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Mesoamerican urbanism revisited: Environmental change, adaptation, resilience, persistence, and collapse

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Urban adaptation to climate change is a global challenge requiring a broad response that can be informed by how urban societies in the past responded to environmental shocks. Yet, interdisciplinary efforts to leverage insights from the urban past have been stymied by disciplinary silos and entrenched misconceptions regarding the nature and diversity of premodern human settlements and institutions, especially in the case of prehispanic Mesoamerica. Long recognized as a distinct cultural region, prehispanic Mesoamerica was the setting for one of the world's original urbanization episodes despite the impediments to communication and resource extraction due to the lack of beasts of burden and wheeled transport, and the limited and relatively late use of metal implements. Our knowledge of prehispanic urbanism in Mesoamerica has been significantly enhanced over the past two decades due to significant advances in excavating, analyzing, and contextualizing archaeological materials. We now understand that Mesoamerican urbanism was as much a story about resilience and adaptation to environmental change as it was about collapse. Here we call for a dialogue among Mesoamerican urban archaeologists, sustainability scientists, and researchers interested in urban adaptation to climate change through a synthetic perspective on the organizational diversity of urbanism. Such a dialogue, seeking insights into what facilitates and hinders urban adaptation to environmental change, can be animated by shifting the long-held emphasis on failure and collapse to a more empirically grounded account of resilience and the factors that fostered adaptation and sustainability.

urbanism | adaptation | climate change | archaeology | Mesoamerica

Global climate change is now recognized to be widespread, rapid, and intensifying with the need to adapt to its effects becoming increasingly urgent (1, 2). Concurrently, urbanization (the concentration of human populations and activities in urban settlements) continues to increase, both driving and accelerating global environmental change. Around the world, cities will face a much higher probability of experiencing severe drought, hotter heat waves, greater flooding, recurrent wildfires, more frequent and more powerful sea storms, and rising sea levels (3).

Adaptation to climate change will be a decidedly urban phenomenon, and urban adaptation will not be implemented solely via the adoption of new technologies or the replacement of current energy technologies; rather, the ways in which humans live in urban environments must change (4).

Urban social organizations vary and are adaptable to environmental change. Worldwide urbanization has been occurring for the past 7,000 y. In this span, individual settlements have come and gone, and some once-flourishing urban systems have vanished. Many other cities and urban systems have lasted for hundreds of years. To achieve such endurance, problems had to be recognized, solutions devised, collective action coordinated, institutions, norms, and beliefs adjusted, new technologies deployed, and previous ways of doing things modified or abandoned (5).

Here, we argue that the history of Mesoamerican urbanism can inform research on how urban societies and systems can adapt to climate change. Adaptation in the case of Mesoamerican urbanism was driven by social reorganization and changes in practice. Recent advances–methodological, empirical, and conceptual–have greatly improved, and even revised, our understanding of Mesoamerican urban societies and their responses, over a long period of time, to environmental disruptions.

Prehispanic Mesoamerica (Fig. 1)—the southern two-thirds of what is today Mexico, in addition to Guatemala, Belize, and

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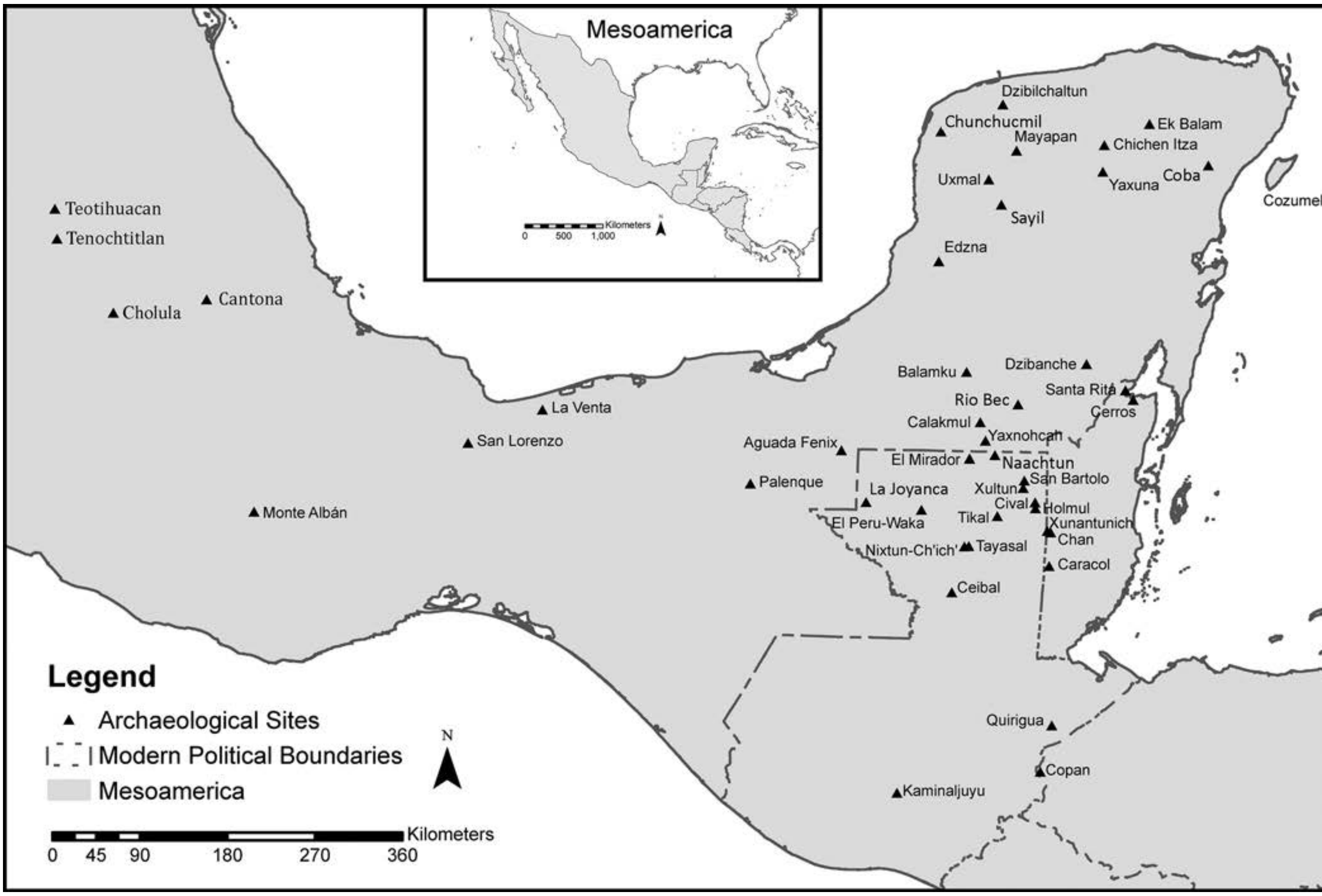

