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The vulnerability of aging states: A survival analysis across premodern societies

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How states and great powers rise and fall is an intriguing enigma of human history. Are there any patterns? Do polities become more vulnerable over time as they age? We analyze longevity in hundreds of premodern states using survival analysis to help provide initial insights into these questions. This approach is commonly used to study the risk of death in biological organisms or failure in mechanical systems. The results reveal that the risk of state termination increased steeply over approximately the first two centuries after formation and stabilized thereafter. This provides the first quantitative support for the hypothesis that the resilience of political states decreases over time. Potential mechanisms that could drive such declining resilience include environmental degradation, increasing complexity, growing inequality, and extractive institutions. While the cases are from premodern times, such dynamics and drivers of vulnerability may remain relevant today.

archaeology | resilience | societies | civilizations | longevity

Significance

Humans become increasingly fragile as they age. We show that something similar may happen to states, although for states, the risk of termination levels off as they grow older, allowing some to persist for millennia. Proximate causes of their demise such as conquest, coups, earthquakes, and droughts are easy to spot and have received significant attention. However, our results suggest that unraveling what shapes resilience to such events is equally important if we are to understand state longevity and collapse. Risk of termination rises over the first 200 y, inviting a search for mechanisms that can undermine resilience at this timescale.

How large-scale, hierarchical organization of societies emerged and why it sometimes abruptly broke down remains difficult to answer. Cases differ, and as more details emerge often generalities break down (1–3). Here, rather than going into the details of particular cases, we look across a large dataset to explore if aging affects the chances of termination. For this enterprise, it is important to first ask what precisely is our unit of study. Big history datasets and books cover a range of entities: societies, polities, states, civilizations, complex societies, and world systems. For this article we focus on states: sets of centralized institutions that extract resources from, and impose rules on, a territorially circumscribed population (4). This is similar, albeit not identical, to the canonical definition of a society as a set of overlapping and intersecting socio-spatial power (ideological, economic, military, and political) networks (5). Indeed, both societies and states may be seen as interconnected power networks. In our quantitative analysis, we will study "states" for practical reasons. It is easier in practice to determine when a particular state has ceased to function than when the power networks constituting a smaller-scale society disappear or sufficiently splinter and change. Nonetheless, the culture-history approach in archeology has identified many important qualitative changes in power and culture. In our discussion of the quantitative patterns we find, we address the broader concept of "society" in this light.

Our goal is to revisit the classical question of what can explain the termination of large-scale social organizations such as states. An extensive literature on the end of states points to effects of climate change, extreme events, overpopulation, social competition/tension, wars, revolutions, the costs of rising complexity, extractive institutions, and inequality (6–10). This tangle of proposed mechanisms can be crudely divided into two broad categories: adverse external shocks such as earthquakes or climate change, versus a build-up of vulnerability due to intrinsic mechanisms such as rising inequality or depletion of natural resources. The two are not mutually exclusive. For example, while a range of studies across continents has revealed a plausible role of adverse climate conditions in the termination of political orders (11–18), inherent resilience can be critical in determining whether a state weathers climatic variation or withers in its face (19). Importantly, external shocks tend to leave a visible historical trace, but resilience is difficult to see. While the topic has attracted much interest (7, 8, 20–22), most studies consider the fates of particular states or regions. Here, rather than looking at specific societies in detail, we examine the overall pattern of longevity across two large, worldwide samples of premodern states to probe whether there is evidence for a loss of resilience over time. This constitutes the largest and most systematic study of state lifespans to date.

