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Kuznets' tides: An archaeological perspective on the long-term dynamics of sustainable development

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Understanding the relationship between inequality and economic growth is a critical science problem that hinders sustainable development. In 1955, Simon Kuznets hypothesized that rising economic growth raises inequality, which levels off as that growth continues. Kuznets' "curve," which is a cornerstone of development economics, was based on data from a small sample of rich capitalist economies. Here, we draw on the GINI database, which includes area measurements of 53,464 residences from 1,176 settlements dating from 21,000 BC to the present, and published data from the Spatial Analysis in Maya Studies (SAMS) group, to radically reevaluate Kuznets' curve. We use Gini coefficients of residential disparity, a proxy of inequality, and mean residence area, a proxy of productivity, to investigate past sustainable development in the Bronze Age Interaction Zone (BAIZ), the Mundo Maya, and Britain prior to, over the course of, and after the Roman conquest. We interpolate spatial patterns across each zone to statistically evaluate changes in inequality and economic growth. We find a recurring pattern in which phases of sustainable development, a rise in productivity without a rise in inequality, gave way to increasing inequality. These patterns resemble those Branko Milanovic termed "Kuznets' waves," albeit at timescales better described as "tides," which began after the introduction of weight metrology, an early form of economic governance associated with long-distance exchange. We posit that past sustainable development was predicated on balancing reciprocity from the bottom–up with mechanisms like early weight metrology but was repeatedly forestalled as inchoate elites co-opted these mechanisms.

inequality | sustainable development | productivity | economic growth | archaeology

The United Nations' Sustainable Development Goals aim to provide decent work and economic growth (SDG-8) while reducing inequality (SDG-10). In other words, economic growth that does not increase inequality is a defining feature of sustainable development. However, there is debate about both the nature of economic growth (1–4), which is at the crux of SDG-8, and its relationship to the dynamics of inequality (5–7), which is critical to SDG-10. Though these debates focus on industrialized capitalist economies, they are nonetheless rooted in data from the past. They harken back to Simon Kuznets' hallmark analysis of historical data from the United States, Britain, and Germany in the late 19th century (8), a relatively constrained sample of past economies that has played an outsized role in framing today's debates about sustainable development. This perspective argues that data from a more representative sample of past economies are necessary to expand the time horizon of analysis, reduce our reliance on data from the capitalist economies of minority countries, and radically transform our understanding of sustainable development today.

Archaeology can access evidence from a more diverse range of societies and over longer timescales than is available to other disciplines (9–15). Though archaeological data, which are derived from the material remains of past economies, can be fragmentary and heterogenous, their depth and breadth can reveal patterns that are otherwise invisible (16). Critical paleoeconomics (CPE) is a theoretical framework that aims to update archaeology's engagement with economics (16). In doing so, CPE offers a pathway toward addressing the limitations of more general economic models, expanding their time frames, and incorporating data from noncapitalist economies. Here, we draw on CPE to evaluate the spatial dimension of past economic activity and offer a preliminary perspective on how robust archaeological datasets, such as the GINI database (17, 18), can reveal processes fundamental to achieving both SDG-8 and SDG-10 at the same time.

Economic Growth, Inequality, Sustainable Development, and their Long-Term Dynamics

Drawing on historical records, Simon Kuznets (8) argued that the structural changes necessary for economic growth inevitably raise inequality, but that as an economy produces

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ever-increasing quantities of goods and services, inequality ultimately falls. Kuznets was concerned with the internal dynamics of sectoral economic change (e.g., a shift from agricultural to industrial production), and his hypothesized "curve" became a cornerstone of modernization theory, which held that the development trajectory of rich countries could be replicated in poor countries, who should therefore focus on bringing increasing quantities of goods to market to (eventually) lower inequality (19).

As the 20th century unfolded, it became clear that the reductions in inequality that modernization promised rarely manifested. Dependency theory arose in critique of modernization theory, holding that asymmetrical exchanges within a "world system," such as developing raw materials for export to rich countries, actually exacerbated inequalities between rich and poor countries (19–22). It also became clear that there were many differing trajectories by which countries could become richer or poorer, a process that many researchers linked to increases in interaction and exchange between countries that came to be identified as "globalization" (23). Development could not be understood through the analysis of an economy's internal characteristics alone; the nature of interactions between different economies mattered. An ironic outcome of the modernization/dependency debate is that economists all but discontinued research on inequality itself until the end of the Cold War (24). The target of development research became international trade. In modernization theory, inequality would increase then drop as trade stimulated economic growth. In dependency theory, by contrast, inequality rose alongside trade.