Fig. 1. Map of Mesoamerica, including the locations of sites mentioned in the text.

the western parts of Honduras and El Salvador—has long been recognized as a cultural region where early cities (e.g., ref. 6) and large-scale polities (politically organized societies) (7) arose autochthonously despite impediments to communication and resource extraction (e.g., the lack of beasts of burden and wheeled transport and the limited and relatively late use of metal implements) (8). Despite their significant population size, areal extent (Figs. 2 and 3 and 9–11), longevity, and the environmental, organizational, and institutional diversity found within this part of the world (12), Mesoamerican urbanism often appears in collapse narratives and represents, by extension, a source of negative lessons (13, 14). Yet, when seen as a history of longevity, adaptation, collapse, and reconfiguration, Mesoamerican urbanism can inform contemporary discussions of urban sustainability (15).

The sudden, by historical standards, diminution, and in some cases outright disappearance, of prominent urban centers was indeed a feature of Maya history. However, the collapse was not a sudden unitary phenomenon; it took place over almost 200 y and Maya peoples continued to build new cities in other locations. While the causes of the Classic lowland Maya collapse remain a subject of coalescing debate (16, 17–20), sizeable changes in the populations of many cities occurred (21). These changes in population have largely blinded scholars to the remarkable successes of lowland Maya cities that persisted, adapted, and flourished for many centuries and were then replaced by smaller cities that subsequently arose and flourished. It has been argued that the abandonment of previously established equitable and sustainable practices was a factor in this collapse (11, 16).

Archaeological data from Maya and other prehispanic Mesoamerican cities reveal that these settlements were the sites of long-term occupation and transformation and that environmental change affected them differently, triggering varied responses. The resilience of these systems was based in infrastructural enhancements (e.g., roads, markets, agricultural terracing) as well as socioeconomic changes (e.g., to governance, institutions, social norms). We would argue that any collapse seen in the past archaeological record was in part the result of vulnerability due to the removal or rejection of previously established risk reduction practices in antiquity.

Conceptions concerning the existence of ancient tropical lowland cities have cycled between recognition and outright denial (22, 23). Currently, many lowland Maya cities are recognized as being characterized by variable urban forms and population densities (Fig. 4 and 6, 24) operating within a Mesoamerican-wide economy (25) that significantly impacted their environments (26, 27). The availability and use of lidar (light detecting and ranging), have made the large size of some ancient Maya cities clear (Fig. 3) and, coupled with ground-based chronological research, are making it easier to estimate population size and density for a specific moment in time (28). Societal changes inferred from the archaeological record at the end of the ninth century CE are now recognized across Mesoamerica, resulting from myriad internal and external causes (29). Urbanism in Mesoamerica was differently

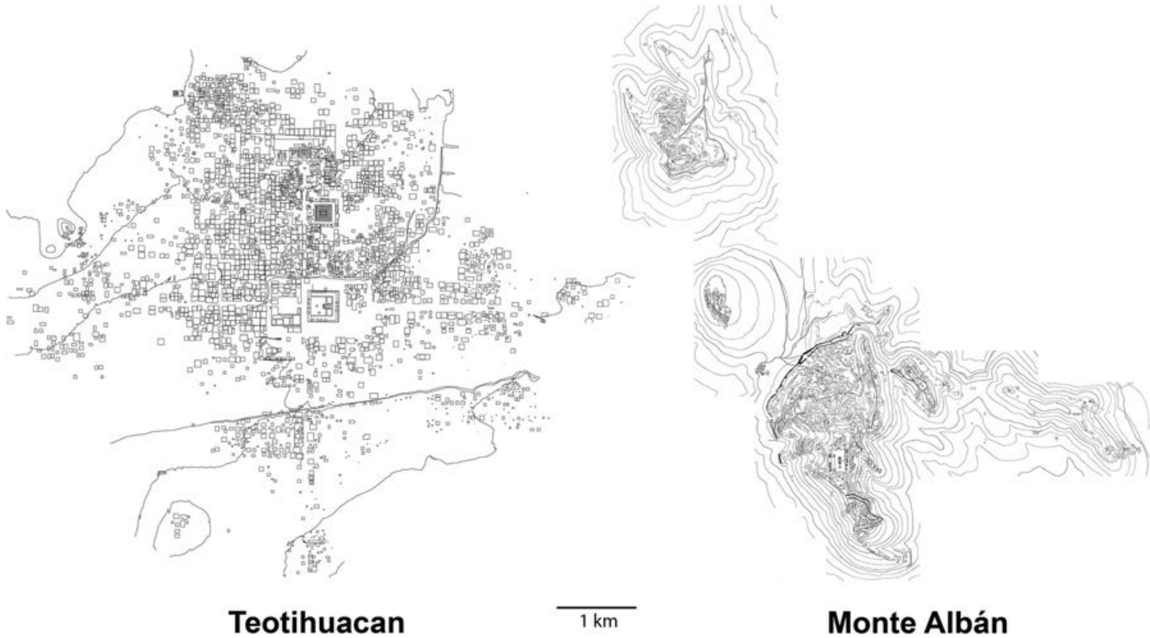

Fig. 2. Map of the highland Mexican cities of Teotihuacan and Monte Alban (adapted from figures in refs. 9 and 10). Both cities were densely nucleated, but the orthogonal and apartment focused layout of Teotihuacan contrasts with the hilltop layout of Monte Alban. Contour linesare 25 m.

constituted compared to Afro-Eurasian cultures, opening for investigation a range of behavioral options not considered when the focus is mainly on Western urbanization and modernity.