Assembling the Data

We assembled a list of premodern states spanning a period of about five millennia (the Mortality of States dataset, or "MOROS." See *SI Appendix*, section 1). For each state, we have an estimated formation and end date that draw on commonly accepted distinctions

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in history and archeology. Our data cover a broad set of entities ranging from persistent empires to fleeting polities such as the Maukhari dynasty of Northern India or multiple Khaganates that lasted under a century. The way these states "terminated" also varies significantly. State failure did not always correspond to societal collapse, and the end may take many forms (3). It can involve the loss, or significant transformation, of the institutional structure (see *SI Appendix*, section 1, for further details as to how the end of a state was identified), sometimes accompanied by a reduction in population density, hierarchy, urbanism, economic capital, writing, trade, and stratification (a package of traits often, although not necessarily accurately, referred to as "societal complexity"). Such changes detected in the archeological record can be dramatic and enduring. For instance, the end of the Late Bronze Age society on Crete in the early 12th century BCE greatly reduced its population, the palatial system, and its scripts, resulting in a rural economy for centuries (23). Other terminations are less marked. For instance, many dynastic changes in ancient China were largely just a replacement of the ruling elite. Invasions often entailed a similar continuity, with foreigners introducing puppet rulers. While the terminations differ widely in character, the common element is sufficient political reorganization to be commonly recognized in the historical record as a change in the state. To test the robustness of our results against the choices made in dividing up societies (such as by excluding dynasties), we repeated our analyses for various subsets and for the independently curated Seshat databank which differs in the periodization of polities (but overlaps with MOROS). In *SI Appendix*, section 1, we give a complete description of data and selection criteria. All data are available as a *SI Appendix*.

To delineate the time span for our analysis, we first scanned the mean longevity of societies across times for the two databases we analyze (Fig. 1). Seshat starts with societies originating ~10,000 years ago, while the oldest states in MOROS date to around 3000 BCE. Notably, the oldest recorded societies in Seshat have a much higher recorded longevity than later ones. Such extreme longevities could be real but are more likely an artifact of sparser archeological data and documentation and an accompanying lower precision in dating. This makes identifying changes in political organization difficult, particularly since polities are highly local, and continuity may often be mistakenly assumed. At the other extreme, MOROS includes modern societies. States originating after ~1800 CE have a substantially shorter lifespan (*SI Appendix*, Fig. S5) and potentially different dynamics. Hence, we restrict our analysis to states originating in the period between 2000 BCE and 1800 CE. This period encompasses 324 recorded states in MOROS and 291 polities in Seshat. We chose these cut-off dates as 2000 BCE covers more well-documented states with clearer dates, while 1800 roughly marks industrialization and the beginning of more precise datasets such as the Correlates of War project.

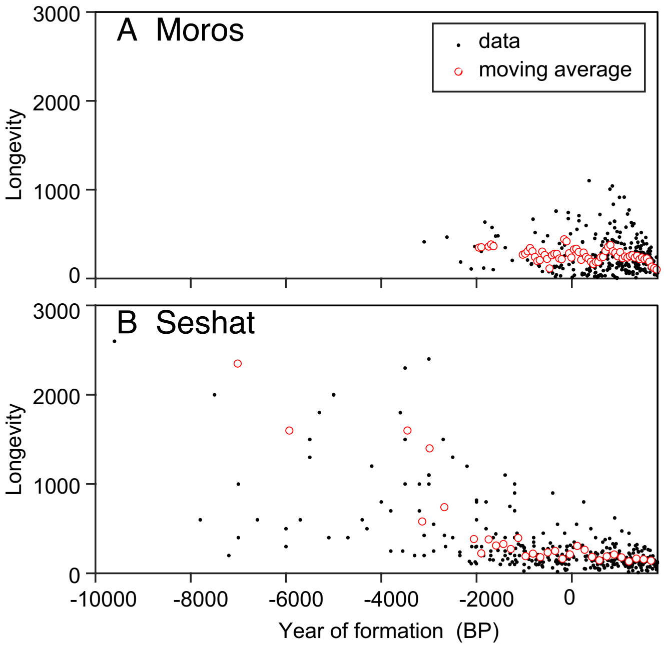

Fig. 1. The longevity of societies plotted against their year of formation for (*A*) the MOROS database and (*B*) Seshat database. Red circles are means for time windows each covering 1% of the data. Note that Seshat includes much older polities than MOROS and that those older polities have a much higher recorded longevity. By contrast, MOROS includes modern societies, but longevity drops off for societies starting after 1800 (*SI Appendix*, Fig. S5). We limited the longevity analysis in the main text to societies forming between 2000 BCE and 1800 CE.