After the Great Recession of 2008, many researchers resumed investigating the stubborn tendency of inequality, in this case wealth disparities, to continuously rise. Indeed, globalization, which had indeed led to increases in productivity across the world, brought unemployment back to previously rich economies (7, 23). Branko Milanovic (7) returned to Kuznets' hypothesis, extending his analysis with records from preindustrial economies and finding that multiple curves had unfolded over the last century; the relationship between economic growth and inequality resembled more a "wave" than a "curve." Also following in Kuznets' tradition, Thomas Piketty assembled historical records from capitalist economies spanning nearly four centuries. He found that within his sample, changes in economic growth best explained how much of a society's wealth the top decile controlled (6). This, according to Piketty, is why overall wealth disparities dropped following the world wars, when economic growth rapidly rose and Kuznets defined his curve. Ultimately, Piketty's theory drew criticism because his data derived from wealthy capitalist economies in minority countries (25), perhaps overemphasizing economic growth (26). However, Piketty, alongside Milanovic and building on Kuznets, clearly demonstrated the importance of extending the temporal frame of economic data deeper into the past. What happens when we extend our perspective further to encompass archaeological timescales?

Assessing Kuznets' Curve in the Deep Past

Archaeological evidence can help address the limitations of economic data through the analysis of a more diverse range of economies and by revealing how they changed over longer timescales. There is substantial evidence that wealth and power disparities have transformed since the advent of farming, so inequality is a key focus for archaeological research (13, 14). A proxy for measuring this transformation using data from past societies is disparity in residence areas measured using Gini coefficients (27), and Gini-based studies have prompted debate about the origins of inequality and its dynamics over long timescales (17, 28).

Understanding inequality in the past is the primary aim of Gini-based archaeological studies, and it is also essential to incorporate that understanding into debates about how human economies work today. CPE posits that the dynamics of economic growth that drive Piketty's theory emerged deep in the past, where the earliest high-growth economies, such as those of the world's first cities, exhibited muted levels of inequality (16). It also holds that inequality is closely linked to a past society's economic governance, often manifested in its "metrological regime," or system for quantifying economic activity (16), such as through the invention of seals and sealings for recording transactions and balancing reciprocity (29), or weights and measures for governing long-distance exchange (16). There is abundant evidence that the world's first weight systems emerged from the bottom–up, through interactions among everyday people (30, 31). However, in some economies, smaller groups of people gain control over economic governance, such as by issuing weights or coins, and reshape metrological regimes to concentrate wealth and power (16). Empirically assessing whether CPE's predictions about economic growth and governance held true in the past can help bring archaeological data into conversation with sustainable development.

The GINI database includes the areas of 53,464 residences from 1,176 settlements dating from 21,000 BC to the present (18). The Spatial Analysis in Maya Studies (SAMS) data provide complementary data points from an additional nine sites from key periods to the sample (32), creating a total sample of 1,185 archaeological sites. Both datasets were assembled to analyze residential disparity, a proxy of inequality, across past societies (17). These datasets include site-level Gini coefficients of residence areas, but to resolve questions about sustainable development, a proxy for measuring economic growth is also needed.

We propose that in addition to providing a proxy of inequality through Gini coefficients, site-level mean residence areas can be used as a proxy of productivity. Drawing on approaches outlined by Kohler et al. (17) and Ortman et al. (33), we argue that residence floor areas provide a base-level space for production and social reproduction—productivity in the broadest sense. In addition to providing spaces for preparing, storing and consuming food, caring for families, protecting people and animals from the elements, and, in some societies, making goods and offering services, floor area creates the conditions necessary to form social relations and ensure economies function. Moreover, the labor a society can invest in creating residence areas will increase as a society's general productivity increases, generating economic growth. We therefore assume that increases in mean floor area will correspond to increases in a society's overall productivity. As space for production increases, productivity rises, and as a society becomes more productive, per capita access to floor area will increase. Rises in productivity over time can, in turn, serve as a proxy for economic growth.

The dependency critique established that economic changes occur as societies interact (21, 34), and the globalization literature stresses that global interaction drives economic and

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cultural processes that cannot be understood solely through an analysis of a society's internal arrangements (23). There is strong evidence that many "world systems" emerged in the deep past; in these areas, people engaged in long-distance exchange, travel, diplomacy, and often conquest and resource extraction, if not quite at a global scale (35). Following Wilkinson (36), we use the term "zonal interaction" to encompass both world-systems and globalization dynamics in the deep past.

We therefore offer a perspective on the relationship between proxies for inequality and economic growth within zones of past interaction (Fig. 1; see supplementary information for a full discussion of material and methods). We statistically assess the spatial structure of inequality across the GINI+SAMS dataset (Fig. 2). We then divide sites into groups that formed zones of interaction within 250-y timeslices, use Gini coefficients as a proxy for inequality and the logarithm of mean residence area as a proxy for productivity within related spatiotemporal contexts. The distribution of the data is log normal, so the logarithm of mean residence areas captures the central tendency of the distribution (33). We use the mean rather than the median because the latter excludes outliers such as palaces, which are clearly important to factor into site productivity. We interpolate both variables across the area encompassed by the Bronze Age Interaction Zone (BAIZ) (36–42), the Mundo Maya (43), and Britain before, during, and after Roman occupation (44). We then measure change in each variable (*Δinequality* and *Δproductivity*) and calculate Pearson Correlation Coefficients for changes in each variable within each resulting timeslice (Fig. 3 and *SI Appendix*, Figs. S1–S5). Both variables are derived from residence area measurements (17), so some of the correlation we observe may be the result of the relationship between the logarithm of mean residence area and the SD of the logarithm of mean residence area, an issue considered more closely by Ortman et al. (33). The impact of this connection should be small, and given that most of our resulting *P*-values were far from marginal (Table 1), we are confident in using the results to plot the trajectory of inequality and economic growth over millennia in three different zones (Fig. 4).

