practice (Ferguson 2014). Nightsoil was also well known to the Aztecs and was employed in their chinampa agriculture (Newman 2023). Modern fertilization practices employed in agriculture tend to use not nightsoil but rather "sewage sludge," a byproduct of modern sanitation systems; while full of nutrients, this sludge contains other ingredients that damage both agricultural fields and human health (Marti et al. 2020).

While the focus of sustainability studies is often on the role of agricultural systems in supplying needed resources, the long-term successful occupation of Caracol would not have been possible without other aspects of its infrastructure. Specifically, the city's walkable layout with distributed public nodes (Figure 3) provided access to both top-down and bottom-up administrative services that ranged from ballcourts to markets and ensured the viability of the general population over time. The city's dendritic road system not only provided easy access to infrastructure but also permitted residents to rapidly reach the city's edge to collect other needed resources and then transport these materials back to their households (D. Chase et al. 2023:6).

Social Lessons

Social factors enhanced sustainability at Caracol. Looking first at landesque capital beyond agricultural terracing, Caracol's plazuela groups existed in the same location for hundreds of years. This location was likely occupied by the same family lineage over time, especially given the presence in most residential groups of an ancestral and ritual eastern shrine (A. Chase and D. Chase 1994b; D. Chase and A. Chase 2004). Thus, attachment to the landscape and a desire to improve it for future use made sense given the

continuation of the family within these residential groups.

Yet, modern populations are very different than the ancient populations at Caracol. While there may be some families that occupy the same house for generations, most modern people are much more mobile. They are less tethered to the land, move to different locations throughout their lives, and, as a result, are less likely to try to improve their immediate houses and landscapes, not thinking about a long distant future. While we now know that there was substantial population movement among the ancient Maya (e.g., Arnauld et al. 2021), there was often greater continuity in occupation in a single locale than takes place today.

A second important practice at Caracol involved fostering a large "middle class" and reducing inequality. The people of Caracol participated in a form of management known as "symbolic egalitarianism," where there were few ostentatious displays of wealth. The well-placed markets across the city contained items for purchase that might be considered the provenance of only the elite in other cities. Thus, prestige items were widely distributed, but the quantity owned depended on household wealth (A. Chase and D. Chase 2009; D. Chase and A. Chase 2017:215-216). This pattern has the same footprint as a market, meaning everything can be bought and sold (Hirth 1998:453–454). Compared to other Maya cities, Caracol has relatively less inequality when viewed in terms of residential area, residential architectural volume, tomb volume, and marketplace accessibility (A.S.Z. Chase et al. 2023).

Monica Smith (2018) has pointed out that the process of urbanization creates a middle class in cities. How people in the past, who would be designated as middle class, accord with today's definitions is conceptually understood, but difficult to operationalize. This middle level expanded at Caracol, and individuals had access to both ritual and goods that were not generally available in other Maya cities. This adaptation helped the city survive for decades. The ancient processes highlight the fact that when more people share in the wealth of a society, that society not only becomes more egalitarian but also increases the accrued wealth of the middle levels of communities, leading to a more stable and prosperous society. The ultimate collapse of the city of Caracol and the onset of extreme social instability in the Southern Maya lowlands only emerged after the breakdown of the market system and the end of symbolic egalitarianism at the city (A. Chase and D. Chase 2021; D. Chase and A. Chase 2017:216-217).

What was not Sustainable

Caracol's Late Classic successes waned during the Terminal Classic Period with changes both internal and external to the polity. While Caracol's fields and household production had long provided sustainable resources, elite dependence on economic exchange with areas beyond its direct political control grew and some keys to the city's successes, including greater shared wealth and lessened inequality, dissipated. Elite dependence on external exchange proved to be unsustainable (D. Chase and A. Chase 2020), likely holding lessons for our modern global economy (see Demarest and Victor 2022). Over time, as the city expanded, Caracol became more dependent on areas outside of its city boundaries for items like storage and cooking pottery and building materials like large wooden posts and roofing guano (see Lentz et al. 2014, 2015 for similar issues at Tikal). While the city was capable of growing the consumables needed by its population, many other quotidian products were not manufactured within the city. Clothing may have been produced in the residential units based on the widespread distribution of spindle whorls, but cotton was likely imported based on the plant's growing conditions relative to rain and moisture timing (A. Chase et al. 2008). Based on reworked items, obsidian may have become harder to obtain in the Terminal Classic Period (after 780 CE; see Johnson 2016). Pottery was imported into Caracol (e.g. A. Chase and C. Chase 2012) and its distribution became limited in the Terminal Classic era with finewares going almost exclusively to the site's elite (e.g., A. Chase and D. Chase 2004). Thus, at the end of the Late Classic, the city's economic systems became compromised. Trade routes were disrupted, causing market goods to be unavailable to the bulk of the population. This contributed to the breakdown of the previous socio-political organization that existed in the city. Inequality grew, the divide between the elite and the rest of the population deepened, and the polity destabilized.

Conclusion

The data from Caracol inform conversations about urban sustainability. While urban sustainability refers to the long-term health and well-being of a city (Munier 2007), many urban theorists (e.g., Newman 2006) also believe that long-term urban sustainability is tied to a reduction in the "ecological footprint" of the city on its environment over time. Caracol's residential settlement and subsistence practices directly impacted its environment and its topography. The city's growth was predicated on walkable access to markets, both top-down and bottom-up administration, and the continued construction of agricultural terracing (D. Chase and A. Chase 2014). Based on the lidar imagery of the site, these agricultural terraces eventually enveloped over 160 square kilometers of Caracol (Figure 2). They created an anthropogenic landscape with a completely redefined ecological and watershed footprint (e.g. A.S.Z. Chase and Cesaretti 2019; A.S.Z. Chase and Weishampel 2016) that permitted sustainable subsistence production. Even though the urban area covered approximately 240 square kilometers (ASZ Chase et al. 2024), the use of terrace-based agriculture reduced the city's ecological footprint. Compared to the broader destructive effects of slash-burn agriculture, this terracing effectively restored and managed the ecology of the broader region – and has positively impacted the modern landscape, even without maintenance (Hightower et al. 2014:10725-10726), something also recorded for other parts of the ancient Maya world (Brokaw et al. 2024). Thus, the incorporation of agriculture within the urban boundaries of Caracol along with other key aspects of its infrastructure and social practice was largely responsible for the city's long-term sustainability – and this green city should be able to provide information that is of use to modern populations.

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