Inferring Hazard from Longevity Distributions. We analyzed the probability distributions of longevity across states using the two datasets as well as some subsets. We are interested in those distributions since they can inform us about the relationship between age and the risk of termination (Fig. 2 and *SI Appendix*, section 2). For instance, if the risk of termination is constant, the resulting age distribution should reflect an exponential decay, with the largest number of states dying young. By contrast, if risk increases with age, the resulting longevity distribution becomes unimodal. A well-known example of the latter is the exponential rise of the risk of death with age in adults of humans and many other animals, known as the Gompertz law (24). This results in a distribution with a mode representing the most common longevity with a rapid drop-off beyond that. Between those extremes lie many possible scenarios.

Our distribution has a mode of around two centuries (Fig. 3). The mere fact that the longevity distribution is unimodal implies that the states we studied ran a rising risk of termination (at least over the first two centuries). To see more precisely how risk of termination changes with age, we fit different types of "hazard functions" and evaluate which function best explains the observed probability distributions (*SI Appendix*, sections 2 and 3). Of the eight types of hazard function we examined, a saturating risk with age produced the best fit on the MOROS data (Fig. 4 *A* and *C*). To judge the fit further, we check whether survival functions determined with our models differ significantly from what may be expected based on survival curves and their uncertainties estimated from the raw data (25) (*SI Appendix*, *Supplementary Methods*). The uncertainty margins of the survival curves expected from saturating risk coincide almost entirely with those of the nonparametric estimates (Fig. 4*E*). In contrast, the curve predicted from constant risk lies outside the uncertainty band around the nonparametrically constructed curve (*SI Appendix*, Fig. S3*H*). Indeed, while other hazard functions that capture a rising risk with age may also explain the observed longevity distribution to various extents, assuming constant risk of termination in aging societies consistently produces a bad fit (*SI Appendix*, Fig. S3).

In conclusion, the distribution of longevities reveals that the risk of termination rises over the first two centuries, and then remains roughly constant. That is, newly established states appear to have some benefit of youth in terms of survival chances, but this effect fades away over the first ~200 y. Such a saturating pattern (cf. Fig. 2*B*) is very different from the exponential rise of risk with age observed in humans (cf. Fig. 2*C*). This difference corresponds to the fact that humans have a more-or-less well-defined maximum age, whereas some states may persist extremely long compared to the average lifespan.

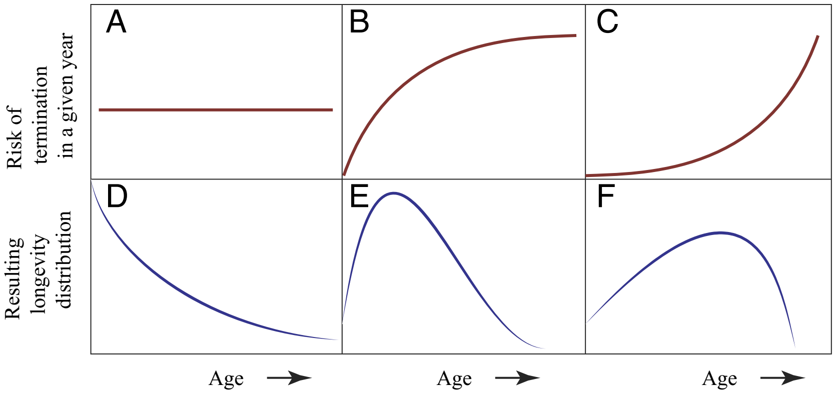

Fig. 2. Schematic representation of how the evolution of risk over time leads to different distributions of longevity. (*A*, *B*, and *C*) represent different ways in which the risk of termination may change with age. (*D*, *E*, and *F*) show the corresponding longevity distributions.