Results

The zonal samples for the BAIZ included 49 sites, the Mundo Maya included 46 sites, and Britain included 200 sites (Table 1). These samples reflect only a subset of the settlements that participated in each zone, but by using Inverse Distance Weighting (IDW) spatial interpolation and by comparing changes between timeslices, we can identify general changes in the relationship between *Δinequality* and *Δproductivity* at large spatial and temporal scales.

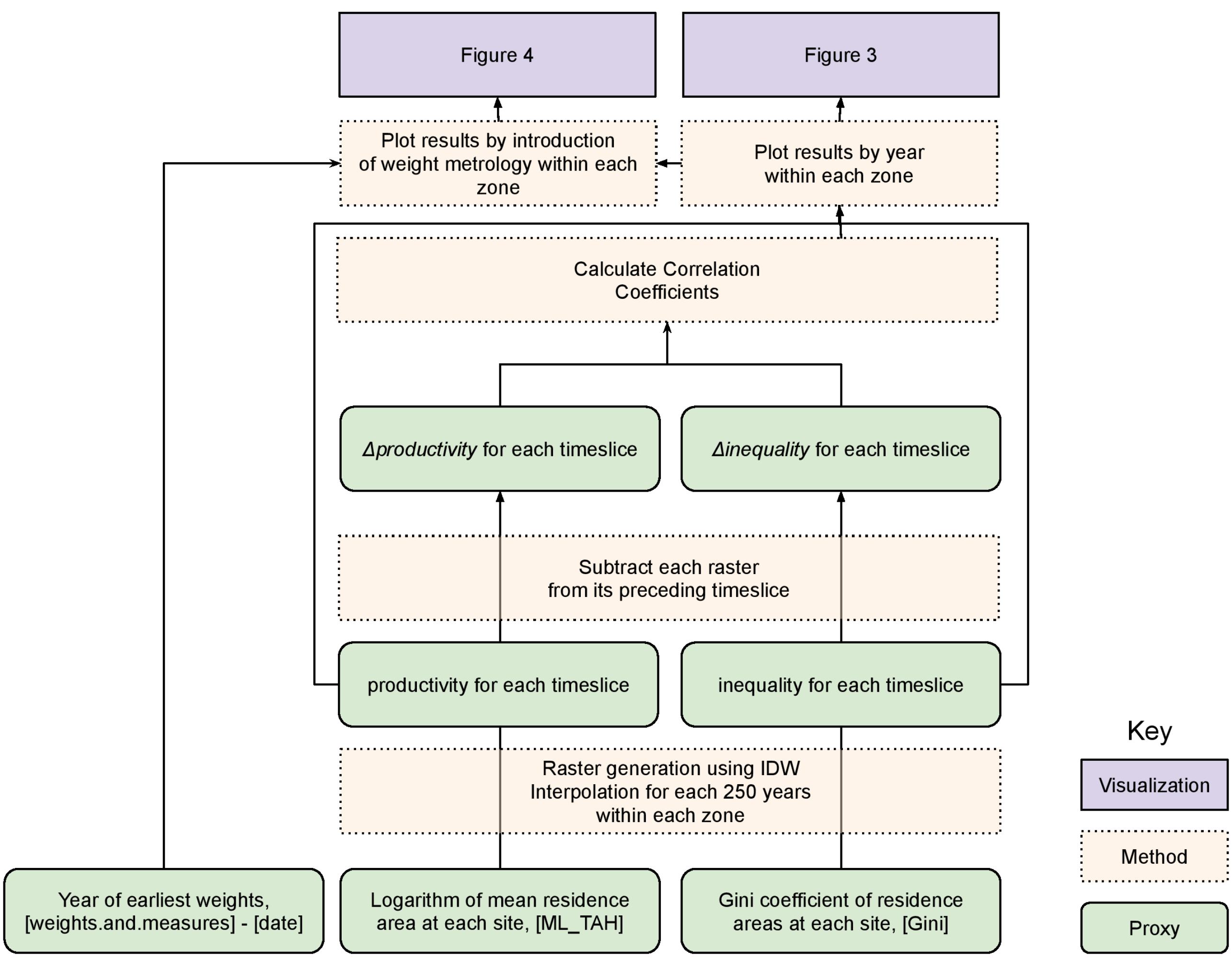

Fig. 1. Workflow for comparing economic growth to inequality using changes in residence area, [ML_TAH], and residential disparity, [Gini], within zones of interaction as proxies.