Risk, Adaptation, and Resilience

When considering how Mesoamerican urbanism was affected by and responded to environmental change, it is helpful to have working definitions of the related concepts of **risk**, **adaptation**, and **resilience.** By applying these concepts, Mesoamerican urban centers can be envisioned in ways that are more accessible and relevant to cross-temporal analysis and comparison. We adopt the definitions used by the IPCC (4, 30) in which a sustainability perspective sees risk, adaptation, and resilience as inherent attributes of human-environmental systems. ***Risk*** is defined as the potential for adverse consequences, caused by climate change, for human or

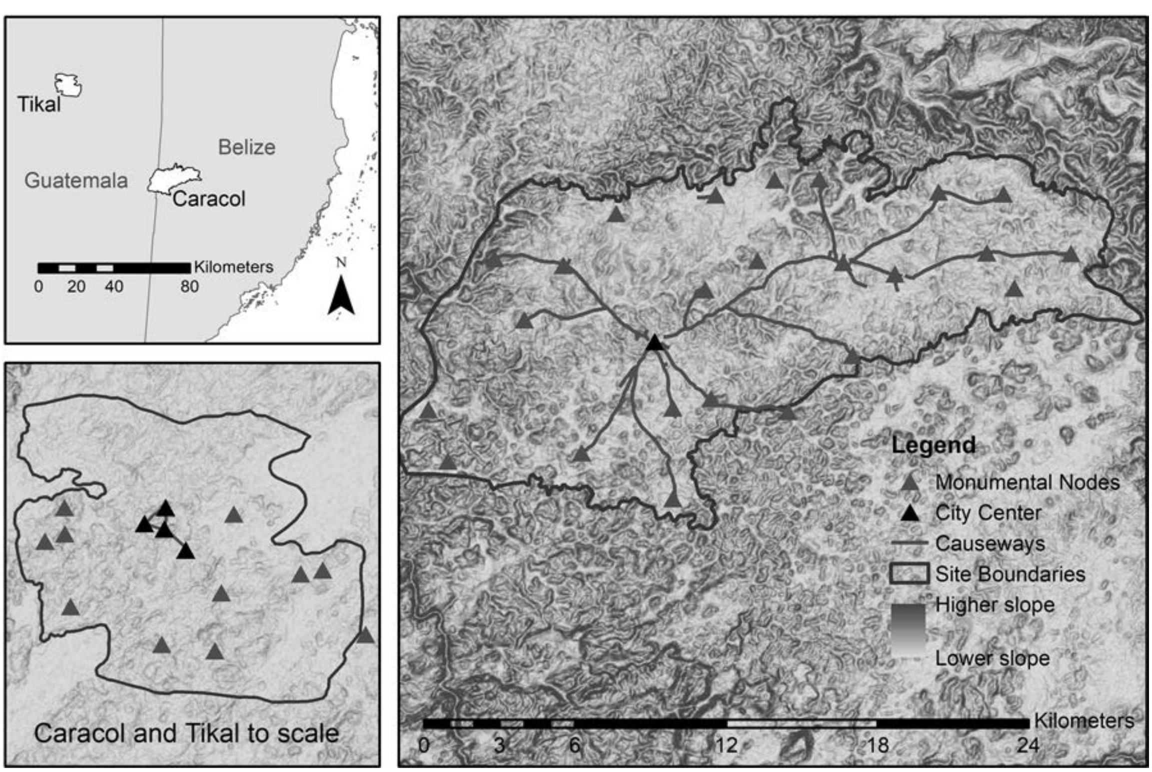

Fig. 3. Settlement areas for the Maya cities of Caracol and Tikal (adapted from figure in ref. 11).

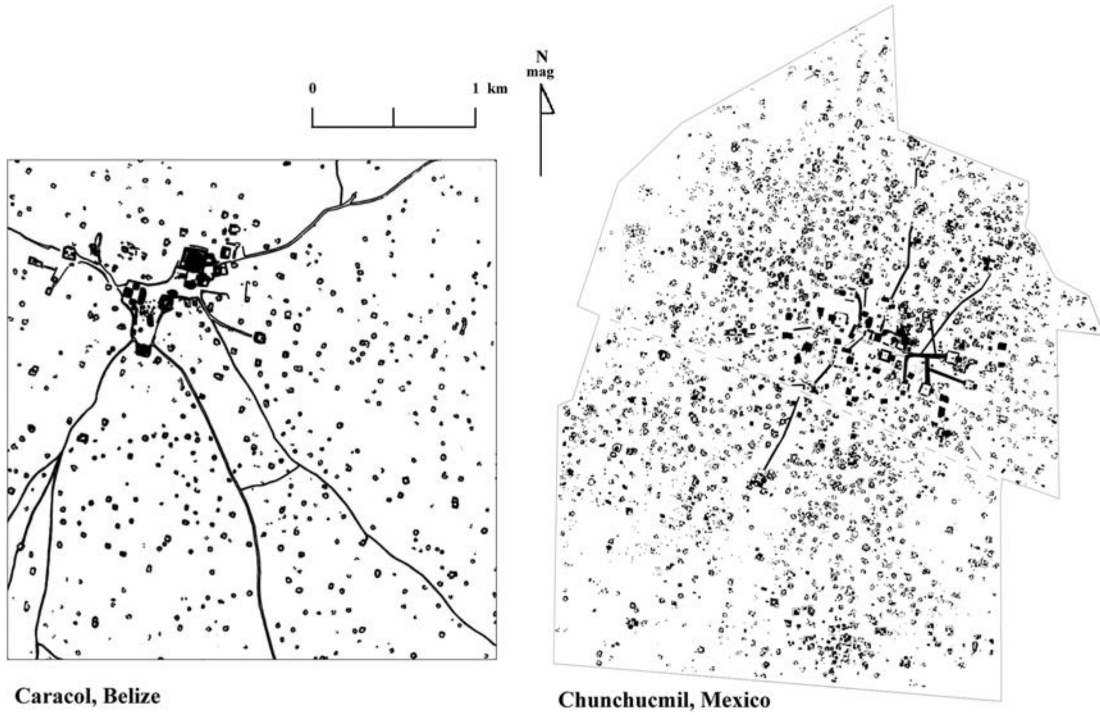

Fig. 4. Comparison of the central 9 sq km of Caracol with the site of Chunchucmil, showing differences in density (adapted from figure in ref. 21); the city of Caracol continues beyond the 9 sq km shown here.

ecological systems. ***Adaptation*** in human societies is defined here as the process of adjustment to changes in the natural (or physical) and social environment and their effects, to moderate harm or exploit opportunities. ***Resilience*** is defined as the capacity of social, economic, and environmental systems to cope with a hazardous event, trend, or disturbance, while responding or reorganizing in ways that maintain their essential function, identity, and structure, as well as the capacity for adaptation, learning, and transformation.