Robustness of the Results Against Data Selection. Inevitably, our sample of states is biased and heterogeneous. We rely on well-documented cases with more reliable estimates of state formation and termination dates. This may imply among other things a bias towards Eurasia. Western countries tend to have more archeological sites with excavations and reports, and the paper historical record is more long-lasting in temperate rather than tropical climates (26). Also, our collection is not homogeneous when it comes to survival chances (Fig. 3 and *SI Appendix*, Fig. S4). Therefore, the hazard curve will depend on the selection of states. To probe the robustness against selection criteria, we ran our analysis on an independently curated set of past societies developed by the Seshat project (27, 28).

Just as in MOROS, the longevity of societies in Seshat follows a roughly lognormal distribution (*SI Appendix*, Fig. S4.1). However, while the means of the distributions in the two datasets are similar, the distribution for MOROS has a higher SD and is also more left-skewed than for Seshat. Thus, MOROS contains relatively more very short-lived societies. To check how that might affect the MOROS results, we reran the analysis excluding the (often ephemeral) dynasties and imperial dynasties. This filtering did not affect the results in the sense that the saturating hazard function remained the best fit (*SI Appendix*, Figs. S10 and S11). A saturating hazard function is also the best fit for the polities in the Seshat database (Fig. 4 *D* and *F* and *SI Appendix*, section 4), but compared to MOROS, the hazard function for Seshat saturates at a higher risk level, implying a lower survival probability for the older states. Indeed, long-lived societies are less common in the Seshat collection compared to MOROS (Fig. 4 *A* and *B*). Note, however, that the fit for the right-hand side of the distribution depends strongly on the few very long-lived societies. Those are often the more ancient societies, where evidence is less detailed.

Our results differ from patterns found in earlier studies with small subsets of states. For instance, in a set of 42 empires, termination risk was independent of age (29), while for 22 Chinese empires, a power-law distribution was found, leading the authors to speculate that this may be due to self-organized criticality (30). While we used much larger datasets, our results should still be considered with caution. The results are inevitably sensitive to decisions on which states to include and how to date them. Dates for both formation and termination are often subject to debate. For instance, should the Eastern Roman Empire be considered as continuous from the Western Roman Empire, or as a separate polity? (MOROS codes them as separate.) Despite such uncertainties, the similar longevity distributions of the two independently curated databases we examined suggest that rising hazard over the first centuries of existence is a feature across a broad range of societies. In the following sections, we first ask how we may understand rising hazard from a complex dynamical systems perspective and then briefly reflect on hypotheses specifying why some states die young and others persist far longer.

Loss of Resilience as a Unifying Principle. The rising risk of termination of states suggests that they can become increasingly vulnerable over the first two centuries. Although there has been speculation about this possibility (7, 8), evidence so far has remained largely anecdotal. This should not be surprising. Extreme events such as droughts, earthquakes, and invasions