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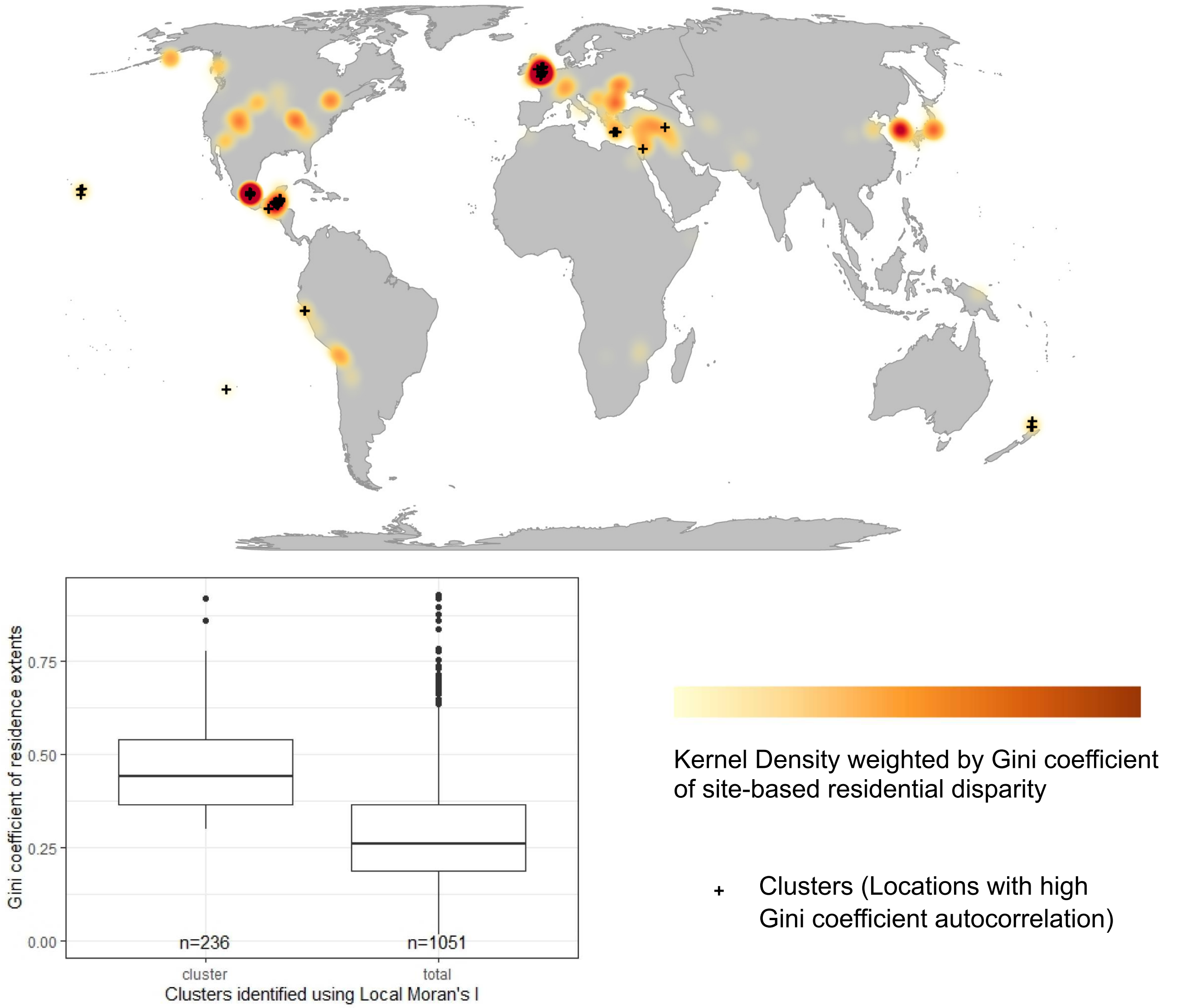

Fig. 2. A global visualization of the GINI database's SiteGiniLevel table. The kernel density of site locations is weighted by [Gini] in those locations. Clusters marked above the visualization, and the mean [Gini] of clusters is compared to that of the total sample. The map was prepared using QGIS 3.32 and a basemap from naturalearth.com projected using the Eckert IV coordinate reference system.

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Zonal Interaction Structured Inequality. Inequality exhibits a high degree of spatial autocorrelation within the sample, indicating that zonal interaction was associated with significant inequality clustering. Global Moran's I is a spatial statistic that measures the clustering of a variable within a sample of locations (45). A positive value indicates clustering among neighboring locations, while a negative value indicates dispersion. The Global Moran's I of the Gini coefficients of residence area within each site, [Gini], is 0.36 with a p-value below 0.05, indicating that nearby sites are more likely to have similar residential disparities. This spatial autocorrelation indicates that proximity to a site with a high Gini coefficient makes it more likely to have a high Gini coefficient. The Local Moran's I spatial statistic calculates the location of clusters. The mean Gini coefficient within the clusters is higher than that of the sample as a whole, in contrast with the pattern observed in β-inequality, or patterns in inequality that appear at regional levels (46), and in neighborhoods (47). Thus, inequality clusters within spatial zones, supporting the expectation of some zonal approaches to sustainable development (though not necessarily classic world-systems theory, as discussed below). Importantly, the Local Moran's I test indicates that each zone of interaction examined in this perspective was a locus of inequality clustering.