Many prehispanic Mesoamerican populations were able to deal with climatic risk through their dispersed settlement patterns and sociopolitical and economic interconnections (*SI Appendix*, Figs. S1–S3 and 31–37). Mesoamerican cities were largely dependent on rainfall agriculture and seasonal cycles for their subsistence, which was provided by traditional use of the forests and landscapes (27) as well as by more intensive agricultural terraces (38) and wetland field systems (39, 40) and other innovations (41). Intensified farmland within cities tended to be perceived as, and equated to, modern high-value urban spaces, likely modifying land tenure customary laws and fixing populations (42). If cities were part of a larger political entity, then they could have offset underproducing areas with yields from other regions (both Maya and Aztec state expansion used such strategies). Rainfall variation, change, or lack of predictability of climatic conditions all presented risks to Mesoamerican cities–although no more than in other parts of the world.

Mesoamerican peoples developed a variety of adaptations in response to environmental change (*SI Appendix*, Table S1). These responses altered local environments to increase agricultural capacity and boost their resilience. Increased investment in landscape modification can render the community exerting that effort less willing to move or change their ways. Consequently, investment in place, resulting in greater "entrenchment," can turn an initially adaptative response into a source of brittleness (42). Importantly, variation in urban form among highland and lowland Mesoamerican cities provided a multitude of different adaptations. While some urban dwellers incorporated agriculture, silviculture, and orchard gardens within the city itself, others primarily practiced agriculture outside city boundaries (24); others relied on imported agricultural goods from elsewhere (43). Differences are also seen in access to potable water with some cities relying on more centralized control of reservoirs than others during the dry season of the tropics (44). The variability of ancient Mesoamerican cities and their incorporation into continent-wide networks (e.g., ref. 45) provided mechanisms that allowed the inhabitants of these cities to adapt to environmental risks through both exchange and migration.

Mesoamerican Urbanism

Mesoamerica (Fig. 1) has long been recognized as a cultural region or a symbiotic "world" to the people who inhabited it (46–50). The diverse peoples of Mesoamerica interacted with each other and were interconnected throughout the archaeological history of this region. This is seen in widespread sharing of ideology that extended back to at least 1200 BCE and is reflected in settlement patterns that focused on specific kinds of architectural units (51, 52). It continues with the interconnections seen throughout Mesoamerica with the ascendency and decline of Monte Albán in Oaxaca and Teotihuacan (Fig. 2) in the Basin of Mexico (53, 54), which may be interlinked with the ascent of the great Maya cities of Tikal, Caracol, and Calakmul (43). Shifting macroscalar interconnections are mirrored in the economic flows of obsidian as the Maya cities came to power in the Late Classic period (55). These changing connections are further reflected in the material culture of Postclassic Mesoamerica with the loss of these lowland Maya cities after 900 CE (56, 57).

Mesoamerica represents the only region of premodern urbanism to develop in the complete absence of large, domesticated animals, with implications for the circulation of goods, agricultural practices, warfare, socioeconomic inequality, disease, and other societal factors. Additionally, the peoples who built Mesoamerican cities did so with few or no utilitarian metallurgic industries, as those technologies largely arrived during the Postclassic period. Both aspects have implications for the energetic costs of labor, the ability to concentrate wealth, and the dynamics of warfare. Particularly important in today's context is that responses to environmental change were occasionally technological, but more often organizational, as the Mesoamerican toolkit did not undergo significant change over the course of its history.

Because of a predisposition to older Western views of urbanism in the form of compact cities, researchers have been involved in a long-standing debate as to whether certain prehispanic Mesoamerican centers were actually urban (e.g., ref. 22). This debate has also been framed in terms of differences between ancient tropical and temperate environments (58), even though common urban scaling principles have been demonstrated to hold true for these prehispanic cities (59, 60). Mesoamerican cities are largely dismissed by researchers in other fields because their past categorization and history complicates existing theoretical models and because archaeological data of past human-environment relations are often less well known to them.

New Insights into Prehispanic Mesoamerican Urbanism

Our knowledge of urbanism in Mesoamerica has been significantly enhanced over the past two decades due to significant advances in excavating, analyzing, and contextualizing archaeological materials. Not only has the number of archaeological projects in this part of the world increased, generating significant new data, but the use of innovative technologies has produced insights into past communities. Whereas archaeologists once questioned the very existence of Mesoamerican cities (61–63), we can now define their boundaries (64), their social compositions and neighborhoods (65–68), migrant populations (69), and their economies (70, 71). Stable isotope analyses permit us to look at past diets within a single population and to determine life histories that include movement and migration (67, 72, 73). Ancient DNA further allows the definition of familial relationships and population interaction (74, 75). Better and more accurate dating is now possible because of advances in collecting and analyzing radiocarbon samples (e.g., ref. 76).

Lidar has enabled researchers to determine the full spatial extent of ancient Mesoamerican cities, helping to define how these settlements were distributed on the landscape, where landscape modifications occurred, and how settlements were bounded (77). Lidar has permitted researchers to make newer and more accurate assessments not only of past population sizes (28, 78) but also of the relative economic prosperity, wealth, and inequality of different past cities (e.g., refs. 64 and 79).

These scientific advances make a consideration of Mesoamerican urbanism particularly timely when considering adaptation, sustainability, and resilience in the face of climate change.

Mesoamerican urbanism encompassed a broad array of urban forms (Figs. 2–4). Urban areas differed in both density and residential arrangement. Some included fortifications. Smaller Formative and Classic period urban settlements, such as those of south-central Veracruz, and potentially other parts of the lowlands, showed considerable durability (29, 80, 81). In contrast to the Classic period, densely occupied, but smaller, cities characterized most settlement in later Postclassic Mesoamerica (e.g., ref. 82).

Several early cities in Mesoamerica had populations of over 50,000 people and a few exceeded 100,000. In highland regions, the primate cities in the Basin of Mexico achieved these numbers, first Teotihuacan by 500 CE and then Tenochtitlan by 1450 CE. In the lowland Maya area, a half dozen cities had achieved this size by 700 CE, among them Caracol (Belize), Tikal (Guatemala), Calakmul (Mexico), and Coba (Mexico). Importantly, urbanism did not take a single form (24). In contrast to Classic era highland Mexico, the largest Classic era Maya cities focused on growing plants and crops within the urban limits, in essence attempting to practice some sustainable farming within the urban environment (42, 64). It is clear, moreover, that both the nature of the topographic setting and the extensive systems of landscape terraforming, a form of landesque capital (26), were intimately tied to the development of lowland Maya urbanism (81, 82). Some of the largest settlements could support sizeable populations because of infrastructural investments like road systems and localized market spaces; the organization of Caracol (Fig. 3) with interconnected administrative districts providing urban services (63, 64, 65, 67) highlights this.