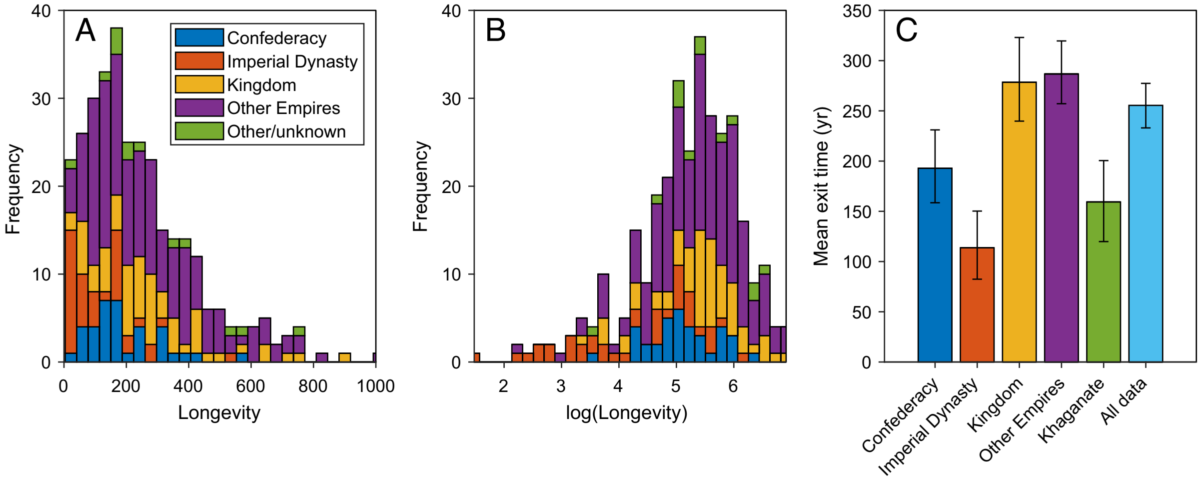

Fig. 3. The distribution of longevities (*A*) and of the logarithms of longevity (*B*) of the 324 polities in the MOROS database that originated before 1800. (*C*) Average longevity of some different political types expressed as the mean exit time of the fitted distributions.

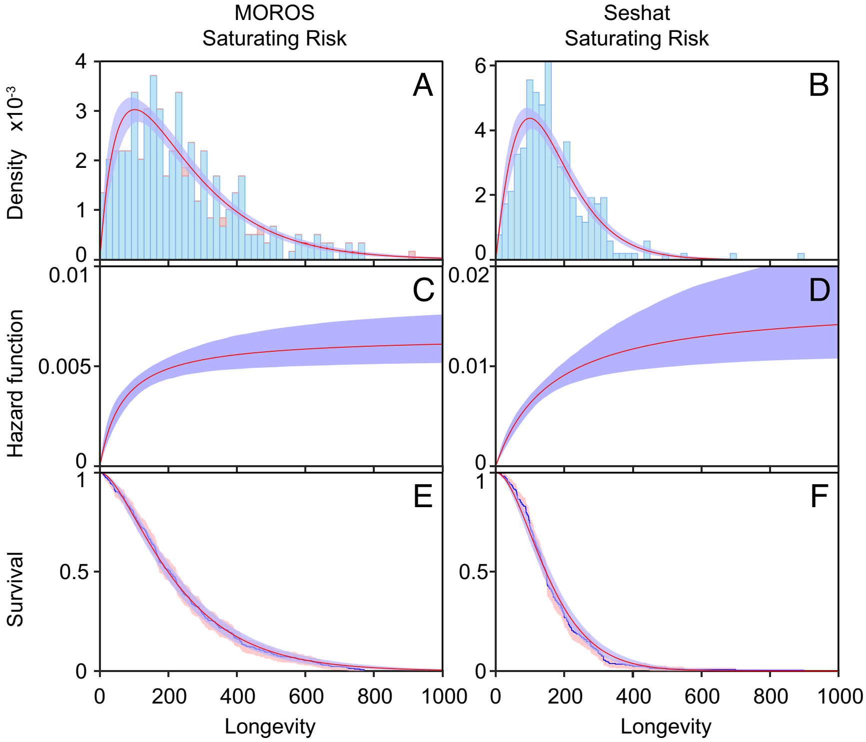

Fig. 4. Observed longevity distributions compared to what might be expected from the best-fitting models in two sets of societies. (*A*, *C*, and *E*) Moros, (*B*, *D*, and *F*) Seshat. The optimized functions relating termination risk with age are represented in the *Middle* and surviving functions in *Lower* panels. Note that the uncertainty band of a nonparametrically derived survival function (orange zone around blue line) overlaps strongly with the fitted saturating risk function (blue zone around red line panel *A*). Shaded zones represent 95% uncertainty margins obtained from bootstrapping (*SI Appendix*, Supplementary Material 2). The ranges around the nonparametric distributions were determined using Greenwood's formula (*SI Appendix*, Supplementary Material 2). Parameter values of the fitted hazard function: MOROS c = 0.0065 h = 67.3 (n = 324); Seshat: c = 0.0165 h = 161.4 (n = 291). For an analysis of the performance of other models, *SI Appendix*, Fig. S1C.