Kuznets' "Tides" Shaped Sustainable Development in the Deep Past. While data representing some 250-y periods were sparse, the rasters for *Δinequality* and *Δproductivity* were derived both from the sites within a particular period and all those that came before that period, increasing the total number of points contributing to each interpolation. The resulting data indicate that Kuznets' waves undulated through each zone of interaction, though at much longer timescales than indicated by Milanovic (7). Given their temporal scale, they are better characterized as "tides."

Contrary to his original theory, Kuznets' tides actually began with periods of sustainable development, when rising economic growth occurred alongside decreasing inequality (Table 1). Within our spatially interpolated sample, a statistically significant negative correlation between increasing *Δproductivity* and

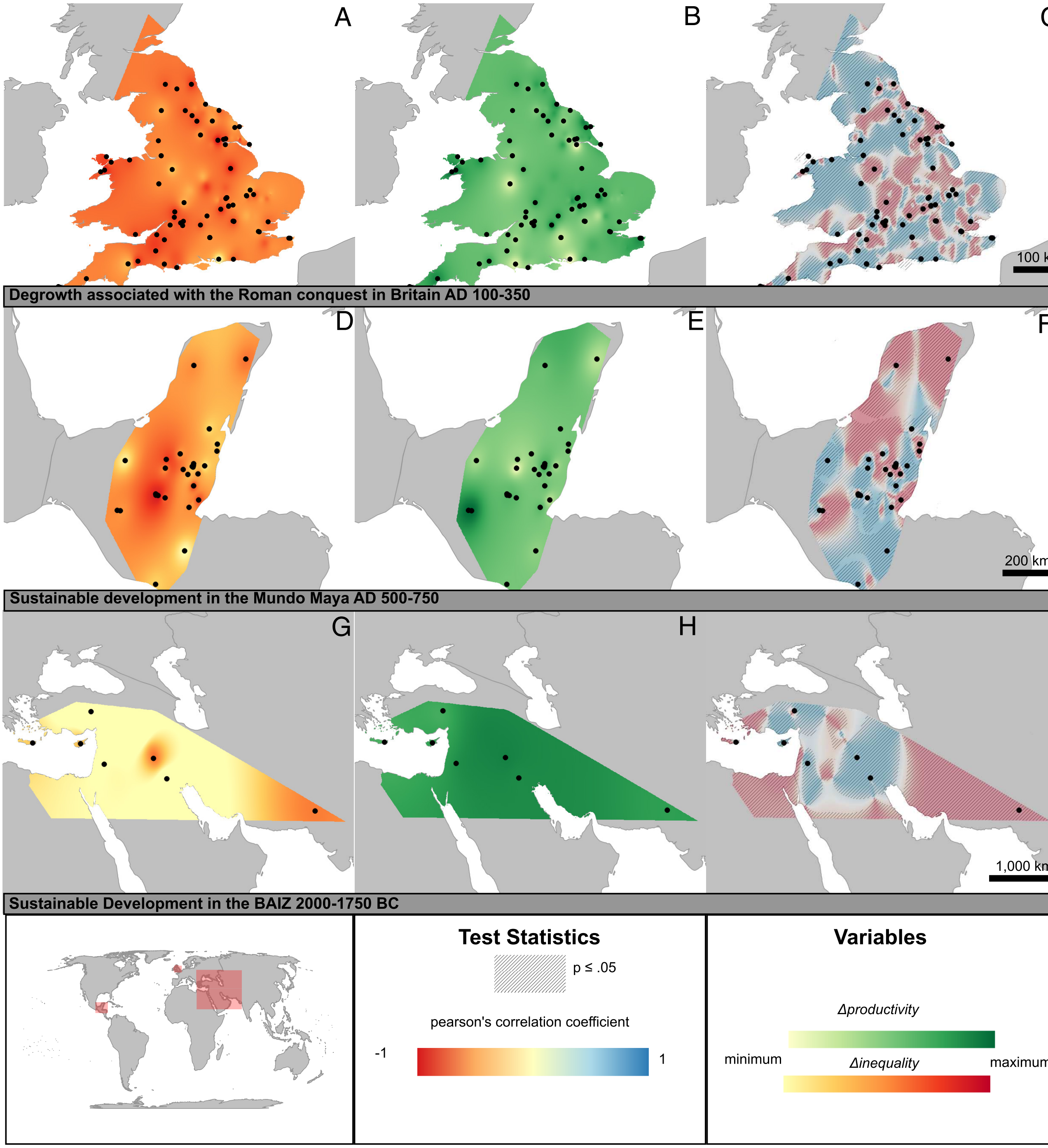

Fig. 3. A comparison of *Δproductivity* and *Δinequality* during different phases of Kuznets' tide within each zone. *A*–*C* present spatial interpolations for Britain, *D*–*F* present spatial interpolations for the Mundo Maya, and *G*–*I* present spatial interpolations for the BAIZ. The maps were prepared using QGIS 3.32 and a basemap from naturalearth.com projected using the Eckert IV coordinate reference system.