The variability seen in Mesoamerican cities encourages us to examine their internal organizations to see what aspects of sociopolitical institutions, urban infrastructure, landesque capital, and norms of human-nature relations were important and critical to the longevity and nimbleness of these cities in the face of ecological challenges. Marketplace exchange was important (48, 70); almost all production was situated in domestic contexts (49, 69, 81), but distribution was focused on markets. In contrast to most modern expectations, many urban residents were farmers who walked to their fields and many rural residents walked to the city for urban services/amenities (this was also a common feature of Bronze Age and Iron Age urbanism in Mesopotamia; e.g., ref. 83). With a few exceptions, Mesoamerican cities often shifted between more autocratic and more collective governance regimes throughout their histories (6, 29, 47, 64).

Sustainability and Adaptation

What do we know about how Mesoamerican urban cities managed to endure? How did they change? What changed? As can be seen in *SI Appendix*, Table S1, urban settlements across Mesoamerica have a long history, with continuous occupation in some locales going from almost 1000 BCE to the present. In combination with archaeological data, hieroglyphic texts in the Maya area document that many cities were politically active and occupied for minimally 400 y (see ref. 84 for detailed examples). These cities were established in different environmental zones, placed in temperate to subtropical and tropical forest areas, and located both in areas that had or lacked riverine or marine resources. Their populations varied from smaller settlements composed of several thousand individuals to cities with over 100,000 people. Population densities in cities varied from 500 to over 5,000 people per sq km. Each city was constructed somewhat differently.

Caracol (Belize) has an extensive system of agricultural terraces within the city itself that provided sufficient subsistence goods for the urban area for minimally half a millennium (85, 86). A strategy of constructing numerous localized reservoirs also reduced reliance on centralized water sources (44, 87). Chunchucmil (Mexico) imported food (88, 89), whereas in Tikal (Guatemala) crops were grown in the area immediately surrounding the urban settlement (90). While there is similarity and variation among these cities, we note that their governance systems and built infrastructure were among their more successful adaptations to forces of external change. At their peaks, most Mesoamerican cities were prosperous and sustainable, often with a form of collective governance (8, 9). Governance, however, was fickle and was subject to shift between more collective and more autocratic systems over the course of history (e.g., ref. 76). Also particularly striking in terms of the abandonments of Mesoamerican cities–and opposed to earlier understandings (e.g., ref. 91)– is that most of their collapses are associated with a rejection of these successful adaptations for strategies more focused on autocracy and inequality, in which there was only limited wealth sharing (11, 16). Subsequent Postclassic lifeways improved over those of the immediately preceding Maya Terminal Classic era, something that has been long established (92–97), but sometimes neglected.

Over the 2700-y history of Mesoamerican urbanism, there were changes in settlement sizes, forms, and locations. Variation in the topography of regions played a strong role in the disposition of urban landscapes. As noted above, Postclassic cities were generally smaller, more compact, and more densely occupied (80) than earlier Classic period cities (98). They were also often, but not always, situated in proximity to water-based trade routes (17). While individual cities flourished and collapsed, urbanism and urbanization remained distinctive features of Mesoamerican societies and differed across regions. In the Oaxacan highlands (Mexico), Classic-era cities tended to be larger, denser, more collectively governed, and more monumental, whereas Postclassic cities were smaller, more dispersed, more autocratic, centered on elaborate palaces, and part of city–state networks. Economic interdependence and other forms of cooperation between households and at middle tiers of organization (neighborhoods, cooperative labor units) often were important, and these institutions may have helped manage risk, decentralize power, and foster resilience (63, 76, 99–103). Mesoamerican cities engaged with each other and disruptions to networks of interaction differentially impacted the sustainability, resilience, and vulnerability of various urban settlements, depending on their particular adaptations. Market networks may have sustained populations in key nodes even in the face of political perturbations, but they also may have been responsible for collapse in a globalized prehispanic Mesoamerican world, especially as the removal of specific nodes due to local polity disintegrations reduced the resilience of the overall system.

Climatic crises and extreme weather events appear not to have been synchronous across Mesoamerica unless they transpired for an extended period of time (104 and *SI Appendix*, Figs. S1–S3): Environmental change caused by drought alone generally was not the primary factor behind the abandonment, relocation, transformation, and reconfiguration of urban centers, as population sometimes grew in dry periods, something also documented in the precontact U.S. Southwest (105). It appears that some Mesoamerican cities adapted to issues in both rainfall and climate change (*SI Appendix*, Figs. S2 and S3). In the Basin of Mexico, the city of Teotihuacan appears to have followed an independent trajectory relative to rainfall, while occupation peaks for overall settlement within the broader region of the basin appear to be correlated with rainfall (*SI Appendix*, Fig. S1). The environmental adaptations made by Maya cities were largely successful until the onset of the Postclassic period after 950 to 1000 CE, although Maya populations at many cities were in steep demographic decline by the onset of the Terminal Classic era in 780 CE (79). The collapse was neither uniform nor synchronized, occurring in staggered phases (16, 106) and being protracted in the northern lowlands (107). The archaeological record suggests the possibility of significant environmental change after 800 CE. Rising sea levels covered Late Classic Maya coastal occupations (e.g., ref. 108). This rise in sea level may be correlated with reduced precipitation that can be seen both archaeologically in a lowered water table (109) and in climate proxies that show the onset of extended drought by CE 1000 (33).

Insights from Adaptations in Past Mesoamerican Cities: Caracol and Teotihuacan

Microclimates are common in Mesoamerica due to sharp contrasts in elevation, differences in precipitation levels, and the role of coastal storm systems from both east (Gulf/Caribbean) and west (Pacific). Ancient urban responses to environmental change were also varied, as seen in the present two salient examples that follow.