leave clear signs for archeologists and historians. By comparison, vulnerability is more difficult to assess. As in other fields (31), this has perhaps produced a tendency for overemphasizing conspicuous proximate triggers rather than vulnerability as an underlying condition to explain collapse. A useful concept to integrate the effects of vulnerability and stochastic challenges is resilience. A common way to define resilience is as the capacity to recover from a perturbation (Fig. 5). This simple definition does not cover the full complexity of the dynamics involved. For instance, in societal systems, adaptation (and thus change) can help a system to persist in a changing environment (32). Clearly, it is not straightforward to define "recovery", assuming that a society never gets back to precisely the same configuration following a perturbation. It is thus important to specify resilience "of what" we mean (33). In our context, the pragmatic answer is states. Other institutions can be persistent even if the centralized political structure seems to change (34). However, in our preliminary analysis of societal longevity, we cannot distinguish such subtleties and simply have to work with state terminations as recorded in the literature. Using that criterion, if we assume perturbations such as climate extremes and earthquakes to hit states randomly independent of their age, our results suggest that resilience of premodern societies declined over the first centuries of their existence.

Evidence for Loss of Resilience in Other Societies. Our evidence for loss of resilience obtained from longevity distributions depends on combining data from many states. This is similar to the interpretation of cohort studies in health science where we see the risk of death rising exponentially with age, despite every person being different. It should be noted that, however, there is also an entirely different approach to quantifying resilience. This approach allows monitoring the resilience of individual societies as they "age." The idea is that dynamical indicators of resilience (DIORs) may be inferred from the pattern of fluctuations in the state of a system, reflecting numerous recoveries from events in the permanent flutter of natural perturbations (36, 37). As resilience declines, such recoveries become slower, and as a result, temporal autocorrelations and variance tend to rise. This is related to a generic phenomenon known as "critical slowing down" which happens across a wide range of complex systems as they approach a tipping point (36, 37), including aging humans (38–42). For instance, DIORs in fluctuations in postural balance can be predictive of successful aging in elderly (43), and DIORs in fluctuations in health care expenditures were found to be predictors of mortality hazards (44).

From this perspective, our inference that resilience of societies declines with age may thus be checked through examination of indicators of their dynamics. Unfortunately, the high-resolution

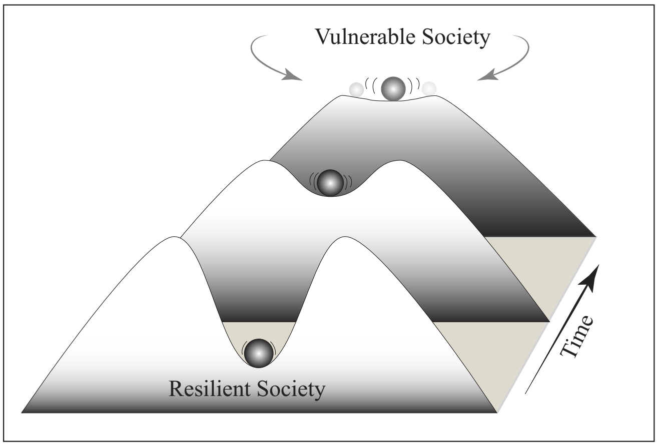

Fig. 5. Conceptual model of the loss of resilience in aging societies. With time, resilient societies become fragile in the sense that even moderate perturbations may drive self-perpetuating change towards another state. Slopes of the valley represent rates of return upon perturbation of the states. Loss of resilience implies flatter slopes causing slower recovery from perturbations as confirmed for Neolithic (35) and for Pueblo societies (22) in the period leading up to collapse (adapted from ref. 22).

time series needed to assess such DIORs are rarely available in archeology. However, this is changing. For instance, a systematic study of dynamics of population size proxied from distributions of ^{14}C dates for European Neolithic societies has found statistically significant evidence for critical slowing down prior to population collapses. This suggests that a loss of resilience occurred prior to their demographic bust (35). Similarly, work using high-resolution time series of a proxy for construction activity has demonstrated highly significant evidence of critical slowing down, implying that declining resilience preceded most of the well-studied transformations of Pueblo societies in the US Southwest (22). Each of the Pueblo periods (most encompassing numerous societies whose developments were coordinated) had a longevity of about two centuries, corresponding well to the pattern we have discovered for state lifespans. Archeological evidence of rising violence surrounding these terminations supports the idea that societal tension destabilized those societies prior to collapse (45). These small societies for which we have the high-resolution time series required for DIORs do not fulfill the criteria to be captured as states in MOROS. However, they do suggest that loss of resilience with aging may well be a pattern across a wider range of societies than the ones we included in the database.