decreasing *Δinequality* characterized much of the area for which data are available from the BAIZ from around 2000–1750 BC (Fig. 3 *G*–*I*). In these periods, when inequality rose, productivity often declined. This period contrasted with earlier phases preceding growth, such as from around 2500–2000 BC, when *Δproductivity* and *Δinequality* fell together, and the correlation coefficient between the two variables gradually shifted from positive to negative (Table 1 and *SI Appendix*, Fig. S1). Similarly, in the Mundo Maya, the initial locus of *Δproductivity* increase was in Southern Belize and in northern Yucatan, while the initial locus of *Δinequality* increase was in the Central Lowlands. Again the variables are negatively correlated (Fig. 3 *D*–*F*). While our sample does not include the earliest phases of zonal interaction in Britain, there was a protracted phase of sustainable development that unfolded during the Iron Age, from approximately 1150–400 BC (Table 1 and *SI Appendix*, Fig. S4 *G*–*O*), which was interrupted by the Roman conquest, slowing economic growth for centuries before a long period of rising inequality that continued until around the Roman withdrawal in AD 410 (Table 1, *SI Appendix*, Fig. S5 *J*–*L*).

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Table 1. Statistical summary of Kuznets' tides

Zone	Date	Years since weights & measures	n	*Δproductivity*	*Δinequality*	Correlation (Pearsons, *P*-value < 0.05)
BAIZ	2625 BC	750	3	0.006328181717	0.000325426876	0.7208667
	2375 BC	1,000	9	−0.005104062386	−0.0005048801656	0.4160467
	2125 BC	1,250	5	−0.003252935674	−0.0005048801656	−0.3128398
	1875 BC	1,500	7	0.002050855762	−0.0006419915636	−0.03185326
	1625 BC	1,750	7	−0.0008449454453	0.0003322742187	0.5124544
	1375 BC	2,000	7	−0.001569188098	−0.0005673776261	0.1963294
	1125 BC	2,250	5	0.002478116169	0.0007594735415	0.229419
Mundo Maya	125 BC	750	2	−0.003121663156	−0.0001385528878	1
	AD 125	1,000	3	−0.001169483675	0.000488462518884441	−0.9888051
	AD 375	1,250	5	−0.001301949038	−0.000079156141158581	−0.7925121
	AD 625	1,500	29	0.0008570665654	−0.0002277065622	0.03042667
	AD 875	1,750	23	−0.0001525449635	−0.00000554432125428872	−0.2538799
Britain	1025 BC	750	16	0.001016327009	−0.0004323082081	−0.1077198
	775 BC	1,000	1	−0.001952540869	0.0008420425566	−0.6672109
	525 BC	1,250	3	0.002098218028	−0.0008343935379	−0.998091
	275 BC	1,500	10	−0.003878667924	0.000275435926	−0.9365714
	25 BC	1,750	55	−0.0000246956550516347	−0.0001012602149	−0.4450587
	AD 225	2,000	85	−0.001233721489	−0.0003318230388	0.1315167
	AD 475	2,250	13	0.001992583288	0.0005078645229	0.4208216
	AD 725	2,500	7	−0.0000666191039744591	0.0000997650387301113	0.2338177
	AD 975	2,750	10	−0.0000985216726708403	−0.0002874559518	0.629259
	AD1225	3,000	4	0.0005309909227	−0.0002395627163	−0.4727431

Extractive Zonal Interactions Precede Degrowth. We find that *Δproductivity* and *Δinequality* enter a positive relationship only in later periods of zonal interaction, when inequality rises to overtake economic growth. Sites in the Levant maintained positive correlations between *Δproductivity* and *Δinequality* throughout the BAIZ. Sites in Anatolia, like Kaneš/Kültepe in Anatolia, which provided raw materials to Assyrian polities in Mesopotamia (48), underwent concomitant rises in productivity and inequality (*SI Appendix*, Figs. S1 and S2). Around 1250 BC in BAIZ, a positive relationship between *Δproductivity* and *Δinequality* emerged throughout the interval of study. In the Mundo Maya, a positive correlation between *Δproductivity* and *Δinequality* precedes a period of decline in both variables between AD 750 and 1000 (Table 1 and *SI Appendix*, Fig. S3 *A–C*). These changes likely foreshadowed widespread shifts in exchange networks and changes in internal economic governance. In Britain, the Roman conquest was initially associated with a prolonged period of slow growth or degrowth, though it is notable that *Δinequality* and *Δproductivity* remained slightly negatively correlated for an extended period of time (Fig. 3). A positive correlation between *Δproductivity* and *Δinequality* increased from AD 850 to 1100, when both variables declined, again signaling a prolonged period of degrowth.