Over 1200 y Caracol (Belize) grew from several small villages into a massive metropolitan complex covering 240 sq km. In its Late Classic form, the city was an oxymoron in terms of current urban typologies (4, pp. 63, 71); it was both walkable and dispersed. A dendritic road system integrated the landscape, permitting easy access to resources and infrastructure for its 100,000 inhabitants (34, 85). The adaptations made within the urban environment resulted in what today is called “high” contributions to climate resilient development (4, p. 44). Physical infrastructure included water storage that was at first centralized and then later localized and associated with over 1,600 households (44, 86). The landscape was completely remodeled into constructed agricultural terraces that effectively moderated water flow and provided drainage as well as soil and water retention (38, 110). The agricultural system that was implemented in this green city matches a modern “nature-based” solution (4, p. 44) and meant that each household could be sustainable, but it also dictated planning and social policy (4, p. 44) with a dispersed system of housing spacing to accommodate urban gardens (24, 111). A side effect of the dispersed settlement system was that the general population was healthier than if it had been concentrated into a more compact settlement (112). Yet, the city could only expand laterally as it grew and its agricultural infrastructure, both constructed terraces and soil, needed to be continually maintained and renewed (42, 113). Caracol's location between two major river systems meant that to some degree, the reliance of its inhabitants on rainfall could theoretically be mitigated by physically transporting water into the city along its causeways from these rivers (114). Circularity strategies were also employed (4, p. 69); waste from the city was reused both as construction material and for the enhancement of agricultural soils (11, 26, 115). During its peak, Caracol mitigated inequality through management strategies that provided distributed infrastructure with market access, shared ritual practices, and household access to land for basic food resources (87). The city practiced a form of collective governance (65) that was correlated with maximum urban size, density, and reduced socioeconomic inequality (115, 116).

Teotihuacan (Mexico) exemplifies a very different urban adaptation. Its development into a city of minimally 100,000 people by CE 500 was realized within a semiarid environment that offered less covering vegetation (117). The city spread over some 25 square kilometers (118). Its households were largely integrated into some 2,000 apartment compounds densely situated within a highly coordinated orthogonal urban plan (119). The Teotihuacanos chose this form of density and corporate living toward the end of the third century at a time of societal crisis, and this adaptation to a city of apartment dwellers permitted its population to prosper for over two more centuries with most inhabitants having a high standard of living (120, 121), despite a high mortality rate (122) that was offset by substantial in-migration (123). The city was built with an existing small river at its center that was channelized to conform with the urban grid, and urban sprawl continued over a second one to the south (124). Agriculture generally occurred outside the urban limits (125). We speculate that a combination of anthropogenic reduction of tree cover and creation of a densely built environment of impermeable surfaces at Teotihuacan may have factored into some urban heat island effects, raising the overall temperature in the valley, something that may have played a factor in the city's demise at a time of changing precipitation in central Mexico (*SI Appendix*, Fig. S1). Even with perennial water available through a system of springs to the city's southwest, Teotihuacan's location on the edge of viability for maize agriculture possibly contributed to its demise during a period of lower estimated annual precipitation and documented social stresses (120). Because of a generally lower elevation and more tropical "green" setting, Maya cities, while still possibly raising temperatures as a result of deforestation (126, 127), had the ability to better ameliorate microclimate variation.

Ongoing Research and a New Research Dialogue

The goal of a new, multidisciplinary, and convergent research dialogue on Mesoamerican urbanism is not to draw facile analogues but rather to bring the rich, varied, and long history of Mesoamerican urban life into comparative efforts to discover what attributes of urban social- ecological systems facilitate and hinder resilience and adaptation. If the urban past is to inform contemporary discussions, there needs to be a scientifically grounded recognition that the past and the present are not as categorically different as many would believe. We need to build knowledge on a wide array of past cases that would allow us to compare processes and outcomes cross-culturally and cross-temporally. Doing so will require collaboration across social and historical sciences (e.g., refs. 128 and 129).

In Mesoamerican cities, we can see the effects of different kinds of infrastructure and urban layouts on long-term resilience and infer the social institutions that were behind these adaptations; insights in this realm have relevance for modern urban sustainability. We can study *green* infrastructure of landscape and land management, a topic of great concern in designing modern cities (130, 131); we can see the *hard* infrastructure that kept a city functioning in a mostly sanitary way, entering into modern discussions of trash disposal (132, 133); we can examine the *social* infrastructure in the shared spaces and amenities that connected households into neighborhoods and communities. The last point is relevant to modern conceptions of neighborhoods (134, 135) that are currently at odds with what is defined archaeologically (64, 65).

Although most of the archaeological record lacks day-to-day detail, archaeological investigations can discern outcomes within longer timeframes (136). Urban archaeology reveals that institutions play an important role in managing risk (137), as factors that shape the adaptive capacity of cities (138), provide adaptation options (2) and are themselves adaptations (139). Mesoamerican societies devoted considerable effort and engaged in extensive coordination and cooperation to build and maintain urban infrastructure. Yet, the manner in which the infrastructure was managed at an institutional level appears to have affected the resilience of Mesoamerican urban settlements (10, 29); in many instances, key infrastructural investments were organized by institutions that were less inclusive than the polity or central rulers (140).

Mesoamerican case studies demonstrate that expensive, labor-intensive, and forward-looking infrastructural investments (e.g., agricultural terracing, wetland agriculture, road systems, neighborhood centers, and other service features) can support long-term population growth in areas that are rainfall dependent (42). Why were certain responses effective for two thousand years and then not? What changed in the socioeconomic and environmental systems (8)? Urban resilience (the capacity of a city to rebound from significant damage or destruction) for modern cities is largely the result of resilient communities and social structures, as well as a diversified base of activities (141, 142). Was this the case in Mesoamerica as well? Archaeological data can shed light on such processes (8, 9, 64, 101, 143) and suggest that sustainability was affected by societal organization, a phenomenon also investigated in modern cities (144).

History is neither directed and progressive nor inevitable, meaning that the future is more conditional, contingent, and potentially multipathed than we are often led to expect (145). Mesoamerican people repeatedly faced drought, flooding, volcanism, earthquakes, and hurricanes. Mesoamerican urban archaeology demonstrates that there were multiple pathways to resiliency in this area that involved a wide range of both bottom–up and top–down strategies. Thus, looking for the impacts of climate change on past societies stands to gain from an archaeological study of Mesoamerican urbanism. These ancient cities adapted to a multitude of different climates and catastrophes over their long histories.