Outlook. As the termination of states or societies has remained difficult to attribute to single causes, scholars have called for a complex systems approach (46, 47). We offer the modest beginnings of this. Our results point to a common pattern of gradual loss of resilience across states during the first two centuries of their existence. Various mechanisms could plausibly contribute to such rising vulnerability. Over time, environmental degradation (e.g., deforestation, soil erosion, and salinization) and growing population numbers may lead to scarcity (8). Also, disease risks may rise in increasingly crowded settings (35, 48). In addition, there is a tendency for wealth to fall increasingly into the hands of a small elite, causing a rising gulf between elites and the rest (20, 21). This can lead to heightening corruption and poorer decision-making (49) and to the exacerbation of a range of social ills, including interpersonal violence (50). Poor decision-making refers to choices which benefit the elite rather than the public (51) and that are less responsive to impending challenges and risks (52, 53). Increasing population and elite numbers coupled with declining real or relative wages could also generate civil strife and breakdown (54). Lastly, the overhead costs of growing societal complexity may drain resources (7). All such mechanisms might make aging societies less resilient when they are hit by adverse events. For instance, soil degradation exacerbates vulnerability to drought and expanding territory can drain budgets and increase the risk of succumbing to invasions. While the tangle of mechanisms may differ from case to case, our results suggest that a common denominator is a rise of vulnerability over time.

Clearly, our study is just an initial foray. It should be seen as a first tentative step towards a broader research agenda aimed at understanding what makes states resilient (Box 1). This is of more than an

Box 1. Outstanding research challenges

I. Crafting better databases

1. Improve estimates of start and termination dates and improve criteria and screening for continuity.
2. Distinguish types of polities systematically and enlarge the database for all polity types.
3. Document proximate drivers of termination such as climate extremes, earthquakes, or invasions.
4. Improve documentation of potential drivers of declining resilience such as rising inequality or environmental degradation.
5. Assemble time series that may be used to analyze Dynamic Indicators of Resilience.

II. Search for mechanisms of resilience across societies over time

6. Which mechanisms contribute to loss of resilience over the first two centuries? Are there any longer-lasting mechanisms?
7. Are there drivers of resilience which could lead to the plateauing of state vulnerability after two centuries?
8. How may those mechanisms interact to produce rising risk of termination?
9. When do patterns of inequality and power networks remain intact upon state termination, or regenerate more quickly thereafter?
10. Why does risk of termination appear to stay constant after two centuries? Do these results replicate with more refined datasets?

III. Investigate the outcomes of different state terminations

11. When and why did state terminations lead to heightened mortality, morbidity, or declines in living standards?
12. What are the potential benefits of state termination or collapses, including wealth leveling, institutional change, and improvements in individual health?
13. What are the costs and benefits of different state configurations across case studies?

IV. Explore how results relate to vulnerability of modern societies

14. Which mechanisms of declining resilience in pre-modern states are relevant to individual modern states, or to larger systems such as global industrialized capitalism?
15. To what extent may globalization buffer the effects of local environmental degradation?
16. How do theories of cyclical change relate to patterns of resilience through time?
17. How might past cascading collapses, as in the Late Bronze Age, inform scenarios for effects of future climate change on stability of the global network of states?
18. How does the information revolution make vulnerability in modern states different from instability in pre-modern times?

academic interest as we cannot be sure that modern societies are immune to the mechanisms that drove the wax and wane of states for millennia. There are obvious ways in which the current globalized society differs from premodern states. For instance, states now have far more advanced technology, often industrial economies, and exist in a single highly interconnected global economic system. Nonetheless, it seems plausible that mechanisms similar to those driving ancient collapses still play a role in the modern globalized world.

Data, Materials, and Software Availability. All study data are included in the article and/or supporting information.

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