Kuznets' Tides Align with Changes in Economic Governance. Kuznets' tides appear to begin with bottom–up efforts to govern long-distance exchange within each zone of interaction. Fig. 4*B* places each zone on an x-axis calculated by years elapsed since the advent of weight metrology, a proxy of economic governance oriented toward long-distance interaction. The dates for the earliest appearance of weights and measures in the Mundo Maya are available in the GINI database, and researchers have also documented the emergence of weight systems in the BAIZ (31) and Britain (30). While additional data are certainly needed to test this result, the beginnings of each tide align closely with this initial change in economic governance. Moreover, periods of sustainable development tend to begin around 1250–1500 y from the advent of weight metrology, suggesting that each tide shifted in response to growing challenges in maintaining balanced reciprocity over long distances as the scale of interaction increased and extractive relationships emerged. In each zone, economic governance was ultimately co-opted by an elite who instituted changes in their metrological regime from the top–down, though the timing of this transformation and the rate at which inequality rose were both variable.

Discussion

If we define sustainable development as economic growth that occurs without increasing inequality, then here we find preliminary evidence that sustainable development occurred in the initial phases of zonal interaction. Some caveats are in order. Our analysis, though statistically robust, is based on an interpolation of spatial patterns from relatively small samples of sites (Table 1). We used spatial interpolation to extend site-specific data over broad areas, which diverge slightly from plots that do not utilize spatial interpolation (e.g., 32:S7). Moreover, as the other contributions to the special feature note, residential disparity is but one proxy for past inequality (16, 49), and the use of residence area as proxy for productivity is novel and should certainly be bolstered by additional lines of evidence in future studies. Even so, the absolute changes

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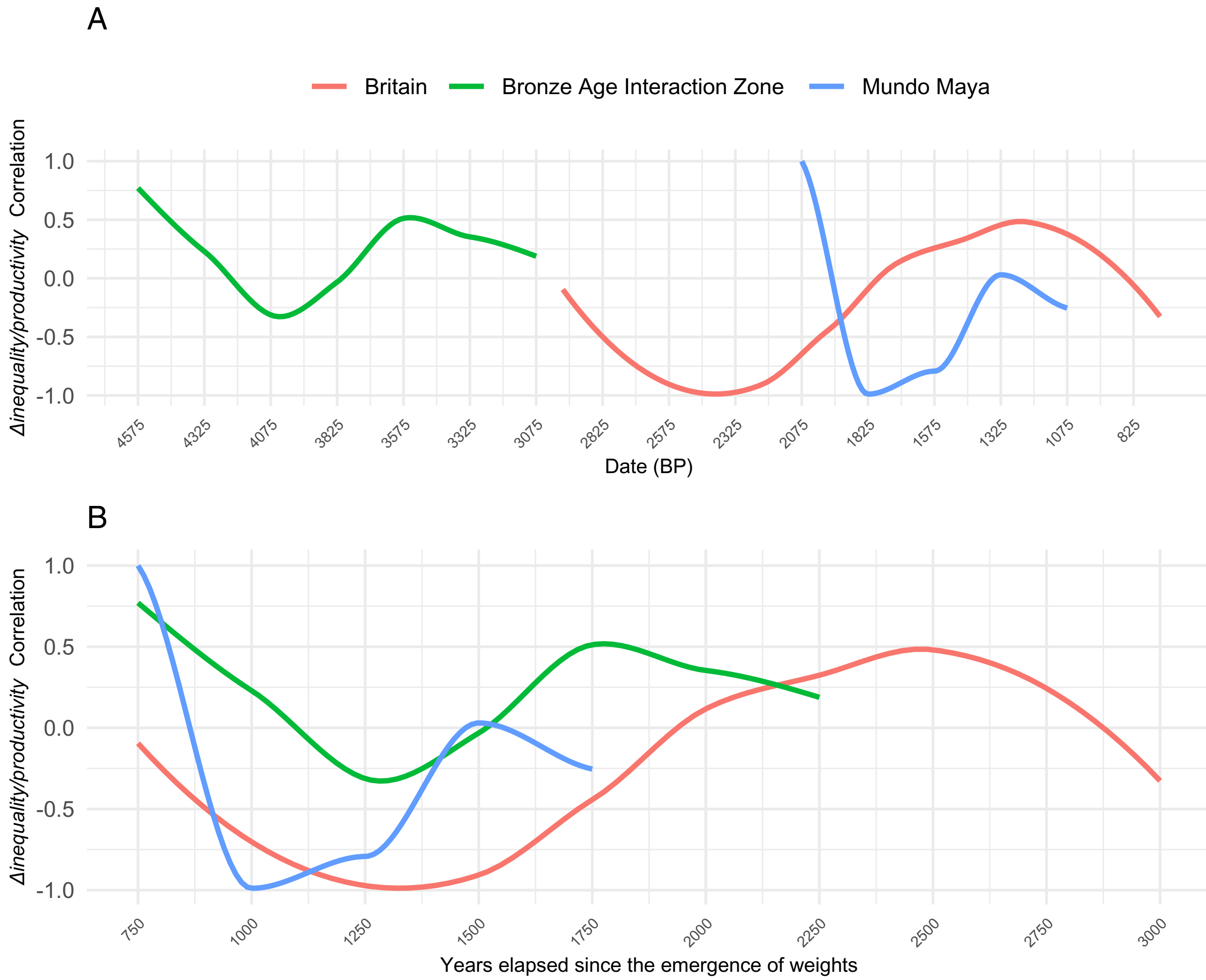