The interdependence between sustainable urban development and urban adaptation to climate change is now recognized (146). Pursuing climate adaptation and development goals in an integrated manner increases both effectiveness and feasibility. Mesoamerican examples of urban adaptation highlight that equity and inclusion, leading to general prosperity, generate and sustain support for the transformative actions needed for adaptation. Yet, too often adaptation actions and socioeconomic development are framed in the modern world as mutually exclusive: "first developments, then adaptation" [in an echo of the Environmental Kuznets Curve (147)]. The history of Mesoamerican urbanism provides examples of urban transformations that not only resulted in the persistence of settlements but also to improvements in the material living conditions of nonelite urban dwellers. Besides being exemplars that adaptation and development are not incompatible, the Mesoamerican urban archeological record provides data on cities that successfully endured for centuries, potentially holding clues for modern responses to climate change. We argue that comprehending how these earlier urban developments resulted and persisted holds valuable clues for modern cities about alternative pathways for dealing with sustainability, social networks, and changing environmental conditions and call for a dialogue across disciplinary boundaries, geographical areas, and timeframes to further advance studies of urbanism, resilience, adaptation, and sustainability.

Data, Materials, and Software Availability. All study data are derived from the referenced published materials and/or from the materials presented in the *SI Appendix*.

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Supporting Information for

Mesoamerican Urbanism Revisited: Environmental Change, Adaptation, Resilience, Persistence, and Collapse

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Figures S1 to S3
Table S1
SI References

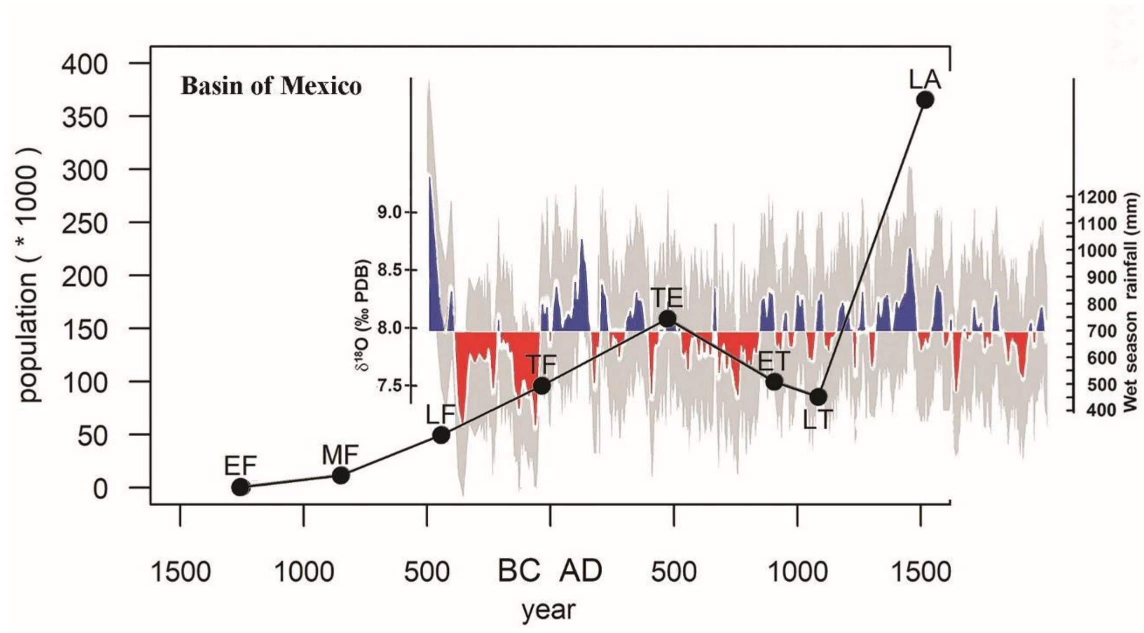

Fig. S1. Comparison of population trajectory for the Basin of Mexico with its potential rainfall history (climate after [*1*] and population after [*2*]) (EF=Early Formative; LF=Late Formative; TF=Terminal Formative; TE=Teotihuacan period; ET=Early Toltec; LT=Late Toltec; LA=Late Aztec).

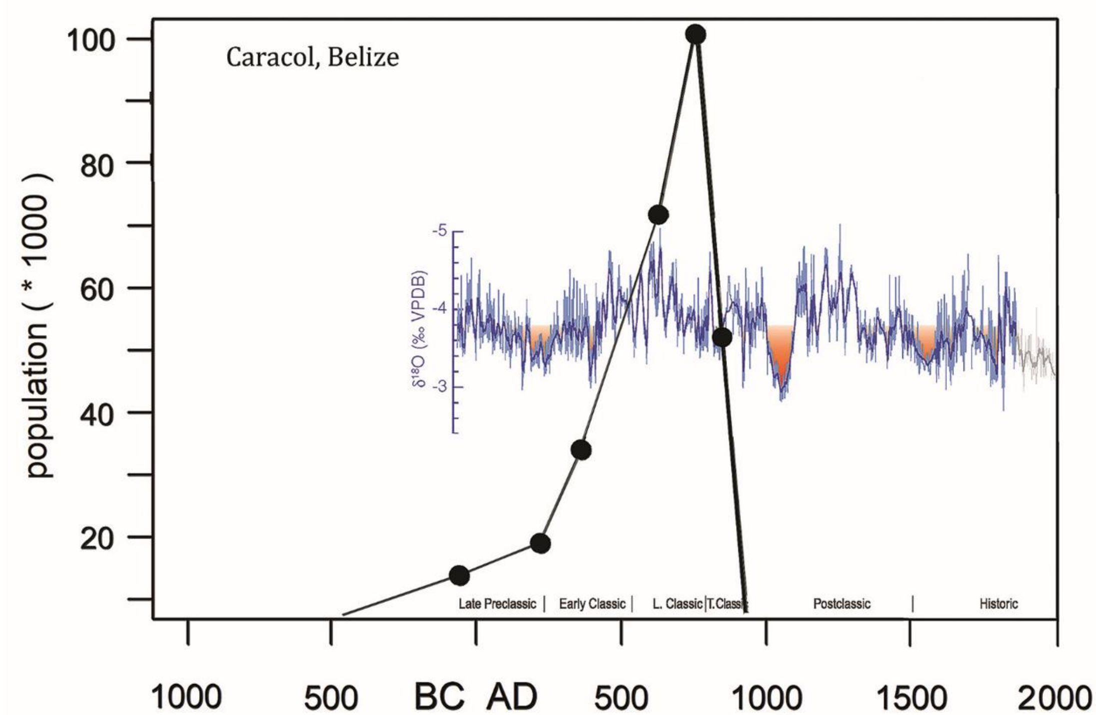

Fig. S2. Comparison of population trajectory for Caracol, Belize with its potential rainfall history (climate after [*3*] and population after [*4*].

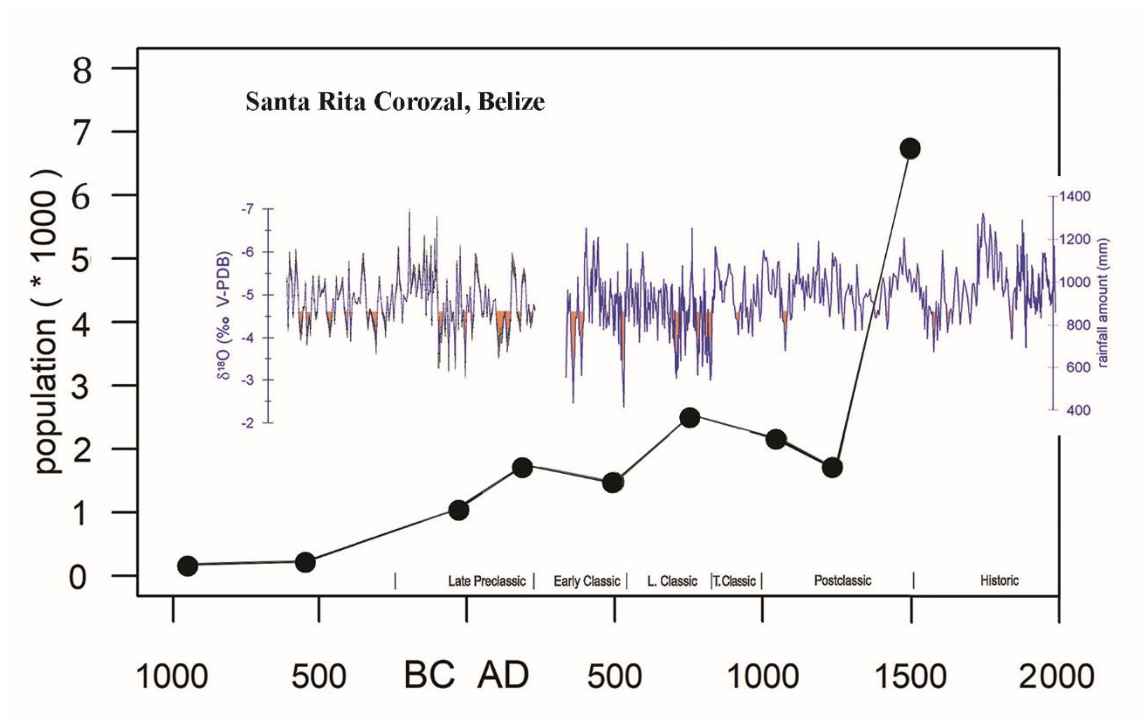

Fig. S3. Comparison of population trajectory for Santa Rita Corozal, Belize with potential rainfall history as reflected in the northern Yucatan [left trajectory is after [*5*] and right trajectory is after [*6*]; settlement data is from [*7*]).

Table S1. Comparative Data on Ancient Mesoamerican Cities. Sources for the information contained in Table 1 may be found in the references and are as follows: Caracol (*4,8-13*) ; Tikal (*14-18*); Santa Rita Corozal (*7,19-22*); Chunchucmil (*23,24*); Monte Alban (*25-28*); Teotihuacan (*2,29,30*); Tenochtitlan (*17,30*); Cantona (*31,32*).

	Caracol, Belize	Tikal, Guatemala	Santa Rita Corozal, Belize	Chunchucmil, Mexico	Monte Alban, Mexico	Teotihuacan, Mexico	Tenochtitlan, Mexico	Cantona, Mexico
Occupation (dates)	**BCE 600 - CE 950**	**BCE 600- CE 950**	**BCE 800 - contact/present**	**BCE700-1100CE**	**BCE 500 - 1520 CE**	**BCE100-600CE**	**CE 1325-1521**	**600 BCE - CE 900**
Length of occupation (yrs)	**1550**	**1550**	**2300/2800**	**1800**	**2020**	**700**	**200**	**1500**
Population Height	**CE 550-800**	**CE 550-800**	**CE 1250-1530**	**CE 400 - 630**	**CE 400-850**	**CE 250-550**	**CE 1450-1521**	**CE 300-900**
Population at Peak	**100,000**	**55,000**	**6,500**	**40,000**	**25,000**	**100,000**	**212,500**	**60,000**
Population Density at Peak (Indiv/Km2)	**500**	**500**	**4,333**	**2,667**	**3,333**	**5,330**	**13,281**	**4,285**
Roads/Transport System at Peak	**Urban: Dendritic**	**Urban: City Center**	**unknown**	**Neighborhood**	**Urban: Dendritic**	**Urban and Neighborhood**	**Urban and Regional**	**Neighborhood**
Markets at Peak: Central or Distributed?	**Central and Distributed Markets**	**Centralized Market**	**Locations Not Known, but Present**	**Centralized Market**	**Several Markets**	**Central and Distributed Markets**	**Central and Distributed Markets**	**Multiple Distributed Markets**
Public Plazas: total area (m2)	**192,170**	**117,626**	**unknown**	**42,000**	**45,000 +**	**82,760/132,110**	**4,400 downtown**	**multiple; largest -2,200**
Agriculture at Peak; Sustainable within city limits?	**Sustainable urban agricult. terracing; exported food**	**Some urban and bajo farming; imported food**	**Outside urban area; kitchen gardens; imported food**	**Outside urban area; kitchen gardens; imported food**	**Outside urban area; imported food**	**Fields north of San Lorenzo and SW of spring zone**	**Chinampa zones in metro area accessed by canoe**	**Dense occupation of malpais with no agriculture**
Housing at Peak	**Plazuelas - Regularly Spaced**	**Plazuelas - Regularly Spaced**	**Plazuelas - Concentrated**	**Plazuelas - Walled and Concentrated**	**Dense Small Multi-Room Residences**	**Apartment Compounds: Regularly Spaced**	**House Compounds: Agglutinated**	**Walled Plazas with Houselots - Concentrated**
Governance Form at Peak	**Collective**	**Autocratic**	**Collective**	**Collective**	**Collective**	**Collective**	**Mixed**	**Collective**
Governance Final Form	**Autocratic**	**Autocratic**	**unknown**	**Collective**	**More autocratic**	**Mixed**	**Mixed**	**Collective**
Inequality at Peak based on GINI	**0.34 (Area); 0.64 (Vol)**	**0.63**	**unknown; vacant terrain**	**0.6**	**0.37**	**0.41**	**0.35**	**0.43**

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