Fig. 4. Kuznets' tides plotted by years before present and by years since the advent of weights and measures. Lines depict the correlation between *Δproductivity* and *Δinequality* across space in different timeslices from each zone. Plot *A* depicts the correlation in years before present and Plot *B* depicts the correlation in years elapsed since the emergence of weights.

in productivity and inequality detected over the course of each tide were often very slight (Table 1). Nonetheless, the repeated appearance of Kuznets' tides across such a wide range of past contexts is significant because it suggests that supposed contradictions between SDG-8 and SDG-10 (2) did not hold true in the deep past and are perhaps a product specific to late capitalism. Far from blunting the significance of our results, these caveats reveal the value of expanding economic analysis with archaeological data and serve as a call for further study.

Contrary to both modernization and dependency theories, Kuznets' tides did not regularly raise both economic development and inequality. In fact, increases in inequality were more likely to co-occur with drops in productivity, ending periods of sustainable development. Moreover, zonal interaction proceeded at different rates, likely at the behest of different drivers, an expectation that has been built into expanded world-systems analysis (38). Over the course of Kuznets' tides, settlements underwent upticks in productivity that were independent from changes in inequality; the variables were often inversely related. In other words, economic growth rises and inequality falls, a pattern that conforms to Piketty's theory (6) and that explains lower coincidences of economic growth and inequality throughout the globe (16). This pattern is clear in the BAIZ and Mundo Maya, and in Britain prior to the Roman conquest. Even after the conquest, the earliest positive correlation between *Δproductivity* and *Δinequality* was weak (0.13), only reaching its apogee at the end of the Roman period.

Why were there Kuznets' tides in the deep past? Answering this question requires additional research, but we can venture some propositions. It is likely that the kind of interaction that occurred between different settlements in each zone shaped the dynamics of economic growth and inequality. Interactions featured varying degrees of travel, migration, exchange of precious goods and raw materials, diplomacy and governance, military competition and conquest, bulk good exchange, and bulk good extraction. However, each form of interaction was subject to some form of economic governance, especially after the advent of weights and measures. When created from the bottom–up by the communities carrying out long-distance exchange (e.g., merchants), as was often the case (16, 30, 31), such tools can help maintain balance reciprocity (29). For example, travel, migration, and exchange of small quantities of goods and knowledge have all occurred since the Neolithic, long before the emergence of elite classes. Even diplomacy and certain forms of bulk good exchange need not solely serve the interest of a restricted class of people, though both forms

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of interaction are perhaps more susceptible to elite co-option. In many contexts, economic governance is co-opted by elites as economies undergo shifts in scale and organization (16); weights and measures famously become key tools for taxation. The more zonal interaction was co-opted by elites (50), say in the form of military conquest or bulk raw material extraction—both of which require top–down forms of economic governance—the more zones behaved along the lines predicted by classic world-systems theory, and parts of the zone become underdeveloped. The equitability and magnitude of zonal interactions, and how they are governed, are essential elements of sustainable development. These variables should be quantified for further analysis, with specific focus on periods of sustainable development and degrowth. The analysis of these variables using archaeological data has the potential to reveal how the caustic effects of inequality on Kuznets' tides may be mitigated, and sustainable development maintained.

Kuznets' tides turned as inequality raced to catch up with economic growth, and positive correlations with inequality became the norm. This pattern conforms to the predictions of classic world-systems theory (21), and explains the prevalence of positive correlations between mean residence area and the Gini coefficient of residential area across the GINI database (17). Many processes can prompt this change. Changes in economic governance may be partially to blame. Systems of balancing reciprocity are vulnerable to the introduction of interest-bearing loans, which can create predatory social relations among equals (29), especially as economic growth slows. Later phases of zonal interaction also saw the emergence of bulk good extraction and military conquest (48, 51, 52). In Fig. 3, this pattern appears in the positive correlation between *Δproductivity* and *Δinequality*, symbolized by blue overtaking red in the test statistic panels. Finally, it is concerning that periods of sustainable development were far outnumbered by those in which inequality rose, or fell along with economic growth. In other words, for each "low tide," in which economic growth rose while inequality fell, there was a protracted "high tide" in which inequality rose irrespective of economic growth or degrowth. This phenomenon begins in peripheries, such as Kaneš/Kültepe in the BAIZ, when the locus of occupation shifts slightly north in the Mundo Maya but also (again) in patches in Britain, especially around the Thames River Valley. The latter pattern can probably be explained by the close proximity of newly established military outposts to conquered peripheral regions. Still, Thames sites have a positive correlation between *Δproductivity* and *Δinequality*, but both decline, diverging somewhat from the pattern seen in other peripheral regions. Critically, in the latter phases of zonal interaction, when inequality and productivity become positively correlated, a period of degrowth often follows, with declining productivity and declining inequality. Over time, rising inequality has often turned the tide against economic growth, ending sustainable development.

Data, Materials, and Software Availability. .csv data have been deposited in tDAR (https://core.tdar.org/project/496853/the-global-dynamics-of-inequality-gini-project) (18